PREFACE

This is the first edition of the *CRC Handbook of Chemistry and Physics* for the 21st Century (as "century" is officially defined). Few would dispute that the 20th Century was the century of science; major paradigm shifts took place first in physics and chemistry and, in the second half of the century, in biology. The "*Rubber Handbook*", so-called after the original name of its publisher, the Chemical Rubber Company, was a fixture for almost all of that eventful century. When the first edition appeared in 1913, the electron had been known for only 17 years, there were 81 elements, and the Bohr theory of the hydrogen atom was still in press. The *Handbook* was a significant innovation. While systematic compilation of data from the chemistry and physics literature had begun earlier, especially in Germany, the massive tomes that were published by Beilstein, Gmelin, and Landolt-Börnstein were strictly for libraries. The *Rubber Handbook* appears to have been the first compact, low-price volume of reference data suitable for students and individual researchers to keep on their desk or laboratory bench. It quickly became a standard and grew from its original 116 pages to the present size of over 2500 pages.

Generations of students have relied on the *CRC Handbook* as a resource in their studies, but the impact has been much broader. Senior research scientists, engineers, and workers in other fields have used the book extensively. Linus Pauling, perhaps the most influential chemist of the 20th century, made the following comments a few years before his death:

"People who have interviewed me have commented on the extensive knowledge that I have about the properties of substances, especially inorganic compounds, including minerals. I attribute this knowledge in part to the fact that I possessed the Rubber Handbook. I remember clearly the five summers, beginning in 1919, when I worked as a paving-plant inspector, supervising the laying of bituminous pavement in the mountainous region of southern Oregon. For much of the time I was free to read, just keeping an eye on the operation of the paving plant. I remember the book that I read over and over was the Rubber Handbook. I puzzled over the tables of properties - hardness, color, melting and boiling point, density, magnetic properties, and others - trying to think of reasonable explanations of the empirical data. Only in the 1920s and 1930s did I have some success in this effort."

Pauling's "success" was the first step in our ability to relate the physical and chemical behavior of bulk materials to their molecular structure in a quantitative manner.

One factor in the success of the *Handbook* has been its annual revisions. This practice, followed throughout the century except for a few wartime years, permitted the replacement of old data with new and more accurate values, as well as the introduction of new topics that became important as science moved forward. This policy has helped the *Handbook* meet the needs of the scientific community in a timely fashion.

The 82nd Edition continues the tradition of updates and improvements. The major change is a revised and expanded table of Physical Constants of Inorganic Compounds. The number of compounds has been increased by 12%, the format improved, and the constants updated. In addition, quantitative data on solubility in water are now included in the table, and a formula index has been added. Other tables that have been expanded and updated include:

- Critical Constants
- Aqueous Solubility and Henry's Law Constants of Organic Compounds
- Chemical Carcinogens
- Threshold Limits for Airborne Contaminants
- Nomenclature for Organic Polymers
- Standard Atomic Weights
- Atomic Masses and Abundances
- Table of the Isotopes

New topics covered in this edition include:

- Surface Tension of Aqueous Mixtures
- Viscosity of Carbon Dioxide along the Saturation Line
- Gibbs Energy of Formation for Important Biological Species
- Optical Properties of Inorganic and Organic Solids
- Interstellar Molecules
- Allocation of Frequencies in the Radio Spectrum
- Units for Magnetic Properties

This electronic version of the *Handbook of Chemistry and Physics* contains all the material from the print version of the 82nd Edition, as well as some additional data that could not be accommodated in the printed book. Powerful search capabilities, which are explained in the Help messages, greatly facilitate the task of locating the data.

The Editor will appreciate suggestions on new topics for the *Handbook* and notification of any errors. Address all comments to Editor, *Handbook of Chemistry and Physics*, CRC Press, Inc., 2000 Corporate Blvd. N. W., Boca Raton, FL 33431. Comments may also be sent by electronic mail to drlide@post.harvard.edu.

The *Handbook of Chemistry and Physics* is dependent on the efforts of many contributors throughout the world. I appreciate the valuable suggestions that have come from the Editorial Advisory Board and from many users. I should also like to thank Susan Fox and the rest of the production team at CRC Press for their excellent support.

David R. Lide
January 1, 2001

This Edition is Dedicated to the Memory of David Reynolds Lide (1901-1976) and Kate Simmons Lide (1896-1991)

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FUNDAMENTAL PHYSICAL CONSTANTS

Peter J. Mohr and Barry N. Taylor

These tables give the 1998 self-consistent set of values of the basic constants and conversion factors of physics and chemistry recommended by the Committee on Data for Science and Technology (CODATA) for international use. The 1998 set replaces the previous set of constants recommended by CODATA in 1986; assigned uncertainties have been reduced by a factor of 1/5 to 1/12 (and sometimes even greater) relative to the 1986 uncertainties. The recommended set is based on a least-squares adjustment involving all of the relevant experimental and theoretical data available through December 31, 1998. Full details of the input data and the adjustment procedure are given in Reference 1.

The 1998 adjustment was carried out by P. J. Mohr and B. N. Taylor of the National Institute of Standards and Technology (NIST) under the auspices of the CODATA Task Group on Fundamental Constants. The Task Group was established in 1969 with the aim of periodically providing the scientific and technological communities with a self-consistent set of internationally recommended values of the fundamental physical constants based on all applicable information available at a given point in time. The first set was published in 1973 and was followed by a revised set first published in 1986; the current 1998 set first appeared in 1999. In the future, the CODATA Task Group plans to take advantage of the high level of automation developed for the current set in order to issue a new set of recommended values at least every four years.

At the time of completion of the 1998 adjustment, the membership of the Task Group was as follows:

F. Cabiati, Istituto Elettrotecnico Nazionale “Galileo Ferraris,” Italy
E. R. Cohen, Science Center, Rockwell International (retired), United States of America
T. Endo, Electrotechnical Laboratory, Japan
R. Liu, National Institute of Metrology, China (People’s Republic of)
B. A. Mamyrin, A. F. Ioffe Physical-Technical Institute, Russian Federation
P. J. Mohr, National Institute of Standards and Technology, United States of America
F. Nez, Laboratoire Kastler-Brossel, France
B. W. Petley, National Physical Laboratory, United Kingdom
T. J. Quinn, Bureau International des Poids et Mesures
B. N. Taylor, National Institute of Standards and Technology, United States of America
V. S. Tuninsky, D. I. Mendeleyev All-Russian Research Institute for Metrology, Russian Federation
W. Wöger, Physikalisch-Technische Bundesanstalt, Germany
B. M. Wood, National Research Council, Canada

REFERENCES

1. Mohr, Peter J., and Taylor, Barry N., *J. Phys Chem. Ref. Data* **28**, 1713, 1999; *Rev. Mod. Phys*. **72**, 351, 2000. The 1998 set of recommended values is also available at the Web site of the Fundamental Constants Data Center of the NIST Physics Laboratory: http://physics.nist.gov/constants.

Fundamental Physical Constants

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
		UNIVERSAL		
speed of light in vacuum	c, c_0	299 792 458	$\mathrm{m\ s^{-1}}$	(exact)
magnetic constant	μ_0	$4\pi \times 10^{-7}$	$\mathrm{N\ A^{-2}}$	
		$= 12.566\,370\,614... \times 10^{-7}$	$\mathrm{N\ A^{-2}}$	(exact)
electric constant $1/\mu_0 c^2$	ε_0	$8.854\,187\,817... \times 10^{-12}$	$\mathrm{F\ m^{-1}}$	(exact)
characteristic impedance of vacuum $\sqrt{\mu_0/\epsilon_0} = \mu_0 c$	Z_0	376.730 313 461...	Ω	(exact)
Newtonian constant of gravitation	G	$6.673(10) \times 10^{-11}$	$\mathrm{m^3\ kg^{-1}\ s^{-2}}$	1.5×10^{-3}
	$G/\hbar c$	$6.707(10) \times 10^{-39}$	$(\mathrm{GeV}/c^2)^{-2}$	1.5×10^{-3}
Planck constant	h	$6.626\,068\,76(52) \times 10^{-34}$	J s	7.8×10^{-8}
in eV s		$4.135\,667\,27(16) \times 10^{-15}$	eV s	3.9×10^{-8}
$h/2\pi$	$\hbar$	$1.054\,571\,596(82) \times 10^{-34}$	J s	7.8×10^{-8}
in eV s		$6.582\,118\,89(26) \times 10^{-16}$	eV s	3.9×10^{-8}
Planck mass $(\hbar c/G)^{1/2}$	m_P	$2.1767(16) \times 10^{-8}$	kg	7.5×10^{-4}
Planck length $\hbar/m_\mathrm{P}c = (\hbar G/c^3)^{1/2}$	l_P	$1.6160(12) \times 10^{-35}$	m	7.5×10^{-4}
Planck time $l_\mathrm{P}/c = (\hbar G/c^5)^{1/2}$	t_P	$5.3906(40) \times 10^{-44}$	s	7.5×10^{-4}
		ELECTROMAGNETIC		
elementary charge	e	$1.602\,176\,462(63) \times 10^{-19}$	C	3.9×10^{-8}
	e/h	$2.417\,989\,491(95) \times 10^{14}$	$\mathrm{A\ J^{-1}}$	3.9×10^{-8}
magnetic flux quantum $h/2e$	Φ_0	$2.067\,833\,636(81) \times 10^{-15}$	Wb	3.9×10^{-8}
conductance quantum $2e^2/h$	G_0	$7.748\,091\,696(28) \times 10^{-5}$	S	3.7×10^{-9}
inverse of conductance quantum	G_0^{-1}	12 906.403 786(47)	Ω	3.7×10^{-9}
Josephson constant[a] $2e/h$	K_J	$483\,597.898(19) \times 10^{9}$	$\mathrm{Hz\ V^{-1}}$	3.9×10^{-8}
von Klitzing constant[b] $h/e^2 = \mu_0 c/2\alpha$	R_K	25 812.807 572(95)	Ω	3.7×10^{-9}
Bohr magneton $e\hbar/2m_\mathrm{e}$	μ_B	$927.400\,899(37) \times 10^{-26}$	$\mathrm{J\ T^{-1}}$	4.0×10^{-8}
in $\mathrm{eV\ T^{-1}}$		$5.788\,381\,749(43) \times 10^{-5}$	$\mathrm{eV\ T^{-1}}$	7.3×10^{-9}
	μ_B/h	$13.996\,246\,24(56) \times 10^{9}$	$\mathrm{Hz\ T^{-1}}$	4.0×10^{-8}
	μ_B/hc	46.686 4521(19)	$\mathrm{m^{-1}\ T^{-1}}$	4.0×10^{-8}
	μ_B/k	0.671 7131(12)	$\mathrm{K\ T^{-1}}$	1.7×10^{-6}
nuclear magneton $e\hbar/2m_\mathrm{p}$	μ_N	$5.050\,783\,17(20) \times 10^{-27}$	$\mathrm{J\ T^{-1}}$	4.0×10^{-8}
in $\mathrm{eV\ T^{-1}}$		$3.152\,451\,238(24) \times 10^{-8}$	$\mathrm{eV\ T^{-1}}$	7.6×10^{-9}
	μ_N/h	7.622 593 96(31)	$\mathrm{MHz\ T^{-1}}$	4.0×10^{-8}
	μ_N/hc	$2.542\,623\,66(10) \times 10^{-2}$	$\mathrm{m^{-1}\ T^{-1}}$	4.0×10^{-8}
	μ_N/k	$3.658\,2638(64) \times 10^{-4}$	$\mathrm{K\ T^{-1}}$	1.7×10^{-6}
		ATOMIC AND NUCLEAR General		
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	α	$7.297\,352\,533(27) \times 10^{-3}$		3.7×10^{-9}
inverse fine-structure constant	α^{-1}	137.035 999 76(50)		3.7×10^{-9}

Fundamental Physical Constants

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
Rydberg constant $\alpha^2 m_e c/2h$	R_∞	10 973 731.568 549(83)	m^{-1}	7.6×10^{-12}
	$R_\infty c$	$3.289\,841\,960\,368(25) \times 10^{15}$	Hz	7.6×10^{-12}
	$R_\infty hc$	$2.179\,871\,90(17) \times 10^{-18}$	J	7.8×10^{-8}
$R_\infty hc$ in eV		13.605 691 72(53)	eV	3.9×10^{-8}
Bohr radius $\alpha/4\pi R_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2$	a_0	$0.529\,177\,2083(19) \times 10^{-10}$	m	3.7×10^{-9}
Hartree energy $e^2/4\pi\varepsilon_0 a_0 = 2R_\infty hc$ $= \alpha^2 m_e c^2$	E_h	$4.359\,743\,81(34) \times 10^{-18}$	J	7.8×10^{-8}
in eV		27.211 3834(11)	eV	3.9×10^{-8}
quantum of circulation	$h/2m_e$	$3.636\,947\,516(27) \times 10^{-4}$	$m^2\ s^{-1}$	7.3×10^{-9}
	h/m_e	$7.273\,895\,032(53) \times 10^{-4}$	$m^2\ s^{-1}$	7.3×10^{-9}
		Electroweak		
Fermi coupling constant[c]	$G_F/(\hbar c)^3$	$1.166\,39(1) \times 10^{-5}$	GeV^{-2}	8.6×10^{-6}
weak mixing angle[d] θ_W (on-shell scheme) $\sin^2\theta_W = s_W^2 \equiv 1 - (m_W/m_Z)^2$	$\sin^2\theta_W$	0.2224(19)		8.7×10^{-3}
		Electron, e^-		
electron mass	m_e	$9.109\,381\,88(72) \times 10^{-31}$	kg	7.9×10^{-8}
in u, $m_e = A_r(e)$ u (electron relative atomic mass times u)		$5.485\,799\,110(12) \times 10^{-4}$	u	2.1×10^{-9}
energy equivalent	$m_e c^2$	$8.187\,104\,14(64) \times 10^{-14}$	J	7.9×10^{-8}
in MeV		0.510 998 902(21)	MeV	4.0×10^{-8}
electron-muon mass ratio	m_e/m_μ	$4.836\,332\,10(15) \times 10^{-3}$		3.0×10^{-8}
electron-tau mass ratio	m_e/m_τ	$2.875\,55(47) \times 10^{-4}$		1.6×10^{-4}
electron-proton mass ratio	m_e/m_p	$5.446\,170\,232(12) \times 10^{-4}$		2.1×10^{-9}
electron-neutron mass ratio	m_e/m_n	$5.438\,673\,462(12) \times 10^{-4}$		2.2×10^{-9}
electron-deuteron mass ratio	m_e/m_d	$2.724\,437\,1170(58) \times 10^{-4}$		2.1×10^{-9}
electron to alpha particle mass ratio	m_e/m_α	$1.370\,933\,5611(29) \times 10^{-4}$		2.1×10^{-9}
electron charge to mass quotient	$-e/m_e$	$-1.758\,820\,174(71) \times 10^{11}$	$C\ kg^{-1}$	4.0×10^{-8}
electron molar mass $N_A m_e$	$M(e), M_e$	$5.485\,799\,110(12) \times 10^{-7}$	$kg\ mol^{-1}$	2.1×10^{-9}
Compton wavelength $h/m_e c$	λ_C	$2.426\,310\,215(18) \times 10^{-12}$	m	7.3×10^{-9}
$\lambda_C/2\pi = \alpha a_0 = \alpha^2/4\pi R_\infty$	$\bar{\lambda}_C$	$386.159\,2642(28) \times 10^{-15}$	m	7.3×10^{-9}
classical electron radius $\alpha^2 a_0$	r_e	$2.817\,940\,285(31) \times 10^{-15}$	m	1.1×10^{-8}
Thomson cross section $(8\pi/3)r_e^2$	σ_e	$0.665\,245\,854(15) \times 10^{-28}$	m^2	2.2×10^{-8}
electron magnetic moment	μ_e	$-928.476\,362(37) \times 10^{-26}$	$J\ T^{-1}$	4.0×10^{-8}
to Bohr magneton ratio	μ_e/μ_B	$-1.001\,159\,652\,1869(41)$		4.1×10^{-12}
to nuclear magneton ratio	μ_e/μ_N	$-1\,838.281\,9660(39)$		2.1×10^{-9}
electron magnetic moment anomaly $\|\mu_e\|/\mu_B - 1$	a_e	$1.159\,652\,1869(41) \times 10^{-3}$		3.5×10^{-9}
electron g-factor $-2(1 + a_e)$	g_e	$-2.002\,319\,304\,3737(82)$		4.1×10^{-12}
electron-muon magnetic moment ratio	μ_e/μ_μ	206.766 9720(63)		3.0×10^{-8}

Fundamental Physical Constants

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
electron-proton				
magnetic moment ratio	μ_e/μ_p	$-658.210\,6875(66)$		1.0×10^{-8}
electron to shielded proton				
magnetic moment ratio	μ_e/μ'_p	$-658.227\,5954(71)$		1.1×10^{-8}
(H_2O, sphere, 25 °C)				
electron-neutron				
magnetic moment ratio	μ_e/μ_n	$960.920\,50(23)$		2.4×10^{-7}
electron-deuteron				
magnetic moment ratio	μ_e/μ_d	$-2\,143.923\,498(23)$		1.1×10^{-8}
electron to shielded helion[e]				
magnetic moment ratio	μ_e/μ'_h	$864.058\,255(10)$		1.2×10^{-8}
(gas, sphere, 25 °C)				
electron gyromagnetic ratio $2\lvert\mu_e\rvert/\hbar$	γ_e	$1.760\,859\,794(71)\times10^{11}$	$s^{-1}\,T^{-1}$	4.0×10^{-8}
	$\gamma_e/2\pi$	$28\,024.9540(11)$	MHz T^{-1}	4.0×10^{-8}
		Muon, μ^-		
muon mass	m_μ	$1.883\,531\,09(16)\times10^{-28}$	kg	8.4×10^{-8}
in u, $m_\mu = A_r(\mu)$ u (muon relative atomic mass times u)		$0.113\,428\,9168(34)$	u	3.0×10^{-8}
energy equivalent	$m_\mu c^2$	$1.692\,833\,32(14)\times10^{-11}$	J	8.4×10^{-8}
in MeV		$105.658\,3568(52)$	MeV	4.9×10^{-8}
muon-electron mass ratio	m_μ/m_e	$206.768\,2657(63)$		3.0×10^{-8}
muon-tau mass ratio	m_μ/m_τ	$5.945\,72(97)\times10^{-2}$		1.6×10^{-4}
muon-proton mass ratio	m_μ/m_p	$0.112\,609\,5173(34)$		3.0×10^{-8}
muon-neutron mass ratio	m_μ/m_n	$0.112\,454\,5079(34)$		3.0×10^{-8}
muon molar mass $N_A m_\mu$	$M(\mu)$, M_μ	$0.113\,428\,9168(34)\times10^{-3}$	kg mol^{-1}	3.0×10^{-8}
muon Compton wavelength $h/m_\mu c$	$\lambda_{C,\mu}$	$11.734\,441\,97(35)\times10^{-15}$	m	2.9×10^{-8}
$\lambda_{C,\mu}/2\pi$	$\bar{\lambda}_{C,\mu}$	$1.867\,594\,444(55)\times10^{-15}$	m	2.9×10^{-8}
muon magnetic moment	μ_μ	$-4.490\,448\,13(22)\times10^{-26}$	J T^{-1}	4.9×10^{-8}
to Bohr magneton ratio	μ_μ/μ_B	$-4.841\,970\,85(15)\times10^{-3}$		3.0×10^{-8}
to nuclear magneton ratio	μ_μ/μ_N	$-8.890\,597\,70(27)$		3.0×10^{-8}
muon magnetic moment anomaly				
$\lvert\mu_\mu\rvert/(e\hbar/2m_\mu)-1$	a_μ	$1.165\,916\,02(64)\times10^{-3}$		5.5×10^{-7}
muon g-factor $-2(1+a_\mu)$	g_μ	$-2.002\,331\,8320(13)$		6.4×10^{-10}
muon-proton				
magnetic moment ratio	μ_μ/μ_p	$-3.183\,345\,39(10)$		3.2×10^{-8}
		Tau, τ^-		
tau mass[f]	m_τ	$3.167\,88(52)\times10^{-27}$	kg	1.6×10^{-4}
in u, $m_\tau = A_r(\tau)$ u (tau relative atomic mass times u)		$1.907\,74(31)$	u	1.6×10^{-4}
energy equivalent	$m_\tau c^2$	$2.847\,15(46)\times10^{-10}$	J	1.6×10^{-4}
in MeV		$1\,777.05(29)$	MeV	1.6×10^{-4}

Fundamental Physical Constants

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
tau-electron mass ratio	m_τ/m_e	3 477.60(57)		1.6×10^{-4}
tau-muon mass ratio	m_τ/m_μ	16.8188(27)		1.6×10^{-4}
tau-proton mass ratio	m_τ/m_p	1.893 96(31)		1.6×10^{-4}
tau-neutron mass ratio	m_τ/m_n	1.891 35(31)		1.6×10^{-4}
tau molar mass $N_A m_\tau$	$M(\tau)$, M_τ	$1.907\,74(31) \times 10^{-3}$	kg mol^{-1}	1.6×10^{-4}
tau Compton wavelength $h/m_\tau c$	$\lambda_{C,\tau}$	$0.697\,70(11) \times 10^{-15}$	m	1.6×10^{-4}
$\lambda_{C,\tau}/2\pi$	$\bar{\lambda}_{C,\tau}$	$0.111\,042(18) \times 10^{-15}$	m	1.6×10^{-4}
		Proton, p		
proton mass	m_p	$1.672\,621\,58(13) \times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_p = A_r(p)$ u (proton relative atomic mass times u)		1.007 276 466 88(13)	u	1.3×10^{-10}
energy equivalent	$m_p c^2$	$1.503\,277\,31(12) \times 10^{-10}$	J	7.9×10^{-8}
in MeV		938.271 998(38)	MeV	4.0×10^{-8}
proton-electron mass ratio	m_p/m_e	1 836.152 6675(39)		2.1×10^{-9}
proton-muon mass ratio	m_p/m_μ	8.880 244 08(27)		3.0×10^{-8}
proton-tau mass ratio	m_p/m_τ	0.527 994(86)		1.6×10^{-4}
proton-neutron mass ratio	m_p/m_n	0.998 623 478 55(58)		5.8×10^{-10}
proton charge to mass quotient	e/m_p	$9.578\,834\,08(38) \times 10^{7}$	C kg^{-1}	4.0×10^{-8}
proton molar mass $N_A m_p$	$M(p)$, M_p	$1.007\,276\,466\,88(13) \times 10^{-3}$	kg mol^{-1}	1.3×10^{-10}
proton Compton wavelength $h/m_p c$	$\lambda_{C,p}$	$1.321\,409\,847(10) \times 10^{-15}$	m	7.6×10^{-9}
$\lambda_{C,p}/2\pi$	$\bar{\lambda}_{C,p}$	$0.210\,308\,9089(16) \times 10^{-15}$	m	7.6×10^{-9}
proton magnetic moment	μ_p	$1.410\,606\,633(58) \times 10^{-26}$	J T^{-1}	4.1×10^{-8}
to Bohr magneton ratio	μ_p/μ_B	$1.521\,032\,203(15) \times 10^{-3}$		1.0×10^{-8}
to nuclear magneton ratio	μ_p/μ_N	2.792 847 337(29)		1.0×10^{-8}
proton g-factor $2\mu_p/\mu_N$	g_p	5.585 694 675(57)		1.0×10^{-8}
proton-neutron magnetic moment ratio	μ_p/μ_n	−1.459 898 05(34)		2.4×10^{-7}
shielded proton magnetic moment (H_2O, sphere, 25 °C)	μ'_p	$1.410\,570\,399(59) \times 10^{-26}$	J T^{-1}	4.2×10^{-8}
to Bohr magneton ratio	μ'_p/μ_B	$1.520\,993\,132(16) \times 10^{-3}$		1.1×10^{-8}
to nuclear magneton ratio	μ'_p/μ_N	2.792 775 597(31)		1.1×10^{-8}
proton magnetic shielding correction $1 - \mu'_p/\mu_p$ (H_2O, sphere, 25 °C)	σ'_p	$25.687(15) \times 10^{-6}$		5.7×10^{-4}
proton gyromagnetic ratio $2\mu_p/\hbar$	γ_p	$2.675\,222\,12(11) \times 10^{8}$	s^{-1} T^{-1}	4.1×10^{-8}
	$\gamma_p/2\pi$	42.577 4825(18)	MHz T^{-1}	4.1×10^{-8}
shielded proton gyromagnetic ratio $2\mu'_p/\hbar$ (H_2O, sphere, 25 °C)	γ'_p	$2.675\,153\,41(11) \times 10^{8}$	s^{-1} T^{-1}	4.2×10^{-8}
	$\gamma'_p/2\pi$	42.576 3888(18)	MHz T^{-1}	4.2×10^{-8}
		Neutron, n		

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
neutron mass	m_n	$1.674\,927\,16(13) \times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_n = A_r(n)$ u (neutron relative atomic mass times u)		$1.008\,664\,915\,78(55)$	u	5.4×10^{-10}
energy equivalent	$m_n c^2$	$1.505\,349\,46(12) \times 10^{-10}$	J	7.9×10^{-8}
in MeV		$939.565\,330(38)$	MeV	4.0×10^{-8}
neutron-electron mass ratio	m_n/m_e	$1\,838.683\,6550(40)$		2.2×10^{-9}
neutron-muon mass ratio	m_n/m_μ	$8.892\,484\,78(27)$		3.0×10^{-8}
neutron-tau mass ratio	m_n/m_τ	$0.528\,722(86)$		1.6×10^{-4}
neutron-proton mass ratio	m_n/m_p	$1.001\,378\,418\,87(58)$		5.8×10^{-10}
neutron molar mass $N_A m_n$	$M(n)$, M_n	$1.008\,664\,915\,78(55) \times 10^{-3}$	kg mol^{-1}	5.4×10^{-10}
neutron Compton wavelength $h/m_n c$	$\lambda_{C,n}$	$1.319\,590\,898(10) \times 10^{-15}$	m	7.6×10^{-9}
$\lambda_{C,n}/2\pi$	$\bar{\lambda}_{C,n}$	$0.210\,019\,4142(16) \times 10^{-15}$	m	7.6×10^{-9}
neutron magnetic moment	μ_n	$-0.966\,236\,40(23) \times 10^{-26}$	J T^{-1}	2.4×10^{-7}
to Bohr magneton ratio	μ_n/μ_B	$-1.041\,875\,63(25) \times 10^{-3}$		2.4×10^{-7}
to nuclear magneton ratio	μ_n/μ_N	$-1.913\,042\,72(45)$		2.4×10^{-7}
neutron g-factor $2\mu_n/\mu_N$	g_n	$-3.826\,085\,45(90)$		2.4×10^{-7}
neutron-electron magnetic moment ratio	μ_n/μ_e	$1.040\,668\,82(25) \times 10^{-3}$		2.4×10^{-7}
neutron-proton magnetic moment ratio	μ_n/μ_p	$-0.684\,979\,34(16)$		2.4×10^{-7}
neutron to shielded proton magnetic moment ratio (H_2O, sphere, 25 °C)	μ_n/μ'_p	$-0.684\,996\,94(16)$		2.4×10^{-7}
neutron gyromagnetic ratio $2\lvert\mu_n\rvert/\hbar$	γ_n	$1.832\,471\,88(44) \times 10^{8}$	s^{-1} T^{-1}	2.4×10^{-7}
	$\gamma_n/2\pi$	$29.164\,6958(70)$	MHz T^{-1}	2.4×10^{-7}
		Deuteron, d		
deuteron mass	m_d	$3.343\,583\,09(26) \times 10^{-27}$	kg	7.9×10^{-8}
in u, $m_d = A_r(d)$ u (deuteron relative atomic mass times u)		$2.013\,553\,212\,71(35)$	u	1.7×10^{-10}
energy equivalent	$m_d c^2$	$3.005\,062\,62(24) \times 10^{-10}$	J	7.9×10^{-8}
in MeV		$1\,875.612\,762(75)$	MeV	4.0×10^{-8}
deuteron-electron mass ratio	m_d/m_e	$3\,670.482\,9550(78)$		2.1×10^{-9}
deuteron-proton mass ratio	m_d/m_p	$1.999\,007\,500\,83(41)$		2.0×10^{-10}
deuteron molar mass $N_A m_d$	$M(d)$, M_d	$2.013\,553\,212\,71(35) \times 10^{-3}$	kg mol^{-1}	1.7×10^{-10}
deuteron magnetic moment	μ_d	$0.433\,073\,457(18) \times 10^{-26}$	J T^{-1}	4.2×10^{-8}
to Bohr magneton ratio	μ_d/μ_B	$0.466\,975\,4556(50) \times 10^{-3}$		1.1×10^{-8}
to nuclear magneton ratio	μ_d/μ_N	$0.857\,438\,2284(94)$		1.1×10^{-8}
deuteron-electron magnetic moment ratio	μ_d/μ_e	$-4.664\,345\,537(50) \times 10^{-4}$		1.1×10^{-8}
deuteron-proton magnetic moment ratio	μ_d/μ_p	$0.307\,012\,2083(45)$		1.5×10^{-8}

Fundamental Physical Constants

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
deuteron-neutron magnetic moment ratio	μ_d/μ_n	$-0.448\,206\,52(11)$		2.4×10^{-7}
Helion, h				
helion mass[e]	m_h	$5.006\,411\,74(39)\times10^{-27}$	kg	7.9×10^{-8}
in u, $m_h = A_r(h)$ u (helion relative atomic mass times u)		$3.014\,932\,234\,69(86)$	u	2.8×10^{-10}
energy equivalent	m_hc^2	$4.499\,538\,48(35)\times10^{-10}$	J	7.9×10^{-8}
in MeV		$2\,808.391\,32(11)$	MeV	4.0×10^{-8}
helion-electron mass ratio	m_h/m_e	$5\,495.885\,238(12)$		2.1×10^{-9}
helion-proton mass ratio	m_h/m_p	$2.993\,152\,658\,50(93)$		3.1×10^{-10}
helion molar mass N_Am_h	$M(h)$, M_h	$3.014\,932\,234\,69(86)\times10^{-3}$	kg mol^{-1}	2.8×10^{-10}
shielded helion magnetic moment (gas, sphere, 25 °C)	μ'_h	$-1.074\,552\,967(45)\times10^{-26}$	J T^{-1}	4.2×10^{-8}
to Bohr magneton ratio	μ'_h/μ_B	$-1.158\,671\,474(14)\times10^{-3}$		1.2×10^{-8}
to nuclear magneton ratio	μ'_h/μ_N	$-2.127\,497\,718(25)$		1.2×10^{-8}
shielded helion to proton magnetic moment ratio (gas, sphere, 25 °C)	μ'_h/μ_p	$-0.761\,766\,563(12)$		1.5×10^{-8}
shielded helion to shielded proton magnetic moment ratio (gas/H_2O, spheres, 25 °C)	μ'_h/μ'_p	$-0.761\,786\,1313(33)$		4.3×10^{-9}
shielded helion gyromagnetic ratio $2\lvert\mu'_h\rvert/\hbar$ (gas, sphere, 25 °C)	γ'_h	$2.037\,894\,764(85)\times10^{8}$	s^{-1} T^{-1}	4.2×10^{-8}
	$\gamma'_h/2\pi$	$32.434\,1025(14)$	MHz T^{-1}	4.2×10^{-8}
Alpha particle, α				
alpha particle mass	m_α	$6.644\,655\,98(52)\times10^{-27}$	kg	7.9×10^{-8}
in u, $m_\alpha = A_r(\alpha)$ u (alpha particle relative atomic mass times u)		$4.001\,506\,1747(10)$	u	2.5×10^{-10}
energy equivalent	$m_\alpha c^2$	$5.971\,918\,97(47)\times10^{-10}$	J	7.9×10^{-8}
in MeV		$3\,727.379\,04(15)$	MeV	4.0×10^{-8}
alpha particle to electron mass ratio	m_α/m_e	$7\,294.299\,508(16)$		2.1×10^{-9}
alpha particle to proton mass ratio	m_α/m_p	$3.972\,599\,6846(11)$		2.8×10^{-10}
alpha particle molar mass N_Am_α	$M(\alpha)$, M_α	$4.001\,506\,1747(10)\times10^{-3}$	kg mol^{-1}	2.5×10^{-10}
PHYSICO-CHEMICAL				
Avogadro constant	N_A, L	$6.022\,141\,99(47)\times10^{23}$	mol^{-1}	7.9×10^{-8}
atomic mass constant $m_u = \frac{1}{12}m(^{12}C) = 1$ u $= 10^{-3}$ kg mol$^{-1}/N_A$	m_u	$1.660\,538\,73(13)\times10^{-27}$	kg	7.9×10^{-8}
energy equivalent	m_uc^2	$1.492\,417\,78(12)\times10^{-10}$	J	7.9×10^{-8}
in MeV		$931.494\,013(37)$	MeV	4.0×10^{-8}
Faraday constant[g] N_Ae	F	$96\,485.3415(39)$	C mol^{-1}	4.0×10^{-8}

Fundamental Physical Constants

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
molar Planck constant	$N_A h$	$3.990\,312\,689(30) \times 10^{-10}$	J s mol^{-1}	7.6×10^{-9}
	$N_A hc$	$0.119\,626\,564\,92(91)$	J m mol^{-1}	7.6×10^{-9}
molar gas constant	R	$8.314\,472(15)$	J mol^{-1} K^{-1}	1.7×10^{-6}
Boltzmann constant R/N_A	k	$1.380\,6503(24) \times 10^{-23}$	J K^{-1}	1.7×10^{-6}
in eV K^{-1}		$8.617\,342(15) \times 10^{-5}$	eV K^{-1}	1.7×10^{-6}
	k/h	$2.083\,6644(36) \times 10^{10}$	Hz K^{-1}	1.7×10^{-6}
	k/hc	$69.503\,56(12)$	m^{-1} K^{-1}	1.7×10^{-6}
molar volume of ideal gas RT/p				
$T = 273.15$ K, $p = 101.325$ kPa	V_m	$22.413\,996(39) \times 10^{-3}$	m^3 mol^{-1}	1.7×10^{-6}
Loschmidt constant N_A/V_m	n_0	$2.686\,7775(47) \times 10^{25}$	m^{-3}	1.7×10^{-6}
$T = 273.15$ K, $p = 100$ kPa	V_m	$22.710\,981(40) \times 10^{-3}$	m^3 mol^{-1}	1.7×10^{-6}
Sackur-Tetrode constant				
(absolute entropy constant)[h]				
$\frac{5}{2} + \ln[(2\pi m_u k T_1/h^2)^{3/2} k T_1/p_0]$				
$T_1 = 1$ K, $p_0 = 100$ kPa	S_0/R	$-1.151\,7048(44)$		3.8×10^{-6}
$T_1 = 1$ K, $p_0 = 101.325$ kPa		$-1.164\,8678(44)$		3.7×10^{-6}
Stefan-Boltzmann constant				
$(\pi^2/60)k^4/\hbar^3 c^2$	σ	$5.670\,400(40) \times 10^{-8}$	W m^{-2} K^{-4}	7.0×10^{-6}
first radiation constant $2\pi hc^2$	c_1	$3.741\,771\,07(29) \times 10^{-16}$	W m^2	7.8×10^{-8}
first radiation constant for spectral radiance $2hc^2$	c_{1L}	$1.191\,042\,722(93) \times 10^{-16}$	W m^2 sr^{-1}	7.8×10^{-8}
second radiation constant hc/k	c_2	$1.438\,7752(25) \times 10^{-2}$	m K	1.7×10^{-6}
Wien displacement law constant				
$b = \lambda_{max} T = c_2/4.965\,114\,231\ldots$	b	$2.897\,7686(51) \times 10^{-3}$	m K	1.7×10^{-6}

[a] See the "Adopted values" table for the conventional value adopted internationally for realizing representations of the volt using the Josephson effect.

[b] See the "Adopted values" table for the conventional value adopted internationally for realizing representations of the ohm using the quantum Hall effect.

[c] Value recommended by the Particle Data Group, Caso et al., Eur. Phys. J. C **3**(1-4), 1-794 (1998).

[d] Based on the ratio of the masses of the W and Z bosons m_W/m_Z recommended by the Particle Data Group (Caso et al., 1998). The value for $\sin^2\theta_W$ they recommend, which is based on a particular variant of the modified minimal subtraction ($\overline{\text{MS}}$) scheme, is $\sin^2\hat{\theta}_W(M_Z) = 0.231\,24(24)$.

[e] The helion, symbol h, is the nucleus of the ^{3}He atom.

[f] This and all other values involving m_τ are based on the value of $m_\tau c^2$ in MeV recommended by the Particle Data Group, Caso et al., Eur. Phys. J. C **3**(1-4), 1-794 (1998), but with a standard uncertainty of 0.29 MeV rather than the quoted uncertainty of −0.26 MeV, +0.29 MeV.

[g] The numerical value of F to be used in coulometric chemical measurements is 96 485.3432(76) [7.9×10^{-8}] when the relevant current is measured in terms of representations of the volt and ohm based on the Josephson and quantum Hall effects and the internationally adopted conventional values of the Josephson and von Klitzing constants K_{J-90} and R_{K-90} given in the "Adopted values" table.

[h] The entropy of an ideal monoatomic gas of relative atomic mass A_r is given by $S = S_0 + \frac{3}{2}R\ \ln A_r - R\ \ln(p/p_0) + \frac{5}{2}R\ \ln(T/\mathrm{K})$.

Fundamental Physical Constants — Adopted values

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
molar mass of ^{12}C	$M(^{12}\mathrm{C})$	12×10^{-3}	kg mol^{-1}	(exact)
molar mass constant[a] $M(^{12}\mathrm{C})/12$	M_u	1×10^{-3}	kg mol^{-1}	(exact)
conventional value of Josephson constant[b]	$K_{\mathrm{J}-90}$	483 597.9	GHz V^{-1}	(exact)
conventional value of von Klitzing constant[c]	$R_{\mathrm{K}-90}$	25 812.807	Ω	(exact)
standard atmosphere		101 325	Pa	(exact)
standard acceleration of gravity	g_n	9.806 65	m s^{-2}	(exact)

[a] The relative atomic mass $A_\mathrm{r}(\mathrm{X})$ of particle X with mass $m(\mathrm{X})$ is defined by $A_\mathrm{r}(\mathrm{X}) = m(\mathrm{X})/m_\mathrm{u}$, where $m_\mathrm{u} = m(^{12}\mathrm{C})/12 = M_\mathrm{u}/N_\mathrm{A} = 1$ u is the atomic mass constant, N_A is the Avogadro constant, and u is the atomic mass unit. Thus the mass of particle X in u is $m(\mathrm{X}) = A_\mathrm{r}(\mathrm{X})$ u and the molar mass of X is $M(\mathrm{X}) = A_\mathrm{r}(\mathrm{X})M_\mathrm{u}$.

[b] This is the value adopted internationally for realizing representations of the volt using the Josephson effect.

[c] This is the value adopted internationally for realizing representations of the ohm using the quantum Hall effect.

Energy Equivalents

	J	kg	m^{-1}	Hz
1 J	(1 J) = 1 J	$(1\ \mathrm{J})/c^2 =$ $1.112\,650\,056 \times 10^{-17}$ kg	$(1\ \mathrm{J})/hc =$ $5.034\,117\,62(39) \times 10^{24}\ \mathrm{m}^{-1}$	$(1\ \mathrm{J})/h =$ $1.509\,190\,50(12) \times 10^{33}$ Hz
1 kg	$(1\ \mathrm{kg})c^2 =$ $8.987\,551\,787 \times 10^{16}$ J	(1 kg) = 1 kg	$(1\ \mathrm{kg})c/h =$ $4.524\,439\,29(35) \times 10^{41}\ \mathrm{m}^{-1}$	$(1\ \mathrm{kg})c^2/h =$ $1.356\,392\,77(11) \times 10^{50}$ Hz
$1\ \mathrm{m}^{-1}$	$(1\ \mathrm{m}^{-1})hc =$ $1.986\,445\,44(16) \times 10^{-25}$ J	$(1\ \mathrm{m}^{-1})h/c =$ $2.210\,218\,63(17) \times 10^{-42}$ kg	$(1\ \mathrm{m}^{-1}) =$ $1\ \mathrm{m}^{-1}$	$(1\ \mathrm{m}^{-1})c =$ 299 792 458 Hz
1 Hz	$(1\ \mathrm{Hz})h =$ $6.626\,068\,76(52) \times 10^{-34}$ J	$(1\ \mathrm{Hz})h/c^2 =$ $7.372\,495\,78(58) \times 10^{-51}$ kg	$(1\ \mathrm{Hz})/c =$ $3.335\,640\,952 \times 10^{-9}\ \mathrm{m}^{-1}$	(1 Hz) = 1 Hz
1 K	$(1\ \mathrm{K})k =$ $1.380\,6503(24) \times 10^{-23}$ J	$(1\ \mathrm{K})k/c^2 =$ $1.536\,1807(27) \times 10^{-40}$ kg	$(1\ \mathrm{K})k/hc =$ $69.503\,56(12)\ \mathrm{m}^{-1}$	$(1\ \mathrm{K})k/h =$ $2.083\,6644(36) \times 10^{10}$ Hz
1 eV	(1 eV) = $1.602\,176\,462(63) \times 10^{-19}$ J	$(1\ \mathrm{eV})/c^2 =$ $1.782\,661\,731(70) \times 10^{-36}$ kg	$(1\ \mathrm{eV})/hc =$ $8.065\,544\,77(32) \times 10^{5}\ \mathrm{m}^{-1}$	$(1\ \mathrm{eV})/h =$ $2.417\,989\,491(95) \times 10^{14}$ Hz
1 u	$(1\ \mathrm{u})c^2 =$ $1.492\,417\,78(12) \times 10^{-10}$ J	(1 u) = $1.660\,538\,73(13) \times 10^{-27}$ kg	$(1\ \mathrm{u})c/h =$ $7.513\,006\,658(57) \times 10^{14}\ \mathrm{m}^{-1}$	$(1\ \mathrm{u})c^2/h =$ $2.252\,342\,733(17) \times 10^{23}$ Hz
$1\ E_\mathrm{h}$	$(1\ E_\mathrm{h}) =$ $4.359\,743\,81(34) \times 10^{-18}$ J	$(1\ E_\mathrm{h})/c^2 =$ $4.850\,869\,19(38) \times 10^{-35}$ kg	$(1\ E_\mathrm{h})/hc =$ $2.194\,746\,313\,710(17) \times 10^{7}\ \mathrm{m}^{-1}$	$(1\ E_\mathrm{h})/h =$ $6.579\,683\,920\,735(50) \times 10^{15}$ Hz

Derived from the relations $E = mc^2 = hc/\lambda = h\nu = kT$, and based on the 1998 CODATA adjustment of the values of the constants; $1\ \mathrm{eV} = (e/\mathrm{C})$ J, $1\ \mathrm{u} = m_\mathrm{u} = \frac{1}{12}m(^{12}\mathrm{C}) = 10^{-3}\ \mathrm{kg\ mol}^{-1}/N_\mathrm{A}$, and $E_\mathrm{h} = 2R_\infty hc = \alpha^2 m_\mathrm{e} c^2$ is the Hartree energy (hartree).

Energy Equivalents

	K	eV	u	E_h
1 J	$(1\ \text{J})/k =$ $7.242\,964(13) \times 10^{22}$ K	$(1\ \text{J}) =$ $6.241\,509\,74(24) \times 10^{18}$ eV	$(1\ \text{J})/c^2 =$ $6.700\,536\,62(53) \times 10^{9}$ u	$(1\ \text{J}) =$ $2.293\,712\,76(18) \times 10^{17}\ E_h$
1 kg	$(1\ \text{kg})c^2/k =$ $6.509\,651(11) \times 10^{39}$ K	$(1\ \text{kg})c^2 =$ $5.609\,589\,21(22) \times 10^{35}$ eV	$(1\ \text{kg}) =$ $6.022\,141\,99(47) \times 10^{26}$ u	$(1\ \text{kg})c^2 =$ $2.061\,486\,22(16) \times 10^{34}\ E_h$
$1\ \text{m}^{-1}$	$(1\ \text{m}^{-1})hc/k =$ $1.438\,7752(25) \times 10^{-2}$ K	$(1\ \text{m}^{-1})hc =$ $1.239\,841\,857(49) \times 10^{-6}$ eV	$(1\ \text{m}^{-1})h/c =$ $1.331\,025\,042(10) \times 10^{-15}$ u	$(1\ \text{m}^{-1})hc =$ $4.556\,335\,252\,750(35) \times 10^{-8}\ E_h$
1 Hz	$(1\ \text{Hz})h/k =$ $4.799\,2374(84) \times 10^{-11}$ K	$(1\ \text{Hz})h =$ $4.135\,667\,27(16) \times 10^{-15}$ eV	$(1\ \text{Hz})h/c^2 =$ $4.439\,821\,637(34) \times 10^{-24}$ u	$(1\ \text{Hz})h =$ $1.519\,829\,846\,003(12) \times 10^{-16}\ E_h$
1 K	$(1\ \text{K}) =$ 1 K	$(1\ \text{K})k =$ $8.617\,342(15) \times 10^{-5}$ eV	$(1\ \text{K})k/c^2 =$ $9.251\,098(16) \times 10^{-14}$ u	$(1\ \text{K})k =$ $3.166\,8153(55) \times 10^{-6}\ E_h$
1 eV	$(1\ \text{eV})/k =$ $1.160\,4506(20) \times 10^{4}$ K	$(1\ \text{eV}) =$ 1 eV	$(1\ \text{eV})/c^2 =$ $1.073\,544\,206(43) \times 10^{-9}$ u	$(1\ \text{eV}) =$ $3.674\,932\,60(14) \times 10^{-2}\ E_h$
1 u	$(1\ \text{u})c^2/k =$ $1.080\,9528(19) \times 10^{13}$ K	$(1\ \text{u})c^2 =$ $931.494\,013(37) \times 10^{6}$ eV	$(1\ \text{u}) =$ 1 u	$(1\ \text{u})c^2 =$ $3.423\,177\,709(26) \times 10^{7}\ E_h$
$1\ E_h$	$(1\ E_h)/k =$ $3.157\,7465(55) \times 10^{5}$ K	$(1\ E_h) =$ $27.211\,3834(11)$ eV	$(1\ E_h)/c^2 =$ $2.921\,262\,304(22) \times 10^{-8}$ u	$(1\ E_h) =$ $1\ E_h$

Derived from the relations $E = mc^2 = hc/\lambda = h\nu = kT$, and based on the 1998 CODATA adjustment of the values of the constants; $1\ \text{eV} = (e/\text{C})\ \text{J}$, $1\ \text{u} = m_u = \frac{1}{12}m(^{12}\text{C}) = 10^{-3}\ \text{kg mol}^{-1}/N_A$, and $E_h = 2R_\infty hc = \alpha^2 m_e c^2$ is the Hartree energy (hartree).

STANDARD ATOMIC WEIGHTS (1997)

This table of atomic weights is reprinted from the 1997 report of the IUPAC Commission on Atomic Weights and Isotopic Abundances. The Standard Atomic Weights apply to the elements as they exist naturally on Earth, and the uncertainties take into account the isotopic variation found in most laboratory samples. Further comments on the variability are given in the footnotes.

The number in parentheses following the atomic weight value gives the uncertainty in the last digit. An entry in brackets indicates the mass number of the longest-lived isotope of an element that has no stable isotopes and for which a Standard Atomic Weight cannot be defined because of wide variability in isotopic composition (or complete absence) in nature.

REFERENCE

Vocke, R. D. (for IUPAC Commission on Atomic Weights and Isotopic Abundances), Atomic Weights of the Elements 1997, *Pure Appl. Chem.*, 71, 1593, 1999.

Name	Symbol	At. no.	Atomic Weight	Footnotes		
Actinium	Ac	89	[227]			
Aluminum	Al	13	26.981538(2)			
Americium	Am	95	[243]			
Antimony	Sb	51	121.760(1)	g		
Argon	Ar	18	39.948(1)	g		r
Arsenic	As	33	74.92160(2)			
Astatine	At	85	[210]			
Barium	Ba	56	137.327(7)			
Berkelium	Bk	97	[247]			
Beryllium	Be	4	9.012182(3)			
Bismuth	Bi	83	208.98038(2)			
Bohrium	Bh	107	[264]			
Boron	B	5	10.811(7)	g	m	r
Bromine	Br	35	79.904(1)			
Cadmium	Cd	48	112.411(8)	g		
Calcium	Ca	20	40.078(4)	g		
Californium	Cf	98	[251]			
Carbon	C	6	12.0107(8)	g		r
Cerium	Ce	58	140.116(1)	g		
Cesium	Cs	55	132.90545(2)			
Chlorine	Cl	17	35.4527(9)		m	
Chromium	Cr	24	51.9961(6)			
Cobalt	Co	27	58.933200(9)			
Copper	Cu	29	63.546(3)			r
Curium	Cm	96	[247]			
Dubnium	Db	105	[262]			
Dysprosium	Dy	66	162.50(3)	g		
Einsteinium	Es	99	[252]			
Erbium	Er	68	167.26(3)	g		
Europium	Eu	63	151.964(1)	g		
Fermium	Fm	100	[257]			
Fluorine	F	9	18.9984032(5)			
Francium	Fr	87	[223]			
Gadolinium	Gd	64	157.25(3)	g		
Gallium	Ga	31	69.723(1)			
Germanium	Ge	32	72.61(2)			
Gold	Au	79	196.96655(2)			
Hafnium	Hf	72	178.49(2)			
Hassium	Hs	108	[269]			
Helium	He	2	4.002602(2)	g		r
Holmium	Ho	67	164.93032(2)			
Hydrogen	H	1	1.00794(7)	g	m	r
Indium	In	49	114.818(3)			
Iodine	I	53	126.90447(3)			

STANDARD ATOMIC WEIGHTS (1997) (continued)

Name	Symbol	At. no.	Atomic Weight	Footnotes		
Iridium	Ir	77	192.217(3)			
Iron	Fe	26	55.845(2)			
Krypton	Kr	36	83.80(1)	g	m	
Lanthanum	La	57	138.9055(2)	g		
Lawrencium	Lr	103	[262]			
Lead	Pb	82	207.2(1)	g		r
Lithium	Li	3	6.941(2)*	g	m	r
Lutetium	Lu	71	174.967(1)	g		
Magnesium	Mg	12	24.3050(6)			
Manganese	Mn	25	54.938049(9)			
Meitnerium	Mt	109	[268]			
Mendelevium	Md	101	[258]			
Mercury	Hg	80	200.59(2)			
Molybdenum	Mo	42	95.94(1)	g		
Neodymium	Nd	60	144.24(3)	g		
Neon	Ne	10	20.1797(6)	g	m	
Neptunium	Np	93	[237]			
Nickel	Ni	28	58.6934(2)			
Niobium	Nb	41	92.90638(2)			
Nitrogen	N	7	14.00674(7)	g		r
Nobelium	No	102	[259]			
Osmium	Os	76	190.23(3)	g		
Oxygen	O	8	15.9994(3)	g		r
Palladium	Pd	46	106.42(1)	g		
Phosphorus	P	15	30.973761(2)			
Platinum	Pt	78	195.078(2)			
Plutonium	Pu	94	[244]			
Polonium	Po	84	[209]			
Potassium	K	19	39.0983(1)	g		
Praseodymium	Pr	59	140.90765(2)			
Promethium	Pm	61	[145]			
Protactinium	Pa	91	231.03588(2)			
Radium	Ra	88	[226]			
Radon	Rn	86	[222]			
Rhenium	Re	75	186.207(1)			
Rhodium	Rh	45	102.90550(2)			
Rubidium	Rb	37	85.4678(3)	g		
Ruthenium	Ru	44	101.07(2)	g		
Rutherfordium	Rf	104	[261]			
Samarium	Sm	62	150.36(3)	g		
Scandium	Sc	21	44.955910(8)			
Seaborgium	Sg	106	[266]			
Selenium	Se	34	78.96(3)			
Silicon	Si	14	28.0855(3)			r
Silver	Ag	47	107.8682(2)	g		
Sodium	Na	11	22.989770(2)			
Strontium	Sr	38	87.62(1)	g		r
Sulfur	S	16	32.066(6)	g		r
Tantalum	Ta	73	180.9479(1)			
Technetium	Tc	43	[98]			
Tellurium	Te	52	127.60(3)	g		
Terbium	Tb	65	158.92534(2)			
Thallium	Tl	81	204.3833(2)			
Thorium	Th	90	232.0381(1)	g		
Thulium	Tm	69	168.93421(2)			
Tin	Sn	50	118.710(7)	g		
Titanium	Ti	22	47.867(1)			
Tungsten	W	74	183.84(1)			

STANDARD ATOMIC WEIGHTS (1997) (continued)

Name	Symbol	At. no.	Atomic Weight	Footnotes	
Uranium	U	92	238.0289(1)	g	m
Vanadium	V	23	50.9415(1)		
Xenon	Xe	54	131.29(2)	g	m
Ytterbium	Yb	70	173.04(3)	g	
Yttrium	Y	39	88.90585(2)		
Zinc	Zn	30	65.39(2)		
Zirconium	Zr	40	91.224(2)	g	

* Commercially available Li materials have atomic weights that are known to range between 6.939 and 6.996; if a more accurate value is required, it must be determined for the specific material.

g geological specimens are known in which the element has an isotopic composition outside the limits for normal material. The difference between the atomic weight of the element in such specimens and that given in the table may exceed the stated uncertainty.

m modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic fractionation. Substantial deviations in atomic weight of the element from that given the table can occur.

r range in isotopic composition of normal terrestrial material prevents a more precise atomic weight being given; the tabulated atomic weight value should be applicable to any normal material.

ATOMIC MASSES AND ABUNDANCES

This table lists the mass (in atomic mass units, symbol u) and the natural abundance (in percent) of the stable nuclides and a few important radioactive nuclides. A complete table of all nuclides may be found in Section 11 ("Table of the Isotopes").

The atomic masses are based on the 1995 evaluation of Audi and Wapstra (Reference 2). The number in parentheses following the mass value is the uncertainty in the last digit(s) given.

Natural abundance values are also followed by uncertainties in the last digit(s) of the stated values. This uncertainty includes both the estimated measurement uncertainty and the reported range of variation in different terrestrial sources of the element (see Reference 3 and 4 for more details). The absence of an entry in the Abundance column indicates a radioactive nuclide not present in nature or an element whose isotopic composition varies so widely that a meaningful natural abundance cannot be defined.

An electronic version of these data is available on the Web site of the NIST Physics Laboratory (Reference 5).

REFERENCES

1. Holden, N. E., "Table of the Isotopes", in Lide, D. R., Ed., *CRC Handbook of Chemistry and Physics, 82nd Ed.*, CRC Press, Boca Raton FL, 2001.
2. Audi, G., and Wapstra, A. H., *Nucl. Phys.*, A595, 409, 1995.
3. Rosman, K. J. R., and Taylor, P. D. P., *J. Phys. Chem. Ref. Data,* 27, 1275, 1998.
4. R. D. Vocke (for IUPAC Commission on Atomic Weights and Isotopic Abundances), *Pure Appl. Chem.*, 71, 1593, 1999.
5. Coursey, J. S., and Dragoset, R. A., *Atomic Weights and Isotopic Compositions* (version 2.1). Available: http://physics.nist.gov/Compositions/ National Institute of Standards and Technology, Gaithersburg, MD.

Z	Isotope	Mass in u	Abundance in %
1	^{1}H	1.0078250321(4)	99.9850(70)
	^{2}D	2.0141017780(4)	0.0115(70)
	^{3}T	3.0160492675(11)	
2	^{3}He	3.0160293097(9)	0.000137(3)
	^{4}He	4.0026032497(10)	99.999863(3)
3	^{6}Li	6.0151223(5)	7.59(4)
	^{7}Li	7.0160040(5)	92.41(4)
4	^{9}Be	9.0121821(4)	100
5	^{10}B	10.0129370(4)	19.9(7)
	^{11}B	11.0093055(5)	80.1(7)
6	^{12}C	12.0000000(0)	98.93(8)
	^{13}C	13.0033548378(10)	1.07(8)
7	^{14}N	14.0030740052(9)	99.632(7)
	^{15}N	15.0001088984(9)	0.368(7)
8	^{16}O	15.9949146221(15)	99.757(16)
	^{17}O	16.99913150(22)	0.038(1)
	^{18}O	17.9991604(9)	0.205(14)
9	^{19}F	18.99840320(7)	100
10	^{20}Ne	19.9924401759(20)	90.48(3)
	^{21}Ne	20.99384674(4)	0.27(1)
	^{22}Ne	21.99138551(23)	9.25(3)
11	^{23}Na	22.98976967(23)	100
12	^{24}Mg	23.98504190(20)	78.99(4)
	^{25}Mg	24.98583702(20)	10.00(1)
	^{26}Mg	25.98259304(21)	11.01(3)
13	^{27}Al	26.98153844(14)	100
14	^{28}Si	27.9769265327(20)	92.2297(7)
	^{29}Si	28.97649472(3)	4.6832(5)
	^{30}Si	29.97377022(5)	3.0872(5)
15	^{31}P	30.97376151(20)	100
16	^{32}S	31.97207069(12)	94.93(31)
	^{33}S	32.97145850(12)	0.76(2)
	^{34}S	33.96786683(11)	4.29(28)
	^{36}S	35.96708088(25)	0.02(1)
17	^{35}Cl	34.96885271(4)	75.78(4)
	^{37}Cl	36.96590260(5)	24.22(4)
18	^{36}Ar	35.96754628(27)	0.3365(30)
	^{38}Ar	37.9627322(5)	0.0632(5)
	^{40}Ar	39.962383123(3)	99.6003(30)
19	^{39}K	38.9637069(3)	93.2581(44)
	^{40}K	39.96399867(29)	0.0117(1)
	^{41}K	40.96182597(28)	6.7302(44)
20	^{40}Ca	39.9625912(3)	96.941(156)
	^{42}Ca	41.9586183(4)	0.647(23)
	^{43}Ca	42.9587668(5)	0.135(10)
	^{44}Ca	43.9554811(9)	2.086(110)
	^{46}Ca	45.9536928(25)	0.004(3)
	^{48}Ca	47.952534(4)	0.187(21)
21	^{45}Sc	44.9559102(12)	100
22	^{46}Ti	45.9526295(12)	8.25(3)
	^{47}Ti	46.9517638(10)	7.44(2)
	^{48}Ti	47.9479471(10)	73.72(3)
	^{49}Ti	48.9478708(10)	5.41(2)
	^{50}Ti	49.9447921(11)	5.18(2)
23	^{50}V	49.9471628(14)	0.250(4)
	^{51}V	50.9439637(14)	99.750(4)
24	^{50}Cr	49.9460496(14)	4.345(13)
	^{52}Cr	51.9405119(15)	83.789(18)
	^{53}Cr	52.9406538(15)	9.501(17)
	^{54}Cr	53.9388849(15)	2.365(7)
25	^{55}Mn	54.9380496(14)	100
26	^{54}Fe	53.9396148(14)	5.845(35)
	^{56}Fe	55.9349421(15)	91.754(36)
	^{57}Fe	56.9353987(15)	2.119(10)
	^{58}Fe	57.9332805(15)	0.282(4)
27	^{59}Co	58.9332002(15)	100
28	^{58}Ni	57.9353479(15)	68.0769(89)
	^{60}Ni	59.9307906(15)	26.2231(77)
	^{61}Ni	60.9310604(15)	1.1399(6)
	^{62}Ni	61.9283488(15)	3.6345(17)
	^{64}Ni	63.9279696(16)	0.9256(9)
29	^{63}Cu	62.9296011(15)	69.17(3)
	^{65}Cu	64.9277937(19)	30.83(3)
30	^{64}Zn	63.9291466(18)	48.63(60)
	^{66}Zn	65.9260368(16)	27.90(27)
	^{67}Zn	66.9271309(17)	4.10(13)

Z	Isotope	Mass in u	Abundance in %
	^{68}Zn	67.9248476(17)	18.75(51)
	^{70}Zn	69.925325(4)	0.62(3)
31	^{69}Ga	68.925581(3)	60.108(9)
	^{71}Ga	70.9247050(19)	39.892(9)
32	^{70}Ge	69.9242504(19)	20.84(87)
	^{72}Ge	71.9220762(16)	27.54(34)
	^{73}Ge	72.9234594(16)	7.73(5)
	^{74}Ge	73.9211782(16)	36.28(73)
	^{76}Ge	75.9214027(16)	7.61(38)
33	^{75}As	74.9215964(18)	100
34	^{74}Se	73.9224766(16)	0.89(4)
	^{76}Se	75.9192141(16)	9.37(29)
	^{77}Se	76.9199146(16)	7.63(16)
	^{78}Se	77.9173095(16)	23.77(28)
	^{80}Se	79.9165218(20)	49.61(41)
	^{82}Se	81.9167000(22)	8.73(22)
35	^{79}Br	78.9183376(20)	50.69(7)
	^{81}Br	80.916291(3)	49.31(7)
36	^{78}Kr	77.920386(7)	0.35(1)
	^{80}Kr	79.916378(4)	2.28(6)
	^{82}Kr	81.9134846(28)	11.58(14)
	^{83}Kr	82.914136(3)	11.49(6)
	^{84}Kr	83.911507(3)	57.00(4)
	^{86}Kr	85.9106103(12)	17.30(22)
37	^{85}Rb	84.9117893(25)	72.17(2)
	^{87}Rb	86.9091835(27)	27.83(2)
38	^{84}Sr	83.913425(4)	0.56(1)
	^{86}Sr	85.9092624(24)	9.86(1)
	^{87}Sr	86.9088793(24)	7.00(1)
	^{88}Sr	87.9056143(24)	82.58(1)
39	^{89}Y	88.9058479(25)	100
40	^{90}Zr	89.9047037(23)	51.45(40)
	^{91}Zr	90.9056450(23)	11.22(5)
	^{92}Zr	91.9050401(23)	17.15(8)
	^{94}Zr	93.9063158(25)	17.38(28)
	^{96}Zr	95.908276(3)	2.80(9)
41	^{93}Nb	92.9063775(24)	100
42	^{92}Mo	91.906810(4)	14.84(35)
	^{94}Mo	93.9050876(20)	9.25(12)
	^{95}Mo	94.9058415(20)	15.92(13)
	^{96}Mo	95.9046789(20)	16.68(2)
	^{97}Mo	96.9060210(20)	9.55(8)
	^{98}Mo	97.9054078(20)	24.13(31)
	^{100}Mo	99.907477(6)	9.63(23)
43	^{97}Tc	96.906365(5)	
	^{98}Tc	97.907216(4)	
	^{99}Tc	98.9062546(21)	
44	^{96}Ru	95.907598(8)	5.54(14)
	^{98}Ru	97.905287(7)	1.87(3)
	^{99}Ru	98.9059393(21)	12.76(14)
	^{100}Ru	99.9042197(22)	12.60(7)
	^{101}Ru	100.9055822(22)	17.06(2)
	^{102}Ru	101.9043495(22)	31.55(14)
	^{104}Ru	103.905430(4)	18.62(27)
45	^{103}Rh	102.905504(3)	100
46	^{102}Pd	101.905608(3)	1.02(1)
	^{104}Pd	103.904035(5)	11.14(8)
	^{105}Pd	104.905084(5)	22.33(8)
	^{106}Pd	105.903483(5)	27.33(3)
	^{108}Pd	107.903894(4)	26.46(9)
	^{110}Pd	109.905152(12)	11.72(9)
47	^{107}Ag	106.905093(6)	51.839(8)
	^{109}Ag	108.904756(3)	48.161(8)
48	^{106}Cd	105.906458(6)	1.25(6)
	^{108}Cd	107.904183(6)	0.89(3)
	^{110}Cd	109.903006(3)	12.49(18)
	^{111}Cd	110.904182(3)	12.80(12)
	^{112}Cd	111.9027572(30)	24.13(21)
	^{113}Cd	112.9044009(30)	12.22(12)
	^{114}Cd	113.9033581(30)	28.73(42)
	^{116}Cd	115.904755(3)	7.49(18)
49	^{113}In	112.904061(4)	4.29(5)
	^{115}In	114.903878(5)	95.71(5)
50	^{112}Sn	111.904821(5)	0.97(1)
	^{114}Sn	113.902782(3)	0.66(1)
	^{115}Sn	114.903346(3)	0.34(1)
	^{116}Sn	115.901744(3)	14.54(9)
	^{117}Sn	116.902954(3)	7.68(7)
	^{118}Sn	117.901606(3)	24.22(9)
	^{119}Sn	118.903309(3)	8.59(4)
	^{120}Sn	119.9021966(27)	32.58(9)
	^{122}Sn	121.9034401(29)	4.63(3)
	^{124}Sn	123.9052746(15)	5.79(5)
51	^{121}Sb	120.9038180(24)	57.21(5)
	^{123}Sb	122.9042157(22)	42.79(5)
52	^{120}Te	119.904020(11)	0.09(1)
	^{122}Te	121.9030471(20)	2.55(12)
	^{123}Te	122.9042730(19)	0.89(3)
	^{124}Te	123.9028195(16)	4.74(14)
	^{125}Te	124.9044247(20)	7.07(15)
	^{126}Te	125.9033055(20)	18.84(25)
	^{128}Te	127.9044614(19)	31.74(8)
	^{130}Te	129.9062228(21)	34.08(62)
53	^{127}I	126.904468(4)	100
54	^{124}Xe	123.9058958(21)	0.09(1)
	^{126}Xe	125.904269(7)	0.09(1)
	^{128}Xe	127.9035304(15)	1.92(3)
	^{129}Xe	128.9047795(9)	26.44(24)
	^{130}Xe	129.9035079(10)	4.08(2)
	^{131}Xe	130.9050819(10)	21.18(3)
	^{132}Xe	131.9041545(12)	26.89(6)
	^{134}Xe	133.9053945(9)	10.44(10)
	^{136}Xe	135.907220(8)	8.87(16)
55	^{133}Cs	132.905447(3)	100
56	^{130}Ba	129.906310(7)	0.106(1)
	^{132}Ba	131.905056(3)	0.101(1)
	^{134}Ba	133.904503(3)	2.417(18)
	^{135}Ba	134.905683(3)	6.592(12)
	^{136}Ba	135.904570(3)	7.854(24)
	^{137}Ba	136.905821(3)	11.232(24)
	^{138}Ba	137.905241(3)	71.698(42)
57	^{138}La	137.907107(4)	0.090(1)
	^{139}La	138.906348(3)	99.910(1)
58	^{136}Ce	135.907140(50)	0.185(2)
	^{138}Ce	137.905986(11)	0.251(2)
	^{140}Ce	139.905434(3)	88.450(51)

ATOMIC MASSES AND ABUNDANCES (continued)

Z	Isotope	Mass in u	Abundance in %
	^{142}Ce	141.909240(4)	11.114(51)
59	^{141}Pr	140.907648(3)	100
60	^{142}Nd	141.907719(3)	27.2(5)
	^{143}Nd	142.909810(3)	12.2(2)
	^{144}Nd	143.910083(3)	23.8(3)
	^{145}Nd	144.912569(3)	8.3(1)
	^{146}Nd	145.913112(3)	17.2(3)
	^{148}Nd	147.916889(3)	5.7(1)
	^{150}Nd	149.920887(4)	5.6(2)
61	^{145}Pm	144.912744(4)	
	^{147}Pm	146.915134(3)	
62	^{144}Sm	143.911995(4)	3.07(7)
	^{147}Sm	146.914893(3)	14.99(18)
	^{148}Sm	147.914818(3)	11.24(10)
	^{149}Sm	148.917180(3)	13.82(7)
	^{150}Sm	149.917271(3)	7.38(1)
	^{152}Sm	151.919728(3)	26.75(16)
	^{154}Sm	153.922205(3)	22.75(29)
63	^{151}Eu	150.919846(3)	47.81(3)
	^{153}Eu	152.921226(3)	52.19(3)
64	^{152}Gd	151.919788(3)	0.20(1)
	^{154}Gd	153.920862(3)	2.18(3)
	^{155}Gd	154.922619(3)	14.80(12)
	^{156}Gd	155.922120(3)	20.47(9)
	^{157}Gd	156.923957(3)	15.65(2)
	^{158}Gd	157.924101(3)	24.84(7)
	^{160}Gd	159.927051(3)	21.86(19)
65	^{159}Tb	158.925343(3)	100
66	^{156}Dy	155.924278(7)	0.06(1)
	^{158}Dy	157.924405(4)	0.10(1)
	^{160}Dy	159.925194(3)	2.34(8)
	^{161}Dy	160.926930(3)	18.91(24)
	^{162}Dy	161.926795(3)	25.51(26)
	^{163}Dy	162.928728(3)	24.90(16)
	^{164}Dy	163.929171(3)	28.18(37)
67	^{165}Ho	164.930319(3)	100
68	^{162}Er	161.928775(4)	0.14(1)
	^{164}Er	163.929197(4)	1.61(3)
	^{166}Er	165.930290(3)	33.61(35)
	^{167}Er	166.932045(3)	22.93(17)
	^{168}Er	167.932368(3)	26.78(26)
	^{170}Er	169.935460(3)	14.93(27)
69	^{169}Tm	168.934211(3)	100
70	^{168}Yb	167.933894(5)	0.13(1)
	^{170}Yb	169.934759(3)	3.04(15)
	^{171}Yb	170.936322(3)	14.28(57)
	^{172}Yb	171.9363777(30)	21.83(67)
	^{173}Yb	172.9382068(30)	16.13(27)
	^{174}Yb	173.9388581(30)	31.83(92)
	^{176}Yb	175.942568(3)	12.76(41)
71	^{175}Lu	174.9407679(28)	97.41(2)
	^{176}Lu	175.9426824(28)	2.59(2)
72	^{174}Hf	173.940040(3)	0.16(1)
	^{176}Hf	175.9414018(29)	5.26(7)
	^{177}Hf	176.9432200(27)	18.60(9)
	^{178}Hf	177.9436977(27)	27.28(7)
	^{179}Hf	178.9458151(27)	13.62(2)
	^{180}Hf	179.9465488(27)	35.08(16)
73	^{180}Ta	179.947466(3)	0.012(2)
	^{181}Ta	180.947996(3)	99.988(2)
74	^{180}W	179.946706(5)	0.12(1)
	^{182}W	181.948206(3)	26.50(16)
	^{183}W	182.9502245(29)	14.31(4)
	^{184}W	183.9509326(29)	30.64(2)
	^{186}W	185.954362(3)	28.43(19)
75	^{185}Re	184.9529557(30)	37.40(2)
	^{187}Re	186.9557508(30)	62.60(2)
76	^{184}Os	183.952491(3)	0.02(1)
	^{186}Os	185.953838(3)	1.59(3)
	^{187}Os	186.9557479(30)	1.96(2)
	^{188}Os	187.9558360(30)	13.24(8)
	^{189}Os	188.9581449(30)	16.15(5)
	^{190}Os	189.958445(3)	26.26(2)
	^{192}Os	191.961479(4)	40.78(19)
77	^{191}Ir	190.960591(3)	37.3(2)
	^{193}Ir	192.962924(3)	62.7(2)
78	^{190}Pt	189.959930(7)	0.014(1)
	^{192}Pt	191.961035(4)	0.782(7)
	^{194}Pt	193.962664(3)	32.967(99)
	^{195}Pt	194.964774(3)	33.832(10)
	^{196}Pt	195.964935(3)	25.242(41)
	^{198}Pt	197.967876(4)	7.163(55)
79	^{197}Au	196.966552(3)	100
80	^{196}Hg	195.965815(4)	0.15(1)
	^{198}Hg	197.966752(3)	9.97(20)
	^{199}Hg	198.968262(3)	16.87(22)
	^{200}Hg	199.968309(3)	23.10(19)
	^{201}Hg	200.970285(3)	13.18(9)
	^{202}Hg	201.970626(3)	29.86(26)
	^{204}Hg	203.973476(3)	6.87(15)
81	^{203}Tl	202.972329(3)	29.524(14)
	^{205}Tl	204.974412(3)	70.476(14)
82	^{204}Pb	203.973029(3)	1.4(1)
	^{206}Pb	205.974449(3)	24.1(1)
	^{207}Pb	206.975881(3)	22.1(1)
	^{208}Pb	207.976636(3)	52.4(1)
83	^{209}Bi	208.980383(3)	100
84	^{209}Po	208.982416(3)	
	^{210}Po	209.982857(3)	
85	^{210}At	209.987131(9)	
	^{211}At	210.987481(4)	
86	^{211}Rn	210.990585(8)	
	^{220}Rn	220.0113841(29)	
	^{222}Rn	222.0175705(27)	
87	^{223}Fr	223.0197307(29)	
88	^{223}Ra	223.018497(3)	
	^{224}Ra	224.0202020(29)	
	^{226}Ra	226.0254026(27)	
	^{228}Ra	228.0310641(27)	
89	^{227}Ac	227.0277470(29)	
90	^{230}Th	230.0331266(22)	
	^{232}Th	232.0380504(22)	100
91	^{231}Pa	231.0358789(28)	100
92	^{233}U	233.039628(3)	
	^{234}U	234.0409456(21)	0.0055(2)
	^{235}U	235.0439231(21)	0.7200(51)

ATOMIC MASSES AND ABUNDANCES (continued)

Z	Isotope	Mass in u	Abundance in %
	^{236}U	236.0455619(21)	
	^{238}U	238.0507826(21)	99.2745(106)
93	^{237}Np	237.0481673(21)	
	^{239}Np	239.0529314(23)	
94	^{238}Pu	238.0495534(21)	
	^{239}Pu	239.0521565(21)	
	^{240}Pu	240.0538075(21)	
	^{241}Pu	241.0568453(21)	
	^{242}Pu	242.0587368(21)	
	^{244}Pu	244.064198(5)	
95	^{241}Am	241.0568229(21)	
	^{243}Am	243.0613727(23)	
96	^{243}Cm	243.0613822(24)	
	^{244}Cm	244.0627463(21)	
	^{245}Cm	245.0654856(29)	
	^{246}Cm	246.0672176(24)	
	^{247}Cm	247.070347(5)	
	^{248}Cm	248.072342(5)	
97	^{247}Bk	247.070299(6)	

Z	Isotope	Mass in u	Abundance in %
	^{249}Bk	249.074980(3)	
98	^{249}Cf	249.074847(3)	
	^{250}Cf	250.0764000(24)	
	^{251}Cf	251.079580(5)	
	^{252}Cf	252.081620(5)	
99	^{252}Es	252.082970(50)	
100	^{257}Fm	257.095099(7)	
101	^{256}Md	256.094050(60)	
	^{258}Md	258.098425(5)	
102	^{259}No	259.101020(110)*	
103	^{262}Lr	262.109690(320)*	
104	^{261}Rf	261.108750(110)*	
105	^{262}Db	262.114150(200)*	
106	^{263}Sg	263.118310(130)*	
107	^{264}Bh	264.124730(300)*	
108	^{265}Hs	265.130000(320)*	
109	^{268}Mt	268.138820(340)*	
110	^{269}Uun	269.145140(310)*	
111	^{272}Uuu	272.153480(360)*	

*Mass values derived not purely from experimental data, but at least partly from systematic trends.

ELECTRON CONFIGURATION OF NEUTRAL ATOMS IN THE GROUND STATE

Atomic		K	L		M			N				O				P			Q
	n =	1	2		3			4				5				6			7
no.	Element	s	s	p	s	p	d	s	p	d	f	s	p	d	f	s	p	d	s
1	H	1																	
2	He	2																	
3	Li	2	1																
4	Be	2	2																
5	B	2	2	1															
6	C	2	2	2															
7	N	2	2	3															
8	O	2	2	4															
9	F	2	2	5															
10	Ne	2	2	6															
11	Na	2	2	6	1														
12	Mg	2	2	6	2														
13	Al	2	2	6	2	1													
14	Si	2	2	6	2	2													
15	P	2	2	6	2	3													
16	S	2	2	6	2	4													
17	Cl	2	2	6	2	5													
18	Ar	2	2	6	2	6													
19	K	2	2	6	2	6		1											
20	Ca	2	2	6	2	6		2											
21	Sc	2	2	6	2	6	1	2											
22	Ti	2	2	6	2	6	2	2											
23	V	2	2	6	2	6	3	2											
24	Cr	2	2	6	2	6	5*	1											
25	Mn	2	2	6	2	6	5	2											
26	Fe	2	2	6	2	6	6	2											
27	Co	2	2	6	2	6	7	2											
28	Ni	2	2	6	2	6	8	2											
29	Cu	2	2	6	2	6	10*	1											
30	Zn	2	2	6	2	6	10	2											
31	Ga	2	2	6	2	6	10	2	1										
32	Ge	2	2	6	2	6	10	2	2										
33	As	2	2	6	2	6	10	2	3										
34	Se	2	2	6	2	6	10	2	4										
35	Br	2	2	6	2	6	10	2	5										
36	Kr	2	2	6	2	6	10	2	6										
37	Rb	2	2	6	2	6	10	2	6			1							
38	Sr	2	2	6	2	6	10	2	6			2							
39	Y	2	2	6	2	6	10	2	6	1		2							
40	Zr	2	2	6	2	6	10	2	6	2		2							
41	Nb	2	2	6	2	6	10	2	6	4*		1							
42	Mo	2	2	6	2	6	10	2	6	5		1							
43	Tc	2	2	6	2	6	10	2	6	5		2							
44	Ru	2	2	6	2	6	10	2	6	7		1							
45	Rh	2	2	6	2	6	10	2	6	8		1							
46	Pd	2	2	6	2	6	10	2	6	10*									
47	Ag	2	2	6	2	6	10	2	6	10		1							
48	Cd	2	2	6	2	6	10	2	6	10		2							
49	In	2	2	6	2	6	10	2	6	10		2	1						
50	Sn	2	2	6	2	6	10	2	6	10		2	2						
51	Sb	2	2	6	2	6	10	2	6	10		2	3						
52	Te	2	2	6	2	6	10	2	6	10		2	4						
53	I	2	2	6	2	6	10	2	6	10		2	5						
54	Xe	2	2	6	2	6	10	2	6	10		2	6						
55	Cs	2	2	6	2	6	10	2	6	10		2	6			1			
56	Ba	2	2	6	2	6	10	2	6	10		2	6			2			

ELECTRON CONFIGURATION OF NEUTRAL ATOMS IN THE GROUND STATE (continued)

Atomic	*n* =	K	L		M			N				O				P			Q
		1	2		3			4				5				6			7
no.	Element	s	s	p	s	p	d	s	p	d	f	s	p	d	f	s	p	d	s
57	La	2	2	6	2	6	10	2	6	10		2	6	1		2			
58	Ce	2	2	6	2	6	10	2	6	10	1*	2	6	1		2			
59	Pr	2	2	6	2	6	10	2	6	10	3	2	6			2			
60	Nd	2	2	6	2	6	10	2	6	10	4	2	6			2			
61	Pm	2	2	6	2	6	10	2	6	10	5	2	6			2			
62	Sm	2	2	6	2	6	10	2	6	10	6	2	6			2			
63	Eu	2	2	6	2	6	10	2	6	10	7	2	6			2			
64	Gd	2	2	6	2	6	10	2	6	10	7	2	6	1		2			
65	Tb	2	2	6	2	6	10	2	6	10	9*	2	6			2			
66	Dy	2	2	6	2	6	10	2	6	10	10	2	6			2			
67	Ho	2	2	6	2	6	10	2	6	10	11	2	6			2			
68	Er	2	2	6	2	6	10	2	6	10	12	2	6			2			
69	Tm	2	2	6	2	6	10	2	6	10	13	2	6			2			
70	Yb	2	2	6	2	6	10	2	6	10	14	2	6			2			
71	Lu	2	2	6	2	6	10	2	6	10	14	2	6	1		2			
72	Hf	2	2	6	2	6	10	2	6	10	14	2	6	2		2			
73	Ta	2	2	6	2	6	10	2	6	10	14	2	6	3		2			
74	W	2	2	6	2	6	10	2	6	10	14	2	6	4		2			
75	Re	2	2	6	2	6	10	2	6	10	14	2	6	5		2			
76	Os	2	2	6	2	6	10	2	6	10	14	2	6	6		2			
77	Ir	2	2	6	2	6	10	2	6	10	14	2	6	7		2			
78	Pt	2	2	6	2	6	10	2	6	10	14	2	6	9		1			
79	Au	2	2	6	2	6	10	2	6	10	14	2	6	10		1			
80	Hg	2	2	6	2	6	10	2	6	10	14	2	6	10		2			
81	Tl	2	2	6	2	6	10	2	6	10	14	2	6	10		2	1		
82	Pb	2	2	6	2	6	10	2	6	10	14	2	6	10		2	2		
83	Bi	2	2	6	2	6	10	2	6	10	14	2	6	10		2	3		
84	Po	2	2	6	2	6	10	2	6	10	14	2	6	10		2	4		
85	At	2	2	6	2	6	10	2	6	10	14	2	6	10		2	5		
86	Rn	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		
87	Fr	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		1
88	Ra	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6		2
89	Ac	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6	1	2
90	Th	2	2	6	2	6	10	2	6	10	14	2	6	10		2	6	2	2
91	Pa	2	2	6	2	6	10	2	6	10	14	2	6	10	2*	2	6	1	2
92	U	2	2	6	2	6	10	2	6	10	14	2	6	10	3	2	6	1	2
93	Np	2	2	6	2	6	10	2	6	10	14	2	6	10	4	2	6	1	2
94	Pu	2	2	6	2	6	10	2	6	10	14	2	6	10	6*	2	6		2
95	Am	2	2	6	2	6	10	2	6	10	14	2	6	10	7	2	6		2
96	Cm	2	2	6	2	6	10	2	6	10	14	2	6	10	7*	2	6	1	2
97	Bk	2	2	6	2	6	10	2	6	10	14	2	6	10	9	2	6		2
98	Cf	2	2	6	2	6	10	2	6	10	14	2	6	10	10	2	6		2
99	Es	2	2	6	2	6	10	2	6	10	14	2	6	10	11	2	6		2
100	Fm	2	2	6	2	6	10	2	6	10	14	2	6	10	12	2	6		2
101	Md	2	2	6	2	6	10	2	6	10	14	2	6	10	13	2	6		2
102	No	2	2	6	2	6	10	2	6	10	14	2	6	10	14	2	6		2
103	Lr	2	2	6	2	6	10	2	6	10	14	2	6	10	14	2	6	1	2
104	Rf	2	2	6	2	6	10	2	6	10	14	2	6	10	14	2	6	2	2

* Note irregularity.

REFERENCE

W. L. Wiese and G. A. Martin, in *A Physicist's Desk Reference*, American Institute of Physics, New York, 1989, 94.

INTERNATIONAL TEMPERATURE SCALE OF 1990 (ITS-90)

B. W. Mangum

A new temperature scale, the International Temperature Scale of 1990 (ITS-90), was officially adopted by the Comité International des Poids et Mesures (CIPM), meeting 26—28 September 1989 at the Bureau International des Poids et Mesures (BIPM). The ITS-90 was recommended to the CIPM for its adoption following the completion of the final details of the new scale by the Comité Consultatif de Thermométrie (CCT), meeting 12—14 September 1989 at the BIPM in its 17th Session. The ITS-90 became the official international temperature scale on 1 January 1990. The ITS-90 supersedes the present scales, the International Practical Temperature Scale of 1968 (IPTS-68) and the 1976 Provisional 0.5 to 30 K Temperature Scale (EPT-76).

The ITS-90 extends upward from 0.65 K, and temperatures on this scale are in much better agreement with thermodynamic values that are those on the IPTS-68 and the EPT-76. The new scale has subranges and alternative definitions in certain ranges that greatly facilitate its use. Furthermore, its continuity, precision, and reproducibility throughout its ranges are much improved over that of the present scales. The replacement of the thermocouple with the platinum resistance thermometer at temperatures below 961.78°C resulted in the biggest improvement in reproducibility.

The ITS-90 is divided into four primary ranges:

1. Between 0.65 and 3.2 K, the ITS-90 is defined by the vapor pressure-temperature relation of ^{3}He, and between 1.25 and 2.1768 K (the λ point) and between 2.1768 and 5.0 K by the vapor pressure-temperature relations of ^{4}He. T_{90} is defined by the vapor pressure equations of the form:

$$T_{90}/\mathrm{K} = A_0 + \sum_{i=1}^{9} A_i\left[\left(\ln(p/\mathrm{Pa}) - B\right)/C\right]^i$$

   The values of the coefficients A_i, and of the constants A_o, B, and C of the equations are given below.
2. Between 3.0 and 24.5561 K, the ITS-90 is defined in terms of a ^{3}He or ^{4}He constant volume gas thermometer (CVGT). The thermometer is calibrated at three temperatures — at the triple point of neon (24.5561 K), at the triple point of equilibrium hydrogen (13.8033 K), and at a temperature between 3.0 and 5.0 K, the value of which is determined by using either ^{3}He or ^{4}He vapor pressure thermometry.
3. Between 13.8033 K (–259.3467°C) and 1234.93 K (961.78°C), the ITS-90 is defined in terms of the specified fixed points given below, by resistance ratios of platinum resistance thermometers obtained by calibration at specified sets of the fixed points, and by reference functions and deviation functions of resistance ratios which relate to T_{90} between the fixed points.
4. Above 1234.93 K, the ITS-90 is defined in terms of Planck's radiation law, using the freezing-point temperature of either silver, gold, or copper as the reference temperature.

Full details of the calibration procedures and reference functions for various subranges are given in:

The International Temperature Scale of 1990, *Metrologia*, 27, 3, 1990; errata in *Metrologia*, 27, 107, 1990.

Defining Fixed Points of the ITS-90

Material[a]	Equilibrium state[b]	Temperature	
		T_{90} (K)	t_{90} (°C)
He	VP	3 to 5	–270.15 to –268.15
e-H_2	TP	13.8033	–259.3467
e-H_2 (or He)	VP (or CVGT)	≈17	≈ –256.15
e-H_2 (or He)	VP (or CVGT)	≈20.3	≈ –252.85
Ne[c]	TP	24.5561	–248.5939
O_2	TP	54.3584	–218.7916
Ar	TP	83.8058	–189.3442
Hg[c]	TP	234.3156	–38.8344
H_2O	TP	273.16	0.01
Ga[c]	MP	302.9146	29.7646
In[c]	FP	429.7485	156.5985
Sn	FP	505.078	231.928
Zn	FP	692.677	419.527
Al[c]	FP	933.473	660.323
Ag	FP	1234.93	961.78
Au	FP	1337.33	1064.18
Cu[c]	FP	1357.77	1084.62

Defining Fixed Points of the ITS-90 (continued)

[a] e-H_2 indicates equilibrium hydrogen, that is, hydrogen with the equilibrium distribution of its ortho and para states. Normal hydrogen at room temperature contains 25% para hydrogen and 75% ortho hydrogen.

[b] VP indicates vapor pressure point; CVGT indicates constant volume gas thermometer point; TP indicates triple point (equilibrium temperature at which the solid, liquid, and vapor phases coexist); FP indicates freezing point, and MP indicates melting point (the equilibrium temperatures at which the solid and liquid phases coexist under a pressure of 101 325 Pa, one standard atmosphere). The isotopic composition is that naturally occurring.

[c] Previously, these were secondary fixed points.

Values of Coefficients in the Vapor Pressure Equations for Helium

Coef.or constant	^{3}He 0.65—3.2 K	^{4}He 1.25—2.1768 K	^{4}He 2.1768—5.0 K
A_0	1.053 447	1.392 408	3.146 631
A_1	0.980 106	0.527 153	1.357 655
A_2	0.676 380	0.166 756	0.413 923
A_3	0.372 692	0.050 988	0.091 159
A_4	0.151 656	0.026 514	0.016 349
A_5	–0.002 263	0.001 975	0.001 826
A_6	0.006 596	–0.017 976	–0.004 325
A_7	0.088 966	0.005 409	–0.004 973
A_8	–0.004 770	0.013 259	0
A_9	–0.054 943	0	0
B	7.3	5.6	10.3
C	4.3	2.9	1.9

CONVERSION OF TEMPERATURES FROM THE 1948 AND 1968 SCALES TO ITS-90

This table gives temperature corrections from older scales to the current International Temperature Scale of 1990 (see the preceding table for details on ITS-90). The first part of the table may be used for converting Celsius temperatures in the range -180 to 4000°C from IPTS-68 or IPTS-48 to ITS-90. Within the accuracy of the corrections, the temperature in the first column may be identified with either t_{68}, t_{48}, or t_{90}. The second part of the table is designed for use at lower temperatures to convert values expressed in kelvins from EPT-76 or IPTS-68 to ITS-90.

The references give analytical equations for expressing these relations. Note that Reference 1 supersedes Reference 2 with respect to corrections in the 630 to 1064°C range.

REFERENCES

1. Burns, G. W. et al., in *Temperature: Its Measurement and Control in Science and Industry*, Vol. 6, Schooley, J. F., Ed., American Institute of Physics, New York, 1993.
2. Goldberg, R. N. and Weir, R. D., *Pure and Appl. Chem.*, 1545, 1992.

t/°C	t_{90}-t_{68}	t_{90}-t_{48}	t/°C	t_{90}-t_{68}	t_{90}-t_{48}	t/°C	t_{90}-t_{68}	t_{90}-t_{48}
-180	0.008	0.020	270	-0.039	0.028	720	0.00	0.45
-170	0.010	0.017	280	-0.039	0.030	730	0.02	0.49
-160	0.012	0.007	290	-0.039	0.032	740	0.03	0.53
-150	0.013	0.000	300	-0.039	0.034	750	0.03	0.56
-140	0.014	0.001	310	-0.039	0.035	760	0.04	0.60
-130	0.014	0.008	320	-0.039	0.036	770	0.05	0.63
-120	0.014	0.017	330	-0.040	0.036	780	0.05	0.66
-110	0.013	0.026	340	-0.040	0.037	790	0.05	0.69
-100	0.013	0.035	350	-0.041	0.036	800	0.05	0.72
-90	0.012	0.041	360	-0.042	0.035	810	0.05	0.75
-80	0.012	0.045	370	-0.043	0.034	820	0.04	0.76
-70	0.011	0.045	380	-0.045	0.032	830	0.04	0.79
-60	0.010	0.042	390	-0.046	0.030	840	0.03	0.81
-50	0.009	0.038	400	-0.048	0.028	850	0.02	0.83
-40	0.008	0.032	410	-0.051	0.024	860	0.01	0.85
-30	0.006	0.024	420	-0.053	0.022	870	0.00	0.87
-20	0.004	0.016	430	-0.056	0.019	880	-0.02	0.87
-10	0.002	0.008	440	-0.059	0.015	890	-0.03	0.89
0	0.000	0.000	450	-0.062	0.012	900	-0.05	0.90
10	-0.002	-0.006	460	-0.065	0.009	910	-0.06	0.92
20	-0.005	-0.012	470	-0.068	0.007	920	-0.08	0.93
30	-0.007	-0.016	480	-0.072	0.004	930	-0.10	0.94
40	-0.010	-0.020	490	-0.075	0.002	940	-0.11	0.96
50	-0.013	-0.023	500	-0.079	0.000	950	-0.13	0.97
60	-0.016	-0.026	510	-0.083	-0.001	960	-0.15	0.97
70	-0.018	-0.026	520	-0.087	-0.002	970	-0.16	0.99
80	-0.021	-0.027	530	-0.090	-0.001	980	-0.18	1.00
90	-0.024	-0.027	540	-0.094	0.000	990	-0.19	1.02
100	-0.026	-0.026	550	-0.098	0.002	1000	-0.20	1.04
110	-0.028	-0.024	560	-0.101	0.007	1010	-0.22	1.05
120	-0.030	-0.023	570	-0.105	0.011	1020	-0.23	1.07
130	-0.032	-0.020	580	-0.108	0.018	1030	-0.23	1.10
140	-0.034	-0.018	590	-0.112	0.025	1040	-0.24	1.12
150	-0.036	-0.016	600	-0.115	0.035	1050	-0.25	1.14
160	-0.037	-0.012	610	-0.118	0.047	1060	-0.25	1.17
170	-0.038	-0.009	620	-0.122	0.060	1070	-0.25	1.19
180	-0.039	-0.005	630	-0.125	0.075	1080	-0.26	1.20
190	-0.039	-0.001	640	-0.11	0.12	1090	-0.26	1.20
200	-0.040	0.003	650	-0.10	0.15	1100	-0.26	1.2
210	-0.040	0.007	660	-0.09	0.19	1200	-0.30	1.4
220	-0.040	0.011	670	-0.07	0.24	1300	-0.35	1.5
230	-0.040	0.014	680	-0.05	0.29	1400	-0.39	1.6
240	-0.040	0.018	690	-0.04	0.32	1500	-0.44	1.8
250	-0.040	0.021	700	-0.02	0.37	1600	-0.49	1.9
260	-0.040	0.024	710	-0.01	0.41	1700	-0.54	2.1

CONVERSION OF TEMPERATURES FROM THE 1948 AND 1968 SCALES TO ITS-90 (continued)

t/°C	t_{90}-t_{68}	t_{90}-t_{48}
1800	-0.60	2.2
1900	-0.66	2.3
2000	-0.72	2.5
2100	-0.79	2.7
2200	-0.85	2.9
2300	-0.93	3.1
2400	-1.00	3.2
2500	-1.07	3.4
2600	-1.15	3.7
2700	-1.24	3.8
2800	-1.32	4.0
2900	-1.41	4.2
3000	-1.50	4.4
3100	-1.59	4.6
3200	-1.69	4.8
3300	-1.78	5.1
3400	-1.89	5.3
3500	-1.99	5.5
3600	-2.10	5.8
3700	-2.21	6.0
3800	-2.32	6.3
3900	-2.43	6.6
4000	-2.55	6.8

T/K	T_{90}-T_{76}	T_{90}-T_{68}
5	-0.0001	
6	-0.0002	
7	-0.0003	
8	-0.0004	
9	-0.0005	
10	-0.0006	
11	-0.0007	
12	-0.0008	
13	-0.0010	
14	-0.0011	-0.006
15	-0.0013	-0.003
16	-0.0014	-0.004
17	-0.0016	-0.006
18	-0.0018	-0.008
19	-0.0020	-0.009
20	-0.0022	-0.009
21	-0.0025	-0.008
22	-0.0027	-0.007
23	-0.0030	-0.007
24	-0.0032	-0.006
25	-0.0035	-0.005
26	-0.0038	-0.004
27	-0.0041	-0.004

T/K	T_{90}-T_{76}	T_{90}-T_{68}
28		-0.005
29		-0.006
30		-0.006
31		-0.007
32		-0.008
33		-0.008
34		-0.008
35		-0.007
36		-0.007
37		-0.007
38		-0.006
39		-0.006
40		-0.006
41		-0.006
42		-0.006
43		-0.006
44		-0.006
45		-0.007
46		-0.007
47		-0.007
48		-0.006
49		-0.006
50		-0.006
51		-0.005
52		-0.005
53		-0.004
54		-0.003
55		-0.002
56		-0.001
57		0.000
58		0.001
59		0.002
60		0.003
61		0.003
62		0.004
63		0.004
64		0.005
65		0.005
66		0.006
67		0.006
68		0.007
69		0.007
70		0.007
71		0.007
72		0.007
73		0.007
74		0.007
75		0.008
76		0.008

T/K	T_{90}-T_{76}	T_{90}-T_{68}
77		0.008
78		0.008
79		0.008
80		0.008
81		0.008
82		0.008
83		0.008
84		0.008
85		0.008
86		0.008
87		0.008
88		0.008
89		0.008
90		0.008
91		0.008
92		0.008
93		0.008
94		0.008
95		0.008
96		0.008
97		0.009
98		0.009
99		0.009
100		0.009
110		0.011
120		0.013
130		0.014
140		0.014
150		0.014
160		0.014
170		0.013
180		0.012
190		0.012
200		0.011
210		0.010
220		0.009
230		0.008
240		0.007
250		0.005
260		0.003
270		0.001
273.16		0.000
300		-0.006
400		-0.031
500		-0.040
600		-0.040
700		-0.055
800		-0.089
900		-0.124

1 SI base units

Table 1 gives the seven base quantities, assumed to be mutually independent, on which the SI is founded; and the names and symbols of their respective units, called ``SI base units.'' Definitions of the SI base units are given in Appendix A. The kelvin and its symbol K are also used to express the value of a temperature interval or a temperature difference.

Table 1. SI base units

Base quantity	SI base unit	
	Name	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

2 SI derived units

Derived units are expressed algebraically in terms of base units or other derived units (including the radian and steradian which are the two supplementary units – see Sec. 3). The symbols for derived units are obtained by means of the mathematical operations of multiplication and division. For example, the derived unit for the derived quantity molar mass (mass divided by amount of substance) is the kilogram per mole, symbol kg/mol. Additional examples of derived units expressed in terms of SI base units are given in Table 2.

Table 2. Examples of SI derived units expressed in terms of SI base units

Derived quantity	SI derived unit	
	Name	Symbol
area	square meter	m^2
volume	cubic meter	m^3
speed, velocity	meter per second	m/s
acceleration	meter per second squared	m/s^2
wave number	reciprocal meter	m^{-1}
mass density (density)	kilogram per cubic meter	kg/m^3
specific volume	cubic meter per kilogram	m^3/kg
current density	ampere per square meter	A/m^2
magnetic field strength	ampere per meter	A/m
amount-of-substance concentration (concentration)	mole per cubic meter	mol/m^3
luminance	candela per square meter	cd/m^2

2.1 SI derived units with special names and symbols

Certain SI derived units have special names and symbols; these are given in Tables 3a and 3b. As discussed in Sec. 3, the radian and steradian, which are the two supplementary units, are included in Table 3a.

Table 3a. SI derived units with special names and symbols, including the radian and steradian

	SI derived unit			
Derived quantity	Special name	Special symbol	Expression in terms of other SI units	Expression in terms of SI base units
plane angle	radian	rad		$m \cdot m^{-1} = 1$
solid angle	steradian	sr		$m^2 \cdot m^{-2} = 1$
frequency	hertz	Hz		s^{-1}
force	newton	N		$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work, quantity of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C		$s \cdot A$
electric potential, potential difference, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	$V \cdot s$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Celsius temperature[(a)]	degree Celsius	°C		K
luminous flux	lumen	lm	$cd \cdot sr$	$cd \cdot sr$[(b)]
illuminance	lux	lx	lm/m^2	$m^{-2} \cdot cd \cdot sr$[(b)]

[(a)] See Sec. 2.1.1.
[(b)] The steradian (sr) is not an SI base unit. However, in photometry the steradian (sr) is maintained in expressions for units (see Sec. 3).

Table 3b. SI derived units with special names and symbols admitted for reasons of safeguarding human health[(a)]

	SI derived unit			
Derived quantity	Special name	Special symbol	Expression in terms of other SI units	Expression in terms of SI base units
activity (of a radionuclide)	becquerel	Bq		s^{-1}
absorbed dose, specific energy (imparted), kerma	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent, ambient dose equivalent, directional dose equivalent, personal dose equivalent, equivalent dose	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$

[(a)] The derived quantities to be expressed in the gray and the sievert have been revised in accordance with the recommendations of the International Commission on Radiation Units and Measurements (ICRU).

2.1.1 Degree Celsius In addition to the quantity thermodynamic temperature (symbol T), expressed in the unit kelvin, use is also made of the quantity Celsius temperature (symbol t) defined by the equation

$$t = T - T_0 \ ,$$

where $T_0 = 273.15$ K by definition. To express Celsius temperature, the unit degree Celsius, symbol °C, which is equal in magnitude to the unit kelvin, is used; in this case, ``degree Celsius'' is a special name used in place of ``kelvin.'' An interval or difference of Celsius temperature can, however, be expressed in the unit kelvin as well as in the unit degree Celsius. (Note that the thermodynamic temperature T_0 is exactly 0.01 K below the thermodynamic temperature of the triple point of water.)

2.2 Use of SI derived units with special names and symbols

Examples of SI derived units that can be expressed with the aid of SI derived units having special names and symbols (including the radian and steradian) are given in Table 4.

Table 4. Examples of SI derived units expressed with the aid of SI derived units having special names and symbols

	SI derived unit		
Derived quantity	Name	Symbol	Expression in terms of SI base units
angular velocity	radian per second	rad/s	$m \cdot m^{-1} \cdot s^{-1} = s^{-1}$
angular acceleration	radian per second squared	rad/s^2	$m \cdot m^{-1} \cdot s^{-2} = s^{-2}$
dynamic viscosity	pascal second	$Pa \cdot s$	$m^{-1} \cdot kg \cdot s^{-1}$
moment of force	newton meter	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
surface tension	newton per meter	N/m	$kg \cdot s^{-2}$
heat flux density, irradiance	watt per square meter	W/m^2	$kg \cdot s^{-3}$
radiant intensity	watt per steradian	W/sr	$m^2 \cdot kg \cdot s^{-3} \cdot sr^{-1}$ [(a)]
radiance	watt per square meter steradian	$W/(m^2 \cdot sr)$	$kg \cdot s^{-3} \cdot sr^{-1}$ [(a)]
heat capacity, entropy	joule per kelvin	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
specific heat capacity, specific entropy	joule per kilogram kelvin	$J/(kg \cdot K)$	$m^2 \cdot s^{-2} \cdot K^{-1}$
specific energy	joule per kilogram	J/kg	$m^2 \cdot s^{-2}$
thermal conductivity	watt per meter kelvin	$W/(m \cdot K)$	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
energy density	joule per cubic meter	J/m^3	$m^{-1} \cdot kg \cdot s^{-2}$
electric field strength	volt per meter	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric charge density	coulomb per cubic meter	C/m^3	$m^{-3} \cdot s \cdot A$
electric flux density	coulomb per square meter	C/m^2	$m^{-2} \cdot s \cdot A$
permittivity	farad per meter	F/m	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
permeability	henry per meter	H/m	$m \cdot kg \cdot s^{-2} \cdot A^{-2}$
molar energy	joule per mole	J/mol	$m^2 \cdot kg \cdot s^{-2} \cdot mol^{-1}$
molar entropy, molar heat capacity	joule per mole kelvin	$J/(mol \cdot K)$	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$
exposure (x and γ rays)	coulomb per kilogram	C/kg	$kg^{-1} \cdot s \cdot A$
absorbed dose rate	gray per second	Gy/s	$m^2 \cdot s^{-3}$

[(a)] The steradian (sr) is not an SI base unit. However, in radiometry the steradian (sr) is maintained in expressions for units (see Sec. 3).

The advantages of using the special names and symbols of SI derived units are apparent in Table 4. Consider, for example, the quantity molar entropy: the unit $J/(mol \cdot K)$ is obviously more easily understood than its SI base-unit equivalent, $m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$. Nevertheless, it should always be recognized that the special names and symbols exist for convenience; either the form in which special names or symbols are used for certain combinations of units or the form in which they are not used is correct. For example, because of the descriptive value implicit in the compound-unit form, communication is sometimes facilitated if magnetic flux (see Table 3a) is expressed in terms of the volt second ($V \cdot s$) instead of the weber (Wb).

Tables 3a, 3b, and 4 also show that the values of several different quantities are expressed in the same SI unit. For example, the joule per kelvin (J/K) is the SI unit for heat capacity as well as for entropy. Thus the name of the unit is not sufficient to define the quantity measured.

A derived unit can often be expressed in several different ways through the use of base units and derived units with special names. In practice, with certain quantities, preference is given to using certain units with special names, or combinations of units, to facilitate the distinction between quantities whose values have identical expressions in terms of SI base units. For example, the SI unit of frequency is specified as the hertz (Hz) rather than the reciprocal second (s^{-1}), and the SI unit of moment of force is specified as the newton meter ($N \cdot m$) rather than the joule (J).

Similarly, in the field of ionizing radiation, the SI unit of activity is designated as the becquerel (Bq) rather than the reciprocal second (s^{-1}), and the SI units of absorbed dose and dose equivalent are designated as the gray (Gy) and the sievert (Sv), respectively, rather than the joule per kilogram (J/kg).

3 SI supplementary units

As previously stated, there are two units in this class: the radian, symbol rad, the SI unit of the quantity plane angle; and the steradian, symbol sr, the SI unit of the quantity solid angle. Definitions of these units are given in Appendix A.

The SI supplementary units are now interpreted as so-called dimensionless derived units for which the CGPM allows the freedom of using or not using them in expressions for SI derived units.[3] Thus the radian and steradian are not given in a separate table but have been included in Table 3a together with other derived units with special names and symbols (seeSec.2.1). This interpretation of the supplementary units implies that plane angle and solid angle are considered derived quantities of dimension one (so-called dimensionless quantities), each of which has the which has the unit one, symbol 1, as its coherent SI unit. However, in practice, when one expresses the values of derived quantities involving plane angle or solid angle, it often aids understanding if the special names (or symbols) ``radian'' (rad) or ``steradian'' (sr) are used in place of the number 1. For example, although values of the derived quantity angular velocity (plane angle divided by time) may be expressed in the unit s^{-1}, such values are usually expressed in the unit rad/s.

Because the radian and steradian are now viewed as so-called dimensionless derived units, the Consultative Committee for Units (CCU, *Comité Consultatif des Unités*) of the CIPM as result of a 1993 request it received from ISO/TC12, recommended to the CIPM that it request the CGPM to abolish the class of supplementary units as a separate class in the SI. The CIPM accepted the CCU recommendation, and if the abolishment is approved by the CGPM as is likely (the question will be on the agenda of the 20th CGPM, October 1995), the SI will consist of only two classes of units: base units and derived units, with the radian and steradian subsumed into the class of derived units of the SI. (The option of using or not using them in expressions for SI derived units, as is convenient, would remain unchanged.)

4 Decimal multiples and submultiples of SI units: SI prefixes

Table 5 gives the SI prefixes that are used to form decimal multiples and submultiples of SI units. They allow very large or very small numerical values to be avoided. A prefix attaches directly to the name of a unit, and a prefix symbol attaches directly to the symbol for a unit. For example, one kilometer, symbol 1 km, is equal to one thousand meters, symbol 1000 m or 10^3 m. When prefixes are attached to SI units, the units so formed are called ``multiples and submultiples of SI units'' in order to distinguish them from the coherent system of SI units.

Note: Alternative definitions of the SI prefixes and their symbols are not permitted. For example, it is unacceptable to use kilo (k) to represent $2^{10} = 1024$, mega (M) to represent $2^{20} = 1\ 048\ 576$, or giga (G) to represent $2^{30} = 1\ 073\ 741\ 824$.

[3] This interpretation was given in 1980 by the CIPM . It was deemed necessary because Resolution 12 of the 11th CGPM, which established the SI in 1960 , did not specify the nature of the supplementary units. The interpretation is based on two principal considerations: that plane angle is generally expressed as the ratio of two lengths and solid angle as the ratio of an area and the square of a length, and are thus quantities of dimension one (so-called dimensionless quantities); and that treating the radian and steradian as SI base units – a possibility not disallowed by Resolution 12 – could compromise the internal coherence of the SI based on only seven base units. (See ISO 31-0 for a discussion of the concept of dimension.)

Table 5. SI prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
$10^{24} = (10^3)^8$	yotta	Y	10^{-1}	deci	d
$10^{21} = (10^3)^7$	zetta	Z	10^{-2}	centi	c
$10^{18} = (10^3)^6$	exa	E	$10^{-3} = (10^3)^{-1}$	milli	m
$10^{15} = (10^3)^5$	peta	P	$10^{-6} = (10^3)^{-2}$	micro	μ
$10^{12} = (10^3)^4$	tera	T	$10^{-9} = (10^3)^{-3}$	nano	n
$10^{9} = (10^3)^3$	giga	G	$10^{-12} = (10^3)^{-4}$	pico	p
$10^{6} = (10^3)^2$	mega	M	$10^{-15} = (10^3)^{-5}$	femto	f
$10^{3} = (10^3)^1$	kilo	k	$10^{-18} = (10^3)^{-6}$	atto	a
10^{2}	hecto	h	$10^{-21} = (10^3)^{-7}$	zepto	z
10^{1}	deka	da	$10^{-24} = (10^3)^{-8}$	yocto	y

5 Units Outside the SI

Units that are outside the SI may be divided into three categories:

– those units that are accepted for use with the SI;

– those units that are temporarily accepted for use with the SI; and

– those units that are not accepted for use with the SI and thus must strictly be avoided.

5.1 Units accepted for use with the SI

The following sections discuss in detail the units that are acceptable for use with the SI.

5.1.1 Hour, degree, liter, and the like

Certain units that are not part of the SI are essential and used so widely that they are accepted by the CIPM for use with the SI. These units are given in Table 6. The combination of units of this table with SI units to form derived units should be restricted to special cases in order not to lose the advantages of the coherence of SI units.

Additionally, it is recognized that it may be necessary on occasion to use time-related units other than those given in Table 6; in particular, circumstances may require that intervals of time be expressed in weeks, months, or years. In such cases, if a standardized symbol for the unit is not available, the name of the unit should be written out in full.

Table 6. Units accepted for use with the SI

Name		Symbol	Value in SI units
minute	time	min	1 min = 60 s
hour	time	h	1 h = 60 min = 3600 s
day	time	d	1 d = 24 h = 86 400 s
degree	plane angle	°	1° = (π/180) rad
minute	plane angle	'	1' = (1/60)° = (π/10 800) rad
second	plane angle	"	1" = (1/60)' = (π/648 000) rad
liter		l, L[b]	1 L = 1 $dm^3 = 10^{-3}$ m^3
metric ton[c]		t	1 t = 10^3 kg

[b] The alternative symbol for the liter, L, was adopted by the CGPM in order to avoid the risk of confusion between the letter l and the number 1 . Thus, although both l and L are internationally accepted symbols for the liter, to avoid this risk the symbol to be used in the United States is L . The script letter ℓ is not an approved symbol for the liter.

[c] This is the name to be used for this unit in the United States; it is also used in some other English-speaking countries. However, ``tonne'' is used in many countries.

5.1.2 Neper, bel, shannon, and the like

There are a few highly specialized units not listed in Table 6 that are given by the International Organization for Standardization (ISO) or the International Electrotechnical Commission (IEC) and which are also acceptable for use with the SI. They include the neper (Np), bel (B), octave, phon, and sone, and units used in information technology, including the baud (Bd), bit (bit), erlang (E), hartley (Hart), and shannon (Sh).[4] It is the position of NIST that the only such additional units that may be used with the SI are those given in either the International Standards on quantities and units of ISO or of IEC .

5.1.3 Electronvolt and unified atomic mass unit

The CIPM also finds it necessary to accept for use with the SI the two units given in Table 7. These units are used in specialized fields; their values in SI units must be obtained from experiment and, therefore, are not known exactly.

Note: In some fields the unified atomic mass unit is called the dalton, symbol Da; however, this name and symbol are not accepted by the CGPM, CIPM, ISO, or IEC for use with the SI. Similarly, AMU is not an acceptable unit symbol for the unified atomic mass unit. The only allowed name is ``unified atomic mass unit'' and the only allowed symbol is u.

Table 7. Units accepted for use with the SI whose values in SI units are obtained experimentally

Name	Symbol	Definition
electronvolt	eV	*(a)*
unified atomic mass unit	u	*(b)*

(a) The electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of 1 V in vacuum; 1 eV = $1.602\ 177\ 33 \times 10^{-19}$ J with a combined standard uncertainty of $0.000\ 000\ 49 \times 10^{-19}$ J .
(b) The unified atomic mass unit is equal to 1/12 of the mass of an atom of the nuclide ^{12}C; 1 u = $1.660\ 540\ 2 \times 10^{-27}$ kg with a combined standard uncertainty of $0.000\ 001\ 0 \times 10^{-27}$ kg .

5.1.4 Natural and atomic units

In some cases, particularly in basic science, the values of quantities are expressed in terms of fundamental constants of nature or so-called natural units.The use of these units with the SI is permissible when it is necessary for the most effective communication of information. In such cases, the specific natural units that are used must be identified. This requirement applies even to the system of units customarily called ``atomicunits'' used in theoretical atomic physics and chemistry, inasmuch as there are several different systems that have the appellation ``atomic units." Examples of physical quantities used as natural units are given in Table 8.

NIST also takes the position that while theoretical results intended primarily for other theorists may be left in natural units, if they are also intended for experimentalists, they must also be given in acceptable units.

[4] The symbol in parentheses following the name of the unit is its internationally accepted unit symbol, but the octave, phon, and sone have no such unit symbols. For additional information on the neper and bel, see Sec. 0.5 of ISO 31-2.
The question of the byte (B) is under international consideration.

Table 8. Examples of physical quantities sometimes used as natural units

Kind of quantity	Physical quantity used as a unit	Symbol
action	Planck constant divided by 2π	$\hbar$
electric charge	elementary charge	e
energy	Hartree energy	E_h
length	Bohr radius	a_0
length	Compton wavelength (electron)	λ_C
magnetic flux	magnetic flux quantum	Φ_0
magnetic moment	Bohr magneton	μ_B
magnetic moment	nuclear magneton	μ_N
mass	electron rest mass	m_e
mass	proton rest mass	m_p
speed	speed of electromagnetic waves in vacuum	c

5.2 Units temporarily accepted for use with the SI

Because of existing practice in certain fields or countries, in 1978 the CIPM considered that it was permissible for the units given in Table 9 to continue to be used with the SI until the CIPM considers that their use is no longer necessary. However, these units must not be introduced where they are not presently used. Further, NIST strongly discourages the continued use of these units except for the nautical mile, knot, are, and hectare; and except for the curie, roentgen, rad, and rem until the year 2000 (the cessation date suggested by the Committee for Ineragency Radiation Research and Policy Coordination or CIRRPC, a United States Government interagency group).[5]

Table 9. Units temporarily accepted for use with the SI[(a)]

Name	Symbol	Value in SI units
nautical mile		1 nautical mile = 1852 m
knot		1 nautical mile per hour = (1852/3600) m/s
ångström	Å	1 Å = 0.1 nm = 10^{-10}m
are[(b)]	a	1 a = 1 dam^2 = 10^2 m^2
hectare[(b)]	ha	1 ha = 1 hm^2 = 10^4 m^2
barn	b	1 b = 100 fm^2 = 10^{-28} m^2
bar	bar	1 bar=0.1 MPa=100 kPa=1000 hPa=10^5 Pa
gal	Gal	1 Gal = 1 cm/s^2 = 10^{-2} m/s^2
curie	Ci	1 Ci = 3.7×10^{10} Bq
roentgen	R	1 R = 2.58×10^{-4} C/kg
rad	rad[(c)]	1 rad = 1 cGy = 10^{-2} Gy
rem	rem	1 rem = 1 cSv = 10^{-2} Sv

(a) See Sec. 5.2 regarding the continued use of these units.
(b) This unit and its symbol are used to express agrarian areas.
(c) When there is risk of confusion with the symbol for the radian, rd may be used as the symbol for rad.

[5] In 1993 the CCU (see Sec. 3) was requested by ISO/TC 12 to consider asking the CIPM to deprecate the use of the units of Table 9 except for the nautical mile and knot, and possibly the are and hectare. The CCU discussed this request at its February 1995 meeting.

Appendix A. Definitions of the SI Base Units and the Radian and Steradian

A.1 Introduction

The following definitions of the SI base units are taken from NIST SP 330; the definitions of the SI supplementary units, the radian and steradian, which are now interpreted as SI derived units (see Sec. 3), are those generally accepted and are the same as those given in ANSI/IEEE Std 268-1992. SI derived units are uniquely defined only in terms of SI base units; for example, $1\ \mathrm{V} = 1\ \mathrm{m}^2 \cdot \mathrm{kg} \cdot \mathrm{s}^{-3} \cdot \mathrm{A}^{-1}$.

A.2 Meter (17th CGPM, 1983)

The meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 *of a second.*

A.3 Kilogram (3d CGPM, 1901)

The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

A.4 Second (13th CGPM, 1967)

The second is the duration of 9 192 631 770 *periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-*133 *atom.*

A.5 Ampere (9th CGPM, 1948)

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 *meter apart in vacuum, would produce between these conductors a force equal to* 2×10^{-7} *newton per meter of length.*

A.6 Kelvin (13th CGPM, 1967)

The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 *of the thermodynamic temperature of the triple point of water.*

A.7 Mole (14th CGPM, 1971)

1. *The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in* 0.012 *kilogram of carbon* 12.

2. *When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.*

In the definition of the mole, it is understood that unbound atoms of carbon 12, at rest and in their ground state, are referred to.

Note that this definition specifies at the same time the nature of the quantity whose unit is the mole.

A.8 Candela (16th CGPM, 1979)

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} *hertz and that has a radiant intensity in that direction of (*1/683*) watt per steradian.*

A.9 Radian

The radian is the plane angle between two radii of a circle that cut off on the circumference an arc equal in length to the radius.

A.10 Steradian

The steradian is the solid angle that, having its vertex in the center of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

CONVERSION FACTORS

The following table gives conversion factors from various units of measure to SI units. It is reproduced from NIST Special Publication 811, *Guide for the Use of the International System of Units (SI)*. The table gives the factor by which a quantity expressed in a non-SI unit should be multiplied in order to calculate its value in the SI. The SI values are expressed in terms of the base, supplementary, and derived units of SI in order to provide a coherent presentation of the conversion factors and facilitate computations (see the table "International System of Units" in this Section). If desired, powers of ten can be avoided by using SI Prefixes and shifting the decimal point if necessary.

Conversion from a non-SI unit to a different non-SI unit may be carried out by using this table in two stages, e.g.,

$$1\ \text{cal}_{\text{th}} = 4.184\ \text{J}$$

$$1\ \text{Btu}_{\text{IT}} = 1.055056\ \text{E+03 J}$$

Thus,

$$1\ \text{Btu}_{\text{IT}} = (1.055056\ \text{E+03} \div 4.184)\ \text{cal}_{\text{th}} = 252.164\ \text{cal}_{\text{th}}$$

Conversion factors are presented for ready adaptation to computer readout and electronic data transmission. The factors are written as a number equal to or greater than one and less than ten with six or fewer decimal places. This number is followed by the letter E (for exponent), a plus or a minus sign, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example:

$$3.523\,907\ \text{E-02 is } 3.523\,907 \times 10^{-2}$$

or

$$0.035\,239\,07$$

Similarly:

$$3.386\,389\ \text{E+03 is } 3.386\,389 \times 10^{3}$$

or

$$3\,386.389$$

A factor in boldface is exact; i.e., all subsequent digits are zero. All other conversion factors have been rounded to the figures given in accordance with accepted practice. Where less than six digits after the decimal point are shown, more precision is not warranted.

It is often desirable to round a number obtained from a conversion of units in order to retain information on the precision of the value. The following rounding rules may be followed:

(1) If the digits to be discarded begin with a digit less than 5, the digit preceding the first discarded digit is not changed.

Example: 6.974 951 5 rounded to 3 digits is 6.97

(2) If the digits to be discarded begin with a digit greater than 5, the digit preceding the first discarded digit is increased by one.

Example: 6.974 951 5 rounded to 4 digits is 6.975

(3) If the digits to be discarded begin with a 5 and at least one of the following digits is greater than 0, the digit preceding the 5 is increased by 1.

Example: 6.974 851 rounded to 5 digits is 6.974 9

(4) If the digits to be discarded begin with a 5 and all of the following digits are 0, the digit preceding the 5 is unchanged if it is even and increased by one if it is odd. (Note that this means that the final digit is always even.)

Examples: 6.974 951 5 rounded to 7 digits is 6.974 952
6.974 950 5 rounded to 7 digits is 6.974 950

REFERENCE

Taylor, B. N., *Guide for the Use of the International System of Units (SI)*, NIST Special Publication 811, 1995 Edition, Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402, 1995.

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Factors in **boldface** are exact

To convert from	to	Multiply by	
abampere	ampere (A)	**1.0**	**E+01**
abcoulomb	coulomb (C)	**1.0**	**E+01**
abfarad	farad (F)	**1.0**	**E+09**
abhenry	henry (H)	**1.0**	**E−09**
abmho	siemens (S)	**1.0**	**E+09**
abohm	ohm (Ω)	**1.0**	**E−09**
abvolt	volt (V)	**1.0**	**E−08**
acceleration of free fall, standard (g_n)	meter per second squared (m/s^2)	**9.806 65**	**E+00**
acre (based on U.S. survey foot)[9]	square meter (m^2)	4.046 873	E+03
acre foot (based on U.S. survey foot)[9]	cubic meter (m^3)	1.233 489	E+03
ampere hour (A · h)	coulomb (C)	**3.6**	**E+03**
ångström (Å)	meter (m)	**1.0**	**E−10**
ångström (Å)	nanometer (nm)	**1.0**	**E−01**
are (a)	square meter (m^2)	**1.0**	**E+02**
astronomical unit (AU)	meter (m)	1.495 979	E+11
atmosphere, standard (atm)	pascal (Pa)	**1.013 25**	**E+05**
atmosphere, standard (atm)	kilopascal (kPa)	**1.013 25**	**E+02**
atmosphere, technical (at)[10]	pascal (Pa)	**9.806 65**	**E+04**
atmosphere, technical (at)[10]	kilopascal (kPa)	**9.806 65**	**E+01**
bar (bar)	pascal (Pa)	**1.0**	**E+05**
bar (bar)	kilopascal (kPa)	**1.0**	**E+02**
barn (b)	square meter (m^2)	**1.0**	**E−28**
barrel [for petroleum, 42 gallons (U.S.)](bbl)	cubic meter (m^3)	1.589 873	E−01
barrel [for petroleum, 42 gallons (U.S.)](bbl)	liter (L)	1.589 873	E+02
biot (Bi)	ampere (A)	**1.0**	**E+01**
British thermal unit$_{IT}$ (Btu$_{IT}$)[11]	joule (J)	1.055 056	E+03
British thermal unit$_{th}$ (Btu$_{th}$)[11]	joule (J)	1.054 350	E+03
British thermal unit (mean) (Btu)	joule (J)	1.055 87	E+03
British thermal unit (39 °F) (Btu)	joule (J)	1.059 67	E+03
British thermal unit (59 °F) (Btu)	joule (J)	1.054 80	E+03
British thermal unit (60 °F) (Btu)	joule (J)	1.054 68	E+03
British thermal unit$_{IT}$ foot per hour square foot degree Fahrenheit [Btu$_{IT}$ · ft/(h · ft^2 · °F)]	watt per meter kelvin [W/(m · K)]	1.730 735	E+00
British thermal unit$_{th}$ foot per hour square foot degree Fahrenheit [Btu$_{th}$ · ft/(h · ft^2 · °F)]	watt per meter kelvin [W/(m · K)]	1.729 577	E+00
British thermal unit$_{IT}$ inch per hour square foot degree Fahrenheit [Btu$_{IT}$ · in/(h · ft^2 · °F)]	watt per meter kelvin [W/(m · K)]	1.442 279	E−01
British thermal unit$_{th}$ inch per hour square foot degree Fahrenheit [Btu$_{th}$ · in/(h · ft^2 · °F)]	watt per meter kelvin [W/(m · K)]	1.441 314	E−01
British thermal unit$_{IT}$ inch per second square foot degree Fahrenheit [Btu$_{IT}$ · in/(s · ft^2 · °F)]	watt per meter kelvin [W/(m · K)]	5.192 204	E+02

[9] The U.S. survey foot equals (1200/3937) m. 1 international foot = 0.999998 survey foot.
[10] One technical atmosphere equals one kilogram-force per square centimeter (1 at = 1 kgf/cm^2).
[11] The Fifth International Conference on the Properties of Steam (London, July 1956) defined the International Table calorie as 4.1868 J. Therefore the exact conversion factor for the International Table Btu is 1.055 055 852 62 kJ. Note that the notation for International Table used in this listing is subscript ''IT''. Similarily, the notation for thermochemical is subscript ''th.'' Further, the thermochemical Btu, Btu$_{th}$, is based on the thermochemical calorie, cal$_{th}$, where cal$_{th}$ = 4.184 J exactly.

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To convert from	to	Multiply by	
British thermal unit$_{th}$ inch per second square foot degree Fahrenheit [$Btu_{th} \cdot in/(s \cdot ft^2 \cdot °F)$]	watt per meter kelvin [$W/(m \cdot K)$]	5.188 732	E+02
British thermal unit$_{IT}$ per cubic foot (Btu_{IT}/ft^3)	joule per cubic meter (J/m^3)	3.725 895	E+04
British thermal unit$_{th}$ per cubic foot (Btu_{th}/ft^3)	joule per cubic meter (J/m^3)	3.723 403	E+04
British thermal unit$_{IT}$ per degree Fahrenheit ($Btu_{IT}/°F$)	joule per kelvin (J/k)	1.899 101	E+03
British thermal unit$_{th}$ per degree Fahrenheit ($Btu_{th}/°F$)	joule per kelvin (J/k)	1.897 830	E+03
British thermal unit$_{IT}$ per degree Rankine ($Btu_{IT}/°R$)	joule per kelvin (J/k)	1.899 101	E+03
British thermal unit$_{th}$ per degree Rankine ($Btu_{th}/°R$)	joule per kelvin (J/k)	1.897 830	E+03
British thermal unit$_{IT}$ per hour (Btu_{IT}/h)	watt (W)	2.930 711	E−01
British thermal unit$_{th}$ per hour (Btu_{th}/h)	watt (W)	2.928 751	E−01
British thermal unit$_{IT}$ per hour square foot degree Fahrenheit [$Btu_{IT}/(h \cdot ft^2 \cdot °F)$]	watt per square meter kelvin [$W/(m^2 \cdot K)$]	5.678 263	E+00
British thermal unit$_{th}$ per hour square foot degree Fahrenheit [$Btu_{th}/(h \cdot ft^2 \cdot °F)$]	watt per square meter kelvin [$W/(m^2 \cdot K)$]	5.674 466	E+00
British thermal unit$_{th}$ per minute (Btu_{th}/min)	watt (W)	1.757 250	E+01
British thermal unit$_{IT}$ per pound (Btu_{IT}/lb)	joule per kilogram (J/kg)	**2.326**	**E+03**
British thermal unit$_{th}$ per pound (Btu_{th}/lb)	joule per kilogram (J/kg)	2.324 444	E+03
British thermal unit$_{IT}$ per pound degree Fahrenheit [$Btu_{IT}/(lb \cdot °F)$]	joule per kilogram kelvin ($J/(kg \cdot K)$]	**4.1868**	**E+03**
British thermal unit$_{th}$ per pound degree Fahrenheit [$Btu_{th}/(lb \cdot °F)$]	joule per kilogram kelvin [$J/(kg \cdot K)$]	**4.184**	**E+03**
British thermal unit$_{IT}$ per pound degree Rankine [$Btu_{IT}/(lb \cdot °R)$]	joule per kilogram kelvin [$J/(kg \cdot K)$]	**4.1868**	**E+03**
British thermal unit$_{th}$ per pound degree Rankine [$Btu_{th}/(lb \cdot °R)$]	joule per kilogram kelvin [$J/(kg \cdot K)$]	**4.184**	**E+03**
British thermal unit$_{IT}$ per second (Btu_{IT}/s)	watt (W)	1.055 056	E+03
British thermal unit$_{th}$ per second (Btu_{th}/s)	watt (W)	1.054 350	E+03
British thermal unit$_{IT}$ per second square foot degree Fahrenheit [$Btu_{IT}/(s \cdot ft^2 \cdot °F)$]	watt per square meter kelvin [$W/(m^2 \cdot K)$]	2.044 175	E+04
British thermal unit$_{th}$ per second square foot degree Fahrenheit [$Btu_{th}/(s \cdot ft^2 \cdot °F)$]	watt per square meter kelvin [$W/(m^2 \cdot K)$]	2.042 808	E+04
British thermal unit$_{IT}$ per square foot (Btu_{IT}/ft^2)	joule per square meter (J/m^2)	1.135 653	E+04
British thermal unit$_{th}$ per square foot (Btu_{th}/ft^2)	joule per square meter (J/m^2)	1.134 893	E+04
British thermal unit$_{IT}$ per square foot hour [($Btu_{IT}/(ft^2 \cdot h)$]	watt per square meter (W/m^2)	3.154 591	E+00
British thermal unit$_{th}$ per square foot hour [$Btu_{th}/(ft^2 \cdot h)$]	watt per square meter (W/m^2)	3.152 481	E+00
British thermal unit$_{th}$ per square foot minute [$Btu_{th}/(ft^2 \cdot min)$]	watt per square meter (W/m^2)	1.891 489	E+02
British thermal unit$_{IT}$ per square foot second [($Btu_{IT}/(ft^2 \cdot s)$]	watt per square meter (W/m^2)	1.135 653	E+04
British thermal unit$_{th}$ per square foot second [$Btu_{th}/(ft^2 \cdot s)$]	watt per square meter (W/m^2)	1.134 893	E+04
British thermal unit$_{th}$ per square inch second [$Btu_{th}/(in^2 \cdot s)$]	watt per square meter (W/m^2)	1.634 246	E+06

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To convert from	to	Multiply by	
bushel (U.S.) (bu)	cubic meter (m^3)	3.523 907	E−02
bushel (U.S.) (bu)	liter (L)	3.523 907	E+01
calorie$_{IT}$ (cal$_{IT}$)[11]	joule (J)	**4.1868**	**E+00**
calorie$_{th}$ (cal$_{th}$)[11]	joule (J)	**4.184**	**E+00**
calorie (cal) (mean)	joule (J)	4.190 02	E+00
calorie (15 °C) (cal$_{15}$)	joule (J)	4.185 80	E+00
calorie (20 °C) (cal$_{20}$)	joule (J)	4.181 90	E+00
calorie$_{IT}$, kilogram (nutrition)[12]	joule (J)	**4.1868**	**E+03**
calorie$_{th}$, kilogram (nutrition)[12]	joule (J)	**4.184**	**E+03**
calorie (mean), kilogram (nutrition)[12]	joule (J)	4.190 02	E+03
calorie$_{th}$ per centimeter second degree Celsius [cal$_{th}$/(cm · s · °C)]	watt per meter kelvin [W/(m · K)]	**4.184**	**E+02**
calorie$_{IT}$ per gram (cal$_{IT}$/g)	joule per kilogram (J/kg)	**4.1868**	**E+03**
calorie$_{th}$ per gram (cal$_{th}$/g)	joule per kilogram (J/kg)	**4.184**	**E+03**
calorie$_{IT}$ per gram degree Celsius [cal$_{IT}$/(g · °C)]	joule per kilogram kelvin [J/(kg · K)]	**4.1868**	**E+03**
calorie$_{th}$ per gram degree Celsius [cal$_{th}$/(g · °C)]	joule per kilogram kelvin [J/(kg · K)]	**4.184**	**E+03**
calorie$_{IT}$ per gram kelvin [cal$_{IT}$/(g · K)]	joule per kilogram kelvin [J/(kg · K)]	**4.1868**	**E+03**
calorie$_{th}$ per gram kelvin [cal$_{th}$/(g · K)]	joule per kilogram kelvin [J/(kg · K)]	**4.184**	**E+03**
calorie$_{th}$ per minute (cal$_{th}$/min)	watt (W)	6.973 333	E−02
calorie$_{th}$ per second (cal$_{th}$/s)	watt (W)	**4.184**	**E+00**
calorie$_{th}$ per square centimeter (cal$_{th}$/cm^2)	joule per square meter (J/m^2)	**4.184**	**E+04**
calorie$_{th}$ per square centimeter minute [cal$_{th}$/(cm^2 · min)]	watt per square meter (W/m^2)	6.973 333	E+02
calorie$_{th}$ per square centimeter second [cal$_{th}$/(cm^2 · s)]	watt per square meter (W/m^2)	**4.184**	**E+04**
candela per square inch (cd/in^2)	candela per square meter (cd/m^2)	1.550 003	E+03
carat, metric	kilogram (kg)	**2.0**	**E−04**
carat, metric	gram (g)	**2.0**	**E−01**
centimeter of mercury (0 °C)[13]	pascal (Pa)	1.333 22	E+03
centimeter of mercury (0 °C)[13]	kilopascal (kPa)	1.333 22	E+00
centimeter of mercury, conventional (cmHg)[13]	pascal (Pa)	1.333 224	E+03
centimeter of mercury, conventional (cmHg)[13]	kilopascal (kPa)	1.333 224	E+00
centimeter of water (4 °C)[13]	pascal (Pa)	9.806 38	E+01
centimeter of water, conventional (cmH_2O)[13]	pascal (Pa)	**9.806 65**	**E+01**
centipoise (cP)	pascal second (Pa · s)	**1.0**	**E−03**
centistokes (cSt)	meter squared per second (m^2/s)	**1.0**	**E−06**
chain (based on U.S. survey foot) (ch)[9]	meter (m)	2.011 684	E+01
circular mil	square meter (m^2)	5.067 075	E−10
circular mil	square millimeter (mm^2)	5.067 075	E−04
clo	square meter kelvin per watt (m^2 · K/W)	1.55	E−01
cord (128 ft^3)	cubic meter (m^3)	3.624 556	E+00
cubic foot (ft^3)	cubic meter (m^3)	2.831 685	E−02
cubic foot per minute (ft^3/min)	cubic meter per second (m^3/s)	4.719 474	E−04
cubic foot per minute (ft^3/min)	liter per second (L/s)	4.719 474	E−01
cubic foot per second (ft^3/s)	cubic meter per second (m^3/s)	2.831 685	E−02

[12] The kilogram calorie or ‘‘large calorie’’ is an obsolete term used for the kilocalorie, which is the calorie used to express the energy content of foods. However, in practice, the prefix ‘‘kilo’’ is usually omitted.

[13] Conversion factors for mercury manometer pressure units are calculated using the standard value for the acceleration of gravity and the density of mercury at the stated temperature. Additional digits are not justified because the definitions of the units do not take into account the compressibility of mercury or the change in density caused by the revised practical temperature scale, ITS-90. Similar comments also apply to water manometer pressure units. Conversion factors for conventional mercury and water manometer pressure units are based on ISO 31-3.

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To convert from	to	Multiply by	
cubic inch (in^3)[14]	cubic meter (m^3)	1.638 706	E−05
cubic inch per minute (in^3/min)	cubic meter per second (m^3/s)	2.731 177	E−07
cubic mile (mi^3)	cubic meter (m^3)	4.168 182	E+09
cubic yard (yd^3)	cubic meter (m^3)	7.645 549	E−01
cubic yard per minute (yd^3/min)	cubic meter per second (m^3/s)	1.274 258	E−02
cup (U.S.)	cubic meter (m^3)	2.365 882	E−04
cup (U.S.)	liter (L)	2.365 882	E−01
cup (U.S.)	milliliter (mL)	2.365 882	E+02
curie (Ci)	becquerel (Bq)	**3.7**	**E+10**
darcy[15]	meter squared (m^2)	9.869 233	E−13
day (d)	second (s)	**8.64**	**E+04**
day (sidereal)	second (s)	8.616 409	E+04
debye (D)	coulomb meter (C · m)	3.335 641	E−30
degree (angle) (°)	radian (rad)	1.745 329	E−02
degree Celsius (temperature) (°C)	kelvin (K)	$T/\mathrm{K} = t/°\mathrm{C} + \mathbf{273.15}$	
degree Celsius (temperature interval) (°C)	kelvin (K)	**1.0**	**E+00**
degree centigrade (temperature)[16]	degree Celsius (°C)	$t/°\mathrm{C} \approx t/\mathrm{deg.\ cent.}$	
degree centigrade (temperature interval)[16]	degree Celsius (°C)	1.0	E+00
degree Fahrenheit (temperature) (°F)	degree Celsius (°C)	$t/°\mathrm{C} = (t/°\mathrm{F} - \mathbf{32})/\mathbf{1.8}$	
degree Fahrenheit (temperature) (°F)	kelvin (K)	$T/\mathrm{K} = (t/°\mathrm{F} + \mathbf{459.67})/\mathbf{1.8}$	
degree Fahrenheit (temperature interval)(°F)	degree Celsius (°C)	5.555 556	E−01
degree Fahrenheit (temperature interval)(°F)	kelvin (K)	5.555 556	E−01
degree Fahrenheit hour per British thermal unit$_{IT}$ (°F · h/Btu_{IT})	kelvin per watt (K/W)	1.895 634	E+00
degree Fahrenheit hour per British thermal unit$_{th}$ (°F · h/Btu_{th})	kelvin per watt (K/W)	1.896 903	E+00
degree Fahrenheit hour square foot per British thermal unit$_{IT}$ (°F · h · ft^2/Btu_{IT})	square meter kelvin per watt (m^2 · K/W)	1.761 102	E−01
degree Fahrenheit hour square foot per British thermal unit$_{th}$ (°F · h · ft^2/Btu_{th})	square meter kelvin per watt (m^2 · K/W)	1.762 280	E−01
degree Fahrenheit hour square foot per British thermal unit$_{IT}$ inch [°F · h · ft^2/(Btu_{IT} · in)]	meter kelvin per watt (m · K/W)	6.933 472	E+00
degree Fahrenheit hour square foot per British thermal unit$_{th}$ inch [°F · h · ft^2/(Btu_{th} · in)]	meter kelvin per watt (m · K/W)	6.938 112	E+00
degree Fahrenheit second per British thermal unit$_{IT}$ (°F · s/Btu_{IT})	kelvin per watt (K/W)	5.265 651	E−04
degree Fahrenheit second per British thermal unit$_{th}$ (°F · s/Btu_{th})	kelvin per watt (K/W)	5.269 175	E−04
degree Rankine (°R)	kelvin (K)	$T/\mathrm{K} = (T/°\mathrm{R})/\mathbf{1.8}$	
degree Rankine (temperature interval) (°R)	kelvin (K)	5.555 556	E−01
denier	kilogram per meter (kg/m)	1.111 111	E−07
denier	gram per meter (g/m)	1.111 111	E−04
dyne (dyn)	newton (N)	**1.0**	**E−05**
dyne centimeter (dyn · cm)	newton meter (N · m)	**1.0**	**E−07**
dyne per square centimeter (dyn/cm^2)	pascal (Pa)	**1.0**	**E−01**
electronvolt (eV)	joule (J)	1.602 177	E−19
EMU of capacitance (abfarad)	farad (F)	**1.0**	**E+09**
EMU of current (abampere)	ampere (A)	**1.0**	**E+01**
EMU of electric potential (abvolt)	volt (V)	**1.0**	**E−08**
EMU of inductance (abhenry)	henry (H)	**1.0**	**E−09**

[14] The exact conversion factor is 1.638 706 4 E−05.
[15] The darcy is a unit for expressing the permeability of porous solids, not area.
[16] The centigrade temperature scale is obsolete; the degree centigrade is only approximately equal to the degree Celsius.

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To convert from	to	Multiply by	
EMU of resistance (abohm)	ohm (Ω)	**1.0**	**E−09**
erg (erg)	joule (J)	**1.0**	**E−07**
erg per second (erg/s)	watt (W)	**1.0**	**E−07**
erg per square centimeter second |1obrkt&1ru|/(cm^2 · s)]	watt per square meter (W/m^2)	**1.0**	**E−03**
ESU of capacitance (statfarad)	farad (F)	1.112 650	E−12
ESU of current (statampere)	ampere (A)	3.335 641	E−10
ESU of electric potential (statvolt)	volt (V)	2.997 925	E+02
ESU of inductance (stathenry)	henry (H)	8.987 552	E+11
ESU of resistance (statohm)	ohm (Ω)	8.987 552	E+11
faraday (based on carbon 12)	coulomb (C)	9.648 531	E+04
fathom (based on U.S. survey foot)[9]	meter (m)	1.828 804	E+00
fermi	meter (m)	**1.0**	**E−15**
fermi	femtometer (fm)	**1.0**	**E+00**
fluid ounce (U.S.) (fl oz)	cubic meter (m^3)	2.957 353	E−05
fluid ounce (U.S.) (fl oz)	milliliter (mL)	2.957 353	E+01
foot (ft)	meter (m)	**3.048**	**E−01**
foot (U.S. survey) (ft)[9]	meter (m)	3.048 006	E−01
footcandle	lux (lx)	1.076 391	E+01
footlambert	candela per square meter (cd/m^2)	3.426 259	E+00
foot of mercury, conventional (ftHg)[13]	pascal (Pa)	4.063 666	E+04
foot of mercury, conventional (ftHg)[13]	kilopascal (kPa)	4.063 666	E+01
foot of water (39.2 °F)[13]	pascal (Pa)	2.988 98	E+03
foot of water (39.2 °F)[13]	kilopascal (kPa)	2.988 98	E+00
foot of water, conventional (ftH$_2$O)[13]	pascal (Pa)	2.989 067	E+03
foot of water, conventional (ftH$_2$O)[13]	kilopascal (kPa)	2.989 067	E+00
foot per hour (ft/h)	meter per second (m/s)	8.466 667	E−05
foot per minute (ft/min)	meter per second (m/s)	**5.08**	**E−03**
foot per second (ft/s)	meter per second (m/s)	**3.048**	**E−01**
foot per second squared (ft/s^2)	meter per second squared (m/s^2)	**3.048**	**E−01**
foot poundal	joule (J)	4.214 011	E−02
foot pound-force (ft · lbf)	joule (J)	1.355 818	E+00
foot pound-force per hour (ft · lbf/h)	watt (W)	3.766 161	E−04
foot pound-force per minute (ft · lbf/min)	watt (W)	2.259 697	E−02
foot pound-force per second (ft · lbf/s)	watt (W)	1.355 818	E+00
foot to the fourth power (ft^4)[17]	meter to the fourth power (m^4)	8.630 975	E−03
franklin (Fr)	coulomb (C)	3.335 641	E−10
gal (Gal)	meter per second squared (m/s^2)	**1.0**	**E−02**
gallon [Canadian and U.K. (Imperial)] (gal)	cubic meter (m^3)	**4.546 09**	**E−03**
gallon [Canadian and U.K. (Imperial)] (gal)	liter (L)	**4.546 09**	**E+00**
gallon (U.S.) (gal)	cubic meter (m^3)	3.785 412	E−03
gallon (U.S.) (gal)	liter (L)	3.785 412	E+00
gallon (U.S.) per day (gal/d)	cubic meter per second (m^3/s)	4.381 264	E−08
gallon (U.S.) per day (gal/d)	liter per second (L/s)	4.381 264	E−05
gallon (U.S.) per horsepower hour [gal/(hp · h)]	cubic meter per joule (m^3/J)	1.410 089	E−09
gallon (U.S.) per horsepower hour [gal/(hp · h)]	liter per joule (L/J)	1.410 089	E−06
gallon (U.S.) per minute (gpm)(gal/min)	cubic meter per second (m^3/s)	6.309 020	E−05
gallon (U.S.) per minute (gpm)(gal/min)	liter per second (L/s)	6.309 020	E−02

[17] This is a unit for the quantity second moment of area, which is sometimes called the ''moment of section'' or ''area moment of inertia'' of a plane section about a specified axis.

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To convert from	to	Multiply by	
gamma (γ)	tesla (T)	**1.0**	**E−09**
gauss (Gs, G)	tesla (T)	**1.0**	**E−04**
gilbert (Gi)	ampere (A)	7.957 747	E−01
gill [Canadian and U.K. (Imperial)] (gi)	cubic meter (m^3)	1.420 653	E−04
gill [Canadian and U.K. (Imperial)] (gi)	liter (L)	1.420 653	E−01
gill (U.S.) (gi)	cubic meter (m^3)	1.182 941	E−04
gill (U.S.) (gi)	liter (L)	1.182 941	E−01
gon (also called grade) (gon)	radian (rad)	1.570 796	E−02
gon (also called grade) (gon)	degree (angle) (°)	**9.0**	**E−01**
grain (gr)	kilogram (kg)	**6.479 891**	**E−05**
grain (gr)	milligram (mg)	**6.479 891**	**E+01**
grain per gallon (U.S.) (gr/gal)	kilogram per cubic meter (kg/m^3)	1.711 806	E−02
grain per gallon (U.S.) (gr/gal)	milligram per liter (mg/L)	1.711 806	E+01
gram-force per square centimeter (gf/cm^2)	pascal (Pa)	**9.806 65**	**E+01**
gram per cubic centimeter (g/cm^3)	kilogram per cubic meter (kg/m^3)	**1.0**	**E+03**
hectare (ha)	square meter (m^2)	**1.0**	**E+04**
horsepower (550 ft · lbf/s) (hp)	watt (W)	7.456 999	E+02
horsepower (boiler)	watt (W)	9.809 50	E+03
horsepower (electric)	watt (W)	**7.46**	**E+02**
horsepower (metric)	watt (W)	7.354 988	E+02
horsepower (U.K.)	watt (W)	7.4570	E+02
horsepower (water)	watt (W)	7.460 43	E+02
hour (h)	second (s)	**3.6**	**E+03**
hour (sidereal)	second (s)	3.590 170	E+03
hundredweight (long, 112 lb)	kilogram (kg)	5.080 235	E+01
hundredweight (short, 100 lb)	kilogram (kg)	4.535 924	E+01
inch (in)	meter (m)	**2.54**	**E−02**
inch (in)	centimeter (cm)	**2.54**	**E+00**
inch of mercury (32 °F)[13]	pascal (Pa)	3.386 38	E+03
inch of mercury (32 °F)[13]	kilopascal (kPa)	3.386 38	E+00
inch of mercury (60 °F)[13]	pascal (Pa)	3.376 85	E+03
inch of mercury (60 °F)[13]	kilopascal (kPa)	3.376 85	E+00
inch of mercury, conventional (inHg)[13]	pascal (Pa)	3.386 389	E+03
inch of mercury, conventional (inHg)[13]	kilopascal (kPa)	3.386 389	E+00
inch of water (39.2 °F)[13]	pascal (Pa)	2.490 82	E+02
inch of water (60 °F)[13]	pascal (Pa)	2.4884	E+02
inch of water, conventional (inH_2O)[13]	pascal (Pa)	2.490 889	E+02
inch per second (in/s)	meter per second (m/s)	**2.54**	**E−02**
inch per second squared (in/s^2)	meter per second squared (m/s^2)	**2.54**	**E−02**
inch to the fourth power (in^4)[17]	meter to the fourth power (m^4)	4.162 314	E−07
kayser (K)	reciprocal meter (m^{-1})	**1.0**	**E+02**
kelvin (K)	degree Celsius (°C)	$t/°C = T/K -$ **273.15**	
kilocalorie$_{IT}$ (kcal$_{IT}$)	joule (J)	**4.1868**	**E+03**
kilocalorie$_{th}$ (kcal$_{th}$)	joule (J)	**4.184**	**E+03**
kilocalorie (mean) (kcal)	joule (J)	4.190 02	E+03
kilocalorie$_{th}$ per minute (kcal$_{th}$/min)	watt (W)	6.973 333	E+01
kilocalorie$_{th}$ per second (kcal$_{th}$/s)	watt (W)	**4.184**	**E+03**
kilogram-force (kgf)	newton (N)	**9.806 65**	**E+00**
kilogram-force meter (kgf · m)	newton meter (N · m)	**9.806 65**	**E+00**

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To convert from	to	Multiply by	
kilogram-force per square centimeter (kgf/cm^2)	pascal (Pa)	**9.806 65**	**E+04**
kilogram-force per square centimeter (kgf/cm^2)	kilopascal (kPa)	**9.806 65**	**E+01**
kilogram-force per square meter (kgf/m^2)	pascal (Pa)	**9.806 65**	**E+00**
kilogram-force per square millimeter (kgf/mm^2)	pascal (Pa)	**9.806 65**	**E+06**
kilogram-force per square millimeter (kgf/mm^2)	megapascal (MPa)	**9.806 65**	**E+00**
kilogram-force second squared per meter ($kgf \cdot s^2/m$)	kilogram (kg)	**9.806 65**	**E+00**
kilometer per hour (km/h)	meter per second (m/s)	2.777 778	E−01
kilopond (kilogram-force) (kp)	newton (N)	**9.806 65**	**E+00**
kilowatt hour (kW · h)	joule (J)	**3.6**	**E+06**
kilowatt hour (kW · h)	megajoule (MJ)	**3.6**	**E+00**
kip (1 kip=1000 lbf)	newton (N)	4.448 222	E+03
kip (1 kip=1000 lbf)	kilonewton (kN)	4.448 222	E+00
kip per square inch (ksi) (kip/in^2)	pascal (Pa)	6.894 757	E+06
kip per square inch (ksi) (kip/in^2)	kilopascal (kPa)	6.894 757	E+03
knot (nautical mile per hour)	meter per second (m/s)	5.144 444	E−01
lambert[18]	candela per square meter (cd/m^2)	3.183 099	E+03
langley (cal_{th}/cm^2)	joule per square meter (J/m^2)	**4.184**	**E+04**
light year (l.y.)[19]	meter (m)	9.460 73	E+15
liter (L)[20]	cubic meter (m^3)	**1.0**	**E−03**
lumen per square foot (lm/ft^2)	lux (lx)	1.076 391	E+01
maxwell (Mx)	weber (Wb)	**1.0**	**E−08**
mho	siemens (S)	**1.0**	**E+00**
microinch	meter (m)	**2.54**	**E−08**
microinch	micrometer (μm)	**2.54**	**E−02**
micron (μ)	meter (m)	**1.0**	**E−06**
micron (μ)	micrometer (μm)	**1.0**	**E+00**
mil (0.001 in)	meter (m)	**2.54**	**E−05**
mil (0.001 in)	millimeter (mm)	**2.54**	**E−02**
mil (angle)	radian (rad)	9.817 477	E−04
mil (angle)	degree (°)	**5.625**	**E−02**
mile (mi)	meter (m)	**1.609 344**	**E+03**
mile (mi)	kilometer (km)	**1.609 344**	**E+00**
mile (based on U.S. survey foot) (mi)[9]	meter (m)	1.609 347	E+03
mile (based on U.S. survey foot) (mi)[9]	kilometer (km)	1.609 347	E+00
mile, nautical[21]	meter (m)	**1.852**	**E+03**
mile per gallon (U.S.) (mpg) (mi/gal)	meter per cubic meter (m/m^3)	4.251 437	E+05
mile per gallon (U.S.) (mpg) (mi/gal)	kilometer per liter (km/L)	4.251 437	E−01
mile per gallon (U.S.) (mpg) (mi/gal)[22]	liter per 100 kilometer (L/100 km)	divide 235.215 by number of miles per gallon	
mile per hour (mi/h)	meter per second (m/s)	**4.4704**	**E−01**
mile per hour (mi/h)	kilometer per hour (km/h)	**1.609 344**	**E+00**

[18] The exact conversion factor is $10^4/\pi$.
[19] This conversion factor is based on 1 d = 86 400 s; and 1 Julian century = 36 525 d. (See *The Astronomical Almanac for the Year 1995*, page K6, U.S. Government Printing Office, Washington, DC, 1994).
[20] In 1964 the General Conference on Weights and Measures reestablished the name ‘‘liter’’ as a special name for the cubic decimeter. Between 1901 and 1964 the liter was slightly larger (1.000 028 dm^3); when one uses high-accuracy volume data of that time, this fact must be kept in mind.
[21] The value of this unit, 1 nautical mile = 1852 m, was adopted by the First International Extraordinary Hydrographic Conference, Monaco, 1929, under the name ‘‘International nautical mile.’’
[22] For converting fuel economy, as used in the U.S., to fuel consumption.

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To convert from	to	Multiply by	
mile per minute (mi/min)	meter per second (m/s)	**2.682 24**	**E+01**
mile per second (mi/s)	meter per second (m/s)	**1.609 344**	**E+03**
millibar (mbar)	pascal (Pa)	**1.0**	**E+02**
millibar (mbar)	kilopascal (kPa)	**1.0**	**E−01**
millimeter of mercury, conventional (mmHg)[13]	pascal (Pa)	1.333 224	E+02
millimeter of water, conventional (mmH_2O)[13]	pascal (Pa)	**9.806 65**	**E+00**
minute (angle) (')	radian (rad)	2.908 882	E−04
minute (min)	second (s)	**6.0**	**E+01**
minute (sidereal)	second (s)	5.983 617	E+01
oersted (Oe)	ampere per meter (A/m)	7.957 747	E+01
ohm centimeter (Ω · cm)	ohm meter (Ω · m)	**1.0**	**E−02**
ohm circular-mil per foot	ohm meter (Ω · m)	1.662 426	E−09
ohm circular-mil per foot	ohm square millimeter per meter ($\Omega \cdot mm^2/m$)	1.662 426	E−03
ounce (avoirdupois) (oz)	kilogram (kg)	2.834 952	E−02
ounce (avoirdupois) (oz)	gram (g)	2.834 952	E+01
ounce (troy or apothecary) (oz)	kilogram (kg)	3.110 348	E−02
ounce (troy or apothecary) (oz)	gram (g)	3.110 348	E+01
ounce [Canadian and U.K. fluid (Imperial)] (fl oz)	cubic meter (m^3)	2.841 306	E−05
ounce [Canadian and U.K. fluid (Imperial)] (fl oz)	milliliter (mL)	2.841 306	E+01
ounce (U.S. fluid) (fl oz)	cubic meter (m^3)	2.957 353	E−05
ounce (U.S. fluid) (fl oz)	millimeter (mL)	2.957 353	E+01
ounce (avoirdupois)-force (ozf)	newton (N)	2.780 139	E−01
ounce (avoirdupois)-force inch (ozf · in)	newton meter (N · m)	7.061 552	E−03
ounce (avoirdupois)-force inch (ozf · in)	millinewton meter (mN · m)	7.061 552	E+00
ounce (avoirdupois) per cubic inch (oz/in^3)	kilogram per cubic meter (kg/m^3)	1.729 994	E+03
ounce (avoirdupois) per gallon [Canadian and U.K. (Imperial)] (oz/gal)	kilogram per cubic meter (kg/m^3)	6.236 023	E+00
ounce (avoirdupois) per gallon [Canadian and U.K. (Imperial)] (oz/gal)	gram per liter (g/L)	6.236 023	E+00
ounce (avoirdupois) per gallon (U.S.) (oz/gal)	kilogram per cubic meter (kg/m^3)	7.489 152	E+00
ounce (avoirdupois) per gallon (U.S.) (oz/gal)	gram per liter (g/L)	7.489 152	E+00
ounce (avoirdupois) per square foot (oz/ft^2)	kilogram per square meter (kg/m^2)	3.051 517	E−01
ounce (avoirdupois) per square inch (oz/in^2)	kilogram per square meter (kg/m^2)	4.394 185	E+01
ounce (avoirdupois) per square yard (oz/yd^2)	kilogram per square meter (kg/m^2)	3.390 575	E−02
parsec (pc)	meter (m)	3.085 678	E+16
peck (U.S.) (pk)	cubic meter (m^3)	8.809 768	E−03
peck (U.S.) (pk)	liter (L)	8.809 768	E+00
pennyweight (dwt)	kilogram (kg)	1.555 174	E−03
pennyweight (dwt)	gram (g)	1.555 174	E+00
perm (0 °C)	kilogram per pascal second square meter [$kg/(Pa \cdot s \cdot m^2)$]	5.721 35	E−11
perm (23 °C)	kilogram per pascal second square meter [$kg/(Pa \cdot s \cdot m^2)$]	5.745 25	E−11
perm inch (0 °C)	kilogram per pascal second meter [$kg/(Pa \cdot s \cdot m)$]	1.453 22	E−12
perm inch (23 °C)	kilogram per pascal second meter [$kg/(Pa \cdot s \cdot m)$]	1.459 29	E−12

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To convert from	to	Multiply by	
phot (ph)	lux (lx)	**1.0**	**E+04**
pica (computer) (1/6 in)	meter (m)	4.233 333	E−03
pica (computer) (1/6 in)	millimeter (mm)	4.233 333	E+00
pica (printer's)	meter (m)	4.217 518	E−03
pica (printer's)	millimeter (mm)	4.217 518	E+00
pint (U.S. dry) (dry pt)	cubic meter (m^3)	5.506 105	E−04
pint (U.S. dry) (dry pt)	liter (L)	5.506 105	E−01
pint (U.S. liquid) (liq pt)	cubic meter (m^3)	4.731 765	E−04
pint (U.S. liquid) (liq pt)	liter (L)	4.731 765	E−01
point (computer) (1/72 in)	meter (m)	3.527 778	E−04
point (computer) (1/72 in)	millimeter (mm)	3.527 778	E−01
point (printer's)	meter (m)	3.514 598	E−04
point (printer's)	millimeter (mm)	3.514 598	E−01
poise (P)	pascal second (Pa · s)	**1.0**	**E−01**
pound (avoirdupois) (lb)[23]	kilogram (kg)	4.535 924	E−01
pound (troy or apothecary) (lb)	kilogram (kg)	3.732 417	E−01
poundal	newton (N)	1.382 550	E−01
poundal per square foot	pascal (Pa)	1.488 164	E+00
poundal second per square foot	pascal second (Pa · s)	1.488 164	E+00
pound foot squared ($lb \cdot ft^2$)	kilogram meter squared ($kg \cdot m^2$)	4.214 011	E−02
pound-force (lbf)[24]	newton (N)	4.448 222	E+00
pound-force foot (lbf · ft)	newton meter (N · m)	1.355 818	E+00
pound-force foot per inch (lbf · ft/in)	newton meter per meter (N · m/m)	5.337 866	E+01
pound-force inch (lbf · in)	newton meter (N · m)	1.129 848	E−01
pound-force inch per inch (lbf · in/in)	newton meter per meter (N · m/m)	4.448 222	E+00
pound-force per foot (lbf/ft)	newton per meter (N/m)	1.459 390	E+01
pound-force per inch (lbf/in)	newton per meter (N/m)	1.751 268	E+02
pound-force per pound (lbf/lb) (thrust to mass ratio)	newton per kilogram (N/kg)	**9.806 65**	**E+00**
pound-force per square foot (lbf/ft^2)	pascal (Pa)	4.788 026	E+01
pound-force per square inch (psi) (lbf/in^2)	pascal (Pa)	6.894 757	E+03
pound-force per square inch (psi) (lbf/in^2)	kilopascal (kPa)	6.894 757	E+00
pound-force second per square foot ($lbf \cdot s/ft^2$)	pascal second (Pa · s)	4.788 026	E+01
pound-force second per square inch ($lbf \cdot s/in^2$)	pascal second (Pa · s)	6.894 757	E+03
pound inch squared ($lb \cdot in^2$)	kilogram meter squared ($kg \cdot m^2$)	2.926 397	E−04
pound per cubic foot (lb/ft^3)	kilogram per cubic meter (kg/m^3)	1.601 846	E+01
pound per cubic inch (lb/in^3)	kilogram per cubic meter (kg/m^3)	2.767 990	E+04
pound per cubic yard (lb/yd^3)	kilogram per cubic meter (kg/m^3)	5.932 764	E−01
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488 164	E+00
pound per foot hour [lb/(ft · h)]	pascal second (Pa · s)	4.133 789	E−04
pound per foot second [lb/(ft · s)]	pascal second (Pa · s)	1.488 164	E+00
pound per gallon [Canadian and U.K. (Imperial)] (lb/gal)	kilogram per cubic meter (kg/m^3)	9.977 637	E+01
pound per gallon [Canadian and U.K. (Imperial)] (lb/gal)	kilogram per liter (kg/L)	9.977 637	E−02
pound per gallon (U.S.) (lb/gal)	kilogram per cubic meter (kg/m^3)	1.198 264	E+02
pound per gallon (U.S.) (lb/gal)	kilogram per liter (kg/L)	1.198 264	E−01
pound per horsepower hour [lb/(hp · h)]	kilogram per joule (kg/J)	1.689 659	E−07
pound per hour (lb/h)	kilogram per second (kg/s)	1.259 979	E−04

[23] The exact conversion factor is 4.535 923 7 E−01. All units that contain the pound refer to the avoirdupois pound.

[24] If the local value of the acceleration of free fall is taken as $g_n = 9.806\,65\ m/s^2$ (the standard value), the exact conversion factor is 4.448 221 615 260 5 E+00.

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To convert from	to	Multiply by	
pound per inch (lb/in)	kilogram per meter (kg/m)	1.785 797	E+01
pound per minute (lb/min)	kilogram per second (kg/s)	7.559 873	E−03
pound per second (lb/s)	kilogram per second (kg/s)	4.535 924	E−01
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882 428	E+00
pound per square inch (*not* pound-force) (lb/in^2)	kilogram per square meter (kg/m^2)	7.030 696	E+02
pound per yard (lb/yd)	kilogram per meter (kg/m)	4.960 546	E−01
psi (pound-force per square inch) (lbf/in^2)	pascal (Pa)	6.894 757	E+03
psi (pound-force per square inch) (lbf/in^2)	kilopascal (kPa)	6.894 757	E+00
quad (10^{15} Btu_{IT})[11]	joule (J)	1.055 056	E+18
quart (U.S. dry) (dry qt)	cubic meter (m^3)	1.101 221	E−03
quart (U.S. dry) (dry qt)	liter (L)	1.101 221	E+00
quart (U.S. liquid) (liq qt)	cubic meter (m^3)	9.463 529	E−04
quart (U.S. liquid) (liq qt)	liter (L)	9.463 529	E−01
rad (absorbed dose) (rad)	gray (Gy)	**1.0**	**E−02**
rem (rem)	sievert (Sv)	**1.0**	**E−02**
revolution (r)	radian (rad)	6.283 185	E+00
revolution per minute (rpm) (r/min)	radian per second (rad/s)	1.047 198	E−01
rhe	reciprocal pascal second [$(Pa \cdot s)^{-1}$]	**1.0**	**E+01**
rod (based on U.S. survey foot) (rd)[9]	meter (m)	5.029 210	E+00
roentgen (R)	coulomb per kilogram (C/kg)	**2.58**	E**−04**
rpm (revolution per minute) (r/min)	radian per second (rad/s)	1.047 198	E−01
second (angle) (")	radian (rad)	4.848 137	E−06
second (sidereal)	second (s)	9.972 696	E−01
shake	second (s)	**1.0**	**E−08**
shake	nanosecond (ns)	**1.0**	**E+01**
slug (slug)	kilogram (kg)	1.459 390	E+01
slug per cubic foot (slug/ft^3)	kilogram per cubic meter (kg/m^3)	5.153 788	E+02
slug per foot second [slug/(ft · s)]	pascal second (Pa · s)	4.788 026	E+01
square foot (ft^2)	square meter (m^2)	**9.290 304**	**E−02**
square foot per hour (ft^2/h)	square meter per second (m^2/s)	**2.580 64**	**E−05**
square foot per second (ft^2/s)	square meter per second (m^2/s)	**9.290 304**	**E−02**
square inch (in^2)	square meter (m^2)	**6.4516**	**E−04**
square inch (in^2)	square centimeter (cm^2)	**6.4516**	**E+00**
square mile (mi^2)	square meter (m^2)	2.589 988	E+06
square mile (mi^2)	square kilometer (km^2)	2.589 988	E+00
square mile (based on U.S. survey foot) (mi^2)[9]	square meter (m^2)	2.589 998	E+06
square mile (based on U.S. survey foot) (mi^2)[9]	square kilometer (km^2)	2.589 998	E+00
square yard (yd^2)	square meter (m^2)	8.361 274	E−01
statampere	ampere (A)	3.335 641	E−10
statcoulomb	coulomb (C)	3.335 641	E−10
statfarad	farad (F)	1.112 650	E−12
stathenry	henry (H)	8.987 552	E+11
statmho	siemens (S)	1.112 650	E−12
statohm	ohm (Ω)	8.987 552	E+11
statvolt	volt (V)	2.997 925	E+02
stere (st)	cubic meter (m^3)	**1.0**	**E+00**
stilb (sb)	candela per square meter (cd/m^2)	**1.0**	**E+04**
stokes (St)	meter squared per second (m^2/s)	**1.0**	**E−04**

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To convert from	to	Multiply by	
tablespoon	cubic meter (m^3)	1.478 676	E−05
tablespoon	milliliter (mL)	1.478 676	E+01
teaspoon	cubic meter (m^3)	4.928 922	E−06
teaspoon	milliliter (mL)	4.928 922	E+00
tex	kilogram per meter (kg/m)	**1.0**	**E−06**
therm (EC)[25]	joule (J)	**1.055 06**	**E+08**
therm (U.S.)[25]	joule (J)	**1.054 804**	**E+08**
ton, assay (AT)	kilogram (kg)	2.916 667	E−02
ton, assay (AT)	gram (g)	2.916 667	E+01
ton-force (2000 lbf)	newton (N)	8.896 443	E+03
ton-force (2000 lbf)	kilonewton (kN)	8.896 443	E+00
ton, long (2240 lb)	kilogram (kg)	1.016 047	E+03
ton, long, per cubic yard	kilogram per cubic meter (kg/m^3)	1.328 939	E+03
ton, metric (t)	kilogram (kg)	**1.0**	**E+03**
tonne (called ‘‘metric ton’’ in U.S.) (t)	kilogram (kg)	**1.0**	**E+03**
ton of refrigeration (12 000 Btu_{IT}/h)	watt (W)	3.516 853	E+03
ton of TNT (energy equivalent)[26]	joule (J)	**4.184**	**E+09**
ton, register	cubic meter (m^3)	2.831 685	E+00
ton, short (2000 lb)	kilogram (kg)	9.071 847	E+02
ton, short, per cubic yard	kilogram per cubic meter (kg/m^3)	1.186 553	E+03
ton, short, per hour	kilogram per second (kg/s)	2.519 958	E−01
torr (Torr)	pascal (Pa)	1.333 224	E+02
unit pole	weber (Wb)	1.256 637	E−07
watt hour (W · h)	joule (J)	**3.6**	**E+03**
watt per square centimeter (W/cm^2)	watt per square meter (W/m^2)	**1.0**	**E+04**
watt per square inch (W/in^2)	watt per square meter (W/m^2)	1.550 003	E+03
watt second (W · s)	joule (J)	**1.0**	**E+00**
yard (yd)	meter (m)	**9.144**	**E−01**
year (365 days)	second (s)	**3.1536**	**E+07**
year (sidereal)	second (s)	3.155 815	E+07
year (tropical)	second (s)	3.155 693	E+07

[25] The therm (EC) is legally defined in the Council Directive of 20 December 1979, Council of the European Communities (now the European Union, EU). The therm (U.S.) is legally defined in the Federal Register of July 27, 1968. Although the therm (EC), which is based on the International Table Btu, is frequently used by engineers in the United States, the therm (U.S.) is the legal unit used by the U.S. natural gas industry.

[26] Defined (not measured) value.

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CONVERSION OF TEMPERATURES

From	To	
Celsius	Fahrenheit	$t_F/^\circ F = (9/5)\, t/^\circ C + 32$
	Kelvin	$T/K = t/^\circ C + 273.15$
	Rankine	$T/^\circ R = (9/5)\,(t/^\circ C + 273.15)$
Fahrenheit	Celsius	$t/^\circ C = (5/9)\,[(t_F/^\circ F) - 32]$
	Kelvin	$T/K = (5/9)\,[(t_F/^\circ F) - 32] + 273.15$
	Rankine	$T/^\circ R = t_F/^\circ F + 459.67$
Kelvin	Celsius	$t/^\circ C = T/K - 273.15$
	Rankine	$T/^\circ R = (9/5)\, T/K$
Rankine	Fahrenheit	$t_F/^\circ F = T/^\circ R - 459.67$
	Kelvin	$T/K = (5/9)\, T/^\circ R$

Definition of symbols:

T = thermodynamic (absolute) temperature
t = Celsius temperature (the symbol θ is also used for Celsius temperature)
t_F = Fahrenheit temperature

DESIGNATION OF LARGE NUMBERS

	U.S.A.	**Other Countries**
10^6	million	million
10^9	billion	milliard
10^{12}	trillion	billion
10^{15}	quadrillion	billiard
10^{18}	quintillion	trillion

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CONVERSION FACTORS FOR ENERGY UNITS

If greater accuracy is required, use the *Energy Equivalents* section of the *Fundamental Physical Constants* table.

	Wavenumber $\bar{\nu}$ cm^{-1}	**Frequency ν** MHz	**Energy E** aJ	**Energy E** eV	**Energy E** E_h	**Molar energy E_m** kJ/mol	**Molar energy E_m** kcal/mol	**Temperature T** K
$\bar{\nu}$: 1 cm^{-1}	≐ 1	2.997925×10^{4}	1.986447×10^{-5}	1.239842×10^{-4}	4.556335×10^{-6}	11.96266×10^{-3}	2.85914×10^{-3}	1.438769
ν: 1 MHz	≐ 3.33564×10^{-5}	1	6.626076×10^{-10}	4.135669×10^{-9}	1.519830×10^{-10}	3.990313×10^{-7}	9.53708×10^{-8}	4.79922×10^{-5}
1 aJ	≐ 50341.1	1.509189×10^{9}	1	6.241506	0.2293710	602.2137	143.9325	7.24292×10^{4}
E: 1 eV	≐ 8065.54	2.417988×10^{8}	0.1602177	1	3.674931×10^{-2}	96.4853	23.0605	1.16045×10^{4}
E_h	≐ 219474.63	6.579684×10^{9}	4.359748	27.2114	1	2625.500	627.510	3.15773×10^{5}
E_m: 1 kJ/mol	≐ 83.5935	2.506069×10^{6}	1.660540×10^{-3}	1.036427×10^{-2}	3.808798×10^{-4}	1	0.239006	120.272
1 kcal/mol	≐ 349.755	1.048539×10^{7}	6.947700×10^{-3}	4.336411×10^{-2}	1.593601×10^{-3}	4.184	1	503.217
T: 1 K	≐ 0.695039	2.08367×10^{4}	1.380658×10^{-5}	8.61738×10^{-5}	3.16683×10^{-6}	8.31451×10^{-3}	1.98722×10^{-3}	1

Examples of the use of this table: 1 aJ ≐ 50341 cm^{-1}
1 eV ≐96.4853 kJ mol^{-1}

The symbol ≐ should be read as meaning "corresponds to" or "is equivalent to".
$E = h\nu = hc\bar{\nu} = kT$; $E_m = N_A E$; E_h is the Hartree energy

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CONVERSION FACTORS FOR PRESSURE UNITS

	Pa	kPa	MPa	bar	atmos	Torr	μmHg	psi
Pa	1	0.001	0.000001	0.00001	9.8692×10^{-6}	0.0075006	7.5006	0.0001450377
kPa	1000	1	0.001	0.01	0.0098692	7.5006	7500.6	0.1450377
MPa	1000000	1000	1	10	9.8692	7500.6	7500600	145.0377
bar	100000	100	0.1	1	0.98692	750.06	750060	14.50377
atmos	101325	101.325	0.101325	1.01325	1	760	760000	14.69594
Torr	133.322	0.133322	0.000133322	0.00133322	0.00131579	1	1000	0.01933672
μmHg	0.133322	0.000133322	1.33322×10^{-7}	1.33322×10^{-6}	1.31579×10^{-6}	0.001	1	1.933672×10^{-5}
psi	6894.757	6.894757	0.006894757	0.06894757	0.068046	51.7151	51715.1	1

To convert a pressure value from a unit in the left hand column to a new unit, multiply the value by the factor appearing in the column for the new unit. For example:

1 kPa = 9.8692×10^{-3} atmos
1 Torr = 1.33322×10^{-4} MPa

Notes: μmHg is often referred to as "micron"
Torr is essentially identical to mmHg
psi is an abbreviation for the unit pound–force per square inch
psia (as a term for a physical quantity) implies the true (absolute) pressure
psig implies the true pressure minus the local atmospheric pressure

CONVERSION FACTORS FOR THERMAL CONDUCTIVITY UNITS

MULTIPLY ↓ by appropriate factor to OBTAIN→	Btu_{IT} h^{-1} ft^{-1} $°F^{-1}$	Btu_{IT} in. h^{-1} ft^{-2} $°F^{-1}$	Btu_{th} h^{-1} ft^{-1} $°F^{-1}$	Btu_{th} in. h^{-1} ft^{-2} $°F^{-1}$	cal_{IT} s^{-1} cm^{-1} $°C^{-1}$	cal_{th} s^{-1} cm^{-1} $°C^{-1}$	$kcal_{th}$ h^{-1} m^{-1} $°C^{-1}$	J s^{-1} cm^{-1} K^{-1}	W cm^{-1} K^{-1}	W m^{-1} K^{-1}	mW cm^{-1} K^{-1}
Btu_{IT} h^{-1} ft^{-1} $°F^{-1}$	1	12	1.00067	12.0080	4.13379×10^{-3}	4.13656×10^{-3}	1.48916	1.73073×10^{-2}	1.73073×10^{-2}	1.73073	17.3073
Btu_{IT} in. h^{-1} ft^{-2} $°F^{-1}$	8.33333×10^{-2}	1	8.33891×10^{-2}	1.00067	3.44482×10^{-4}	3.44713×10^{-4}	0.124097	1.44228×10^{-3}	1.44228×10^{-3}	0.144228	1.44228
Btu_{th} h^{-1} ft^{-1} $°F^{-1}$	0.999331	11.9920	1	12	4.13102×10^{-3}	4.13379×10^{-3}	1.48816	1.72958×10^{-2}	1.72958×10^{-2}	1.72958	17.2958
Btu_{th} in. h^{-1} ft^{-2} $°F^{-1}$	8.32776×10^{-2}	0.999331	8.33333×10^{-2}	1	3.44252×10^{-4}	3.44482×10^{-4}	0.124014	1.44131×10^{-3}	1.44131×10^{-3}	0.144131	1.44131
cal_{IT} s^{-1} cm^{-1} $°C^{-1}$	2.41909×10^{2}	2.90291×10^{3}	2.42071×10^{2}	2.90485×10^{3}	1	1.00067	3.60241×10^{2}	4.1868	4.1868	4.1868×10^{2}	4.1868×10^{3}
cal_{th} s^{-1} cm^{-1} $°C^{-1}$	2.41747×10^{2}	2.90096×10^{3}	2.41909×10^{2}	2.90291×10^{3}	0.999331	1	3.6×10^{2}	4.184	4.184	4.184×10^{2}	4.184×10^{3}
$kcal_{th}$ h^{-1} m^{-1} $°C^{-1}$	0.671520	8.05824	0.671969	8.06363	2.77592×10^{-3}	2.77778×10^{-3}	1	1.16222×10^{-2}	1.16222×10^{-2}	1.16222	11.6222
J s^{-1} cm^{-1} K^{-1}	57.7789	6.93347×10^{2}	57.8176	6.93811×10^{2}	0.238846	0.239006	86.0421	1	1	1×10^{2}	1×10^{3}
W cm^{-1} K^{-1}	57.7789	6.93347×10^{2}	57.8176	6.93811×10^{2}	0.238846	0.239006	86.0421	1	1	1×10^{2}	1×10^{3}
W m^{-1} K^{-1}	0.577789	6.93347	0.578176	6.93811	2.38846×10^{-3}	2.39006×10^{-3}	0.860421	1×10^{-2}	1×10^{-2}	1	10
mW cm^{-1} K^{-1}	5.77789×10^{-2}	0.693347	5.78176×10^{-2}	0.693811	2.38846×10^{-4}	2.39006×10^{-4}	8.60421×10^{-2}	1×10^{-3}	1×10^{-3}	0.1	1

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CONVERSION FACTORS FOR ELECTRICAL RESISTIVITY UNITS

To convert from ↓ multiply by appropriate factor to Obtain →	abΩ cm	μΩ cm	Ω cm	StatΩ cm	Ω m	Ω cir. mil ft^{-1}	Ω in.	Ω ft
abohm centimeter	1	1×10^{-3}	10^{-9}	1.113×10^{-21}	10^{-11}	6.015×10^{-3}	3.937×10^{-10}	3.281×10^{-11}
microohm centimeter	10^{3}	1	10^{-6}	1.113×10^{-18}	10^{-6}	6.015	3.937×10^{-7}	3.281×10^{-6}
ohm centimeter	10^{8}	10^{6}	1	1.113×10^{-12}	1×10^{-2}	6.015×10^{6}	3.937×10^{-1}	3.281×10^{-2}
statohm centimeter (esu)	8.987×10^{20}	8.987×10^{17}	8.987×10^{11}	1	8.987×10^{9}	5.406×10^{18}	3.538×10^{11}	2.949×10^{10}
ohm meter	10^{11}	10^{8}	10^{2}	1.113×10^{-10}	1	6.015×10^{8}	3.937×10^{1}	3.281
ohm circular mil per foot	1.662×10^{2}	1.662×10^{-1}	1.662×10^{-7}	1.850×10^{-19}	1.662×10^{-9}	1	6.54×10^{-6}	5.45×10^{-9}
ohm inch	2.54×10^{9}	2.54×10^{6}	2.54	2.827×10^{-12}	2.54×10^{-2}	1.528×10^{7}	1	8.3×10^{-2}
ohm foot	3.048×10^{10}	3.048×10^{7}	3.048×10^{-1}	3.3924×10^{-11}	3.048×10^{-1}	1.833×10^{8}	12	1

CONVERSION FACTORS FOR CHEMICAL KINETICS

Equivalent second order rate constants

A \ B	$cm^3\ mol^{-1}\ s^{-1}$	$dm^3\ mol^{-1}\ s^{-1}$	$m^3\ mol^{-1}\ s^{-1}$	$cm^3\ molecule^{-1}\ s^{-1}$	$(mm\ Hg)^{-1}\ s^{-1}$	$atm^{-1}\ s^{-1}$	$ppm^{-1}\ min^{-1}$	$m^2\ kN^{-1}\ s^{-1}$
$1\ cm^3\ mol^{-1}\ s^{-1} =$	1	10^{-3}	10^{-6}	1.66×10^{-24}	$1.604 \times 10^{-5}\ T^{-1}$	$1.219 \times 10^{-2}\ T^{-1}$	2.453×10^{-9}	$1.203 \times 10^{-4}\ T^{-1}$
$1\ dm^3\ mol^{-1}\ s^{-1} =$	10^3	1	10^{-3}	1.66×10^{-21}	$1.604 \times 10^{-2}\ T^{-1}$	$12.19\ T^{-1}$	2.453×10^{-6}	$1.203 \times 10^{-1}\ T^{-1}$
$1\ m^3\ mol^{-1}\ s^{-1} =$	10^6	10^3	1	1.66×10^{-18}	$16.04\ T^{-1}$	$1.219 \times 10^4\ T^{-1}$	2.453×10^{-3}	$120.3\ T^{-1}$
$1\ cm^3\ molecule^{-1}\ s^{-1} =$	6.023×10^{23}	6.023×10^{20}	6.023×10^{17}	1	$9.658 \times 10^{18}\ T^{-1}$	$7.34 \times 10^{21}\ T^{-1}$	1.478×10^{15}	$7.244 \times 10^{19}\ T^{-1}$
$1\ (mm\ Hg)^{-1}\ s^{-1} =$	$6.236 \times 10^4\ T$	$62.36\ T$	$6.236 \times 10^{-2}\ T$	$1.035 \times 10^{-19}\ T$	1	760	4.56×10^{-2}	7.500
$1\ atm^{-1}\ s^{-1}$	$82.06\ T$	$8.206 \times 10^{-2}\ T$	$8.206 \times 10^{-5}\ T$	$1.362 \times 10^{-22}\ T$	1.316×10^{-3}	1	6×10^{-5}	9.869×10^{-3}
$1\ ppm^{-1}\ min^{-1} =$ at 298 K, 1 atm total pressure	4.077×10^8	4.077×10^5	407.7	6.76×10^{-16}	21.93	1.667×10^4	1	164.5
$1\ m^2\ kN^{-1}\ s^{-1} =$	$8314\ T$	$8.314\ T$	$8.314 \times 10^{-3}\ T$	$1.38 \times 10^{-20}\ T$	0.1333	101.325	6.079×10^{-3}	1

To convert a rate constant from one set of units A to a new set B find the conversion factor for the row A under column B and multiply the old value by it, e.g. to convert $cm^3\ molecule^{-1}\ s^{-1}$ to $m^3\ mol^{-1}\ s^{-1}$ multiply by 6.023×10^{17}.

Table adapted from High Temperature Reaction Rate Data No. 5, The University, Leeds (1970).

Equivalent third order rate constants

A \ B	$cm^6\ mol^{-2}\ s^{-1}$	$dm^6\ mol^{-2}\ s^{-1}$	$m^6\ mol^{-2}\ s^{-1}$	$cm^6\ molecule^{-2}\ s^{-1}$	$(mm\ Hg)^{-2}\ s^{-1}$	$atm^{-2}\ s^{-1}$	$ppm^{-2}\ min^{-1}$	$m^4\ kN^{-2}\ s^{-1}$
$1\ cm^6\ mol^{-2}\ s^{-1} =$	1	10^{-6}	10^{-12}	2.76×10^{-48}	$2.57 \times 10^{-10}\ T^{-2}$	$1.48 \times 10^{-4}\ T^{-2}$	1.003×10^{-19}	$1.447 \times 10^{-8}\ T^{-2}$
$1\ dm^6\ mol^{-2}\ s^{-1} =$	10^6	1	10^{-6}	2.76×10^{-42}	$2.57 \times 10^{-4}\ T^{-2}$	$148\ T^{-2}$	1.003×10^{-13}	$1.447 \times 10^{-2}\ T^{-2}$
$1\ m^6\ mol^{-2}\ s^{-1} =$	10^{12}	10^6	1	2.76×10^{-36}	$257\ T^{-2}$	$1.48 \times 10^8\ T^{-2}$	1.003×10^{-7}	$1.447 \times 10^4\ T^{-2}$
$1\ cm^6 molecule^{-2}\ s^{-1} =$	3.628×10^{47}	3.628×10^{41}	3.628×10^{35}	1	$9.328 \times 10^{37}\ T^{-2}$	$5.388 \times 10^{43}\ T^{-2}$	3.64×10^{28}	$5.248 \times 10^{39}\ T^{-2}$
$1\ (mm\ Hg)^{-2}\ s^{-1} =$	$3.89 \times 10^9\ T^2$	$3.89 \times 10^3\ T^2$	$3.89 \times 10^{-3}\ T^2$	$1.07 \times 10^{-38}\ T^2$	1	5.776×10^5	3.46×10^{-5}	56.25
$1\ atm^{-2}\ s^{-1} =$	$6.733 \times 10^3\ T^2$	$6.733 \times 10^{-3}\ T^2$	$6.733 \times 10^{-9}\ T^2$	$1.86 \times 10^{-44}\ T^2$	1.73×10^{-6}	1	6×10^{-11}	9.74×10^{-5}
$1\ ppm^{-2}\ min^{-1} =$ at 298 K, 1 atm total pressure	9.97×10^{18}	9.97×10^{12}	9.97×10^6	2.75×10^{-29}	2.89×10^4	1.667×10^{10}	1	1.623×10^6
$1\ m^4\ kN^{-2}\ s^{-1} =$	$6.91 \times 10^7\ T^2$	$6.91\ T^2$	$69.1 \times 10^{-5}\ T^2$	$1.904 \times 10^{-40}\ T^2$	0.0178	1.027×10^4	6.16×10^{-7}	1

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CONVERSION FACTORS FOR IONIZING RADIATION

CONVERSION BETWEEN SI AND OTHER UNITS

Quantity	Symbol for quantity	Expression in SI units	Expression in symbols for SI units	Special name for SI units	Symbols using special names	Conventional units	Symbol for conventional unit	Value of conventional unit in SI units
Activity	*A*	1 per second	s^{-1}	becquerel	Bq	curie	Ci	3.7×10^{10} Bq
Absorbed dose	*D*	joule per kilogram	J kg^{-1}	gray	Gy	rad	rad	0.01 Gy
Absorbed dose rate	$\dot{D}$	joule per kilogram second	J kg^{-1} s^{-1}		Gy s^{-1}	rad	rad s^{-1}	0.01 Gy s^{-1}
Average energy per ion pair	*W*	joule	J			electronvolt	eV	1.602×10^{-19} J
Dose equivalent	*H*	joule per kilogram	J kg^{-1}	sievert	Sv	rem	rem	0.01 Sv
Dose equivalent rate	$\dot{H}$	joule per kilogram second	J kg^{-1} s^{-1}		Sv s^{-1}	rem per second	rem s^{-1}	0.01 Sv s^{-1}
Electric current	*I*	ampere	A			ampere	A	1.0 A
Electric potential difference	*U, V*	watt per ampere	W A^{-1}	volt	V	volt	V	1.0 A
Exposure	*X*	coulomb per kilogram	C kg^{-1}			roentgen	R	2.58×10^{-4} C kg^{-1}
Exposure rate	$\dot{X}$	coulomb per kilogram second	C kg^{-1} s^{-1}			roentgen	R s^{-1}	2.58×10^{-4} C kg^{-1} s^{-1}
Fluence	ϕ	1 per meter squared	m^{-2}			1 per centimeter squared	cm^{-2}	1.0×10^{4} m^{-2}
Fluence rate	Φ	1 per meter squared second	m^{-2} s^{-1}			1 per centimeter squared second	cm^{-2} s^{-1}	1.0×10^{4} m^{-2} s^{-1}
Kerma	*K*	joule per kilogram	J kg^{-1}	gray	Gy	rad	rad	0.01 Gy
Kerma rate	$\dot{K}$	joule per kilogram second	J kg^{-1} s^{-1}		Gy s^{-1}	rad per second	rad s^{-1}	0.01 Gy s^{-1}
Lineal energy	*y*	joule per meter	J m^{-1}			kiloelectron volt per micrometer	keV μm^{-1}	1.602×10^{-10} J m^{-1}
Linear energy transfer	*L*	joule per meter	J m^{-1}			kiloelectron volt per micrometer	keV μm^{-1}	1.602×10^{-10} J m^{-1}
Mass attenuation coefficient	μ/ρ	meter squared per kilogram	m^2 kg^{-1}			centimeter squared per gram	cm^2 g^{-1}	0.1 m^2 kg^{-1}
Mass energy transfer coefficient	μ_{tr}/ρ	meter squared per kilogram	m^2 kg^{-1}			centimeter squared per gram	cm^2 g^{-1}	0.1 m^2 kg^{-1}
Mass energy absorption coefficient	μ_{en}/ρ	meter squared per kilogram	m^2 kg^{-1}			centimeter squared per gram	cm^2 g^{-1}	0.1 m^2 kg^{-1}
Mass stopping power	S/ρ	joule meter squared per kilogram	J m^2 kg^{-1}			MeV centimeter squared per gram	MeV cm^2 g^{-1}	1.602×10^{-14} J m^2 kg^{-1}
Power	*P*	joule per second	J s^{-1}	watt	W	watt	W	1.0 W
Pressure	*p*	newton per meter squared	N m^{-2}	pascal	Pa	torr	torr	(101325/760)Pa
Radiation chemical yield	*G*	mole per joule	mol J^{-1}			molecules per 100 electron volts	molecules $(100\ eV)^{-1}$	1.04×10^{-7} mol J^{-1}
Specific energy	*z*	joule per kilogram	J kg^{-1}	gray	Gy	rad	rad	0.01 Gy

CONVERSION FACTORS FOR IONIZING RADIATION (continued)

CONVERSION OF RADIOACTIVITY UNITS FROM MBq TO mCi AND µCi

MBq	mCi	MBq	mCi	MBq	µCi	MBq	µCi
7000	189.	500	13.5	30	810	1	27
6000	162.	400	10.8	20	540	0.9	24
5000	135.	300	8.1	10	270	0.8	21.6
4000	108.	200	5.4	9	240	0.7	18.9
3000	81.	100	2.7	8	220	0.6	16.2
2000	54.	90	2.4	7	189	0.5	13.5
1000	27.	80	2.16	6	162	0.4	10.8
900	24.	70	1.89	5	135	0.3	8.1
800	21.6	60	1.62	4	108	0.2	5.4
700	18.9	50	1.35	3	81	0.1	2.7
600	16.2	40	1.08	2	54		

CONVERSION OF RADIOACTIVITY UNITS FROM mCi AND µCi TO MBq

mCi	MBq	mCi	MBq	µCi	MBq	µCi	MBq
200	7400	10	370	1000	37.0	80	2.96
150	5550	9	333	900	33.3	70	2.59
100	3700	8	296	800	29.6	60	2.22
90	3330	7	259	700	25.9	50	1.85
80	2960	6	222	600	22.2	40	1.48
70	2590	5	185	500	18.5	30	1.11
60	2220	4	148	400	14.8	20	0.74
50	1850	3	111	300	11.1	10	0.37
40	1480	2	74.0	200	7.4	5	0.185
30	1110	1	37.0	100	3.7	2	0.074
20	740			90	3.33	1	0.037

CONVERSION OF RADIOACTIVITY UNITS

100 TBq (10^{14} Bq)	=	2.7 kCi (2.7×10^{3} Ci)	100 kBq (10^{5} Bq)	=	2.7 µCi (2.7×10^{-6}Ci)
10 TBq (10^{13} Bq)	=	270 Ci (2.7×10^{2} Ci)	10 kBq (10^{4} Bq)	=	270 nCi (2.7×10^{-7} Ci)
1 TBq (10^{12} Bq)	=	27 Ci (2.7×10^{1} Ci)	1 kBq (10^{3} Bq)	=	27 nCi (2.7×10^{-8} Ci)
100 GBq (10^{11} Bq)	=	2.7 Ci (2.7×10^{0} Ci)	100 Bq (10^{2} Bq)	=	2.7 nCi (2.7×10^{-9} Ci)
10 GBq (10^{10} Bq)	=	270 mCi (2.7×10^{-1} Ci)	10 Bq (10^{1} Bq)	=	270 pCi (2.7×10^{-10} Ci)
1 GBq (10^{9} Bq)	=	27 mCi (2.7×10^{-2} Ci)	1 Bq (10^{0} Bq)	=	27 pCi (2.7×10^{-11} Ci)
100 MBq (10^{8} Bq)	=	2.7 mCi (2.7×10^{-3} Ci)	100 mBq (10^{-1} Bq)	=	2.7 pCi (2.7×10^{-12} Ci)
10 MBq (10^{7} Bq)	=	270 µCi (2.7×10^{-4} Ci)	10 mBq (10^{-2} Bq)	=	270 fCi (2.7×10^{-13} Ci)
1 MBq (10^{6} Bq)	=	27 µCi (2.7×10^{-5} Ci)	1 mBq (10^{-3} Bq)	=	27 fCi (2.7×10^{-14} Ci)

CONVERSION OF ABSORBED DOSE UNITS

SI Units		Conventional
100 Gy (10^{2} Gy)	=	10,000 rad (10^{4} rad)
10 Gy (10^{1} Gy)	=	1,000 rad (10^{3} rad)
1 Gy (10^{0} Gy)	=	100 rad (10^{2} rad)
100 mGy (10^{-1} Gy)	=	10 rad (10^{1} rad)
10 mGy (10^{-2} Gy)	=	1 rad (10^{0} rad)
1 mGy (10^{-3} Gy)	=	100 mrad (10^{-1} rad)
100 µGy (10^{-4} Gy)	=	10 mrad (10^{-2} rad)
10 µGy (10^{-5} Gy)	=	1 mrad (10^{-3} rad)
1 µGy (10^{-6} Gy)	=	100 µrad (10^{-4} rad)
100 nGy (10^{-7} Gy)	=	10 µrad (10^{-5} rad)
10 nGy (10^{-8} Gy)	=	1 µrad (10^{-6} rad)
1 nGy (10^{-9} Gy)	=	100 nrad (10^{-7} rad)

CONVERSION OF DOSE EQUIVALENT UNITS

100 Sv (10^{2} Sv)	=	10,000 rem (10^{4} rem)
10 Sv (10^{1} Sv)	=	1,000 rem (10^{3} rem)
1 Sv (10^{0} Sv)	=	100 rem (10^{2} rem)
100 mSv (10^{-1} Sv)	=	10 rem (10^{1} rem)
10 mSv (10^{-2} Sv)	=	1 rem (10^{0} rem)
1 mSv (10^{-3} Sv)	=	100 mrem (10^{-1} rem)
100 µSv (10^{-4} Sv)	=	10 mrem (10^{-2} rem)
10 µSv (10^{-5} Sv)	=	1 mrem (10^{-3} rem)
1 µSv (10^{-6} Sv)	=	100 µrem (10^{-4} rem)
100 nSv (10^{-7} Sv)	=	10 µrem (10^{-5} rem)
10 nSv (10^{-8} Sv)	=	1 µrem (10^{-6} rem)
1 nSv (10^{-9} Sv)	=	100 nrem (10^{-7} rem)

VALUES OF THE GAS CONSTANT IN DIFFERENT UNIT SYSTEMS

In SI units the value of the gas constant, *R*, is:

R =8.314510 Pa m^3 K^{-1} mol^{-1}
= 8314.510 Pa L K^{-1} mol^{-1}
= 0.08314510 bar L K^{-1} mol^{-1}

This table gives the appropriate value of *R* for use in the ideal gas equation, $PV = nRT$, when the variables are expressed in other units. The following conversion factors for pressure units were used in generating the table:

1 atm = 101325 Pa
1 psi = 6894.757 Pa
1 torr (mmHg) = 133.322 Pa [at 0°C]
1 in Hg = 3386.38 Pa [at 0°C]
1 in H_2O = 249.082 Pa [at 4°C]
1 ft H_2O = 2988.98 Pa [at 4°C]

The advice of Prabir K. Chandra is appreciated.

Units of *V*, *T*, *n*			**Units of *P***						
V	***T***	***n***	**kPa**	**atm**	**psi**	**mmHg**	**in Hg**	**in H_2O**	**ft H_2O**
ft^3	K	mol	0.2936241	0.00289785	0.0425866	2.20237	0.0867074	1.17882	0.0982355
		lb·mol	133.1857	1.31444	19.3169	998.978	39.3298	534.706	44.5589
	°R	mol	0.1631245	0.00160991	0.0236592	1.22354	0.0481708	0.654903	0.0545753
		lb·mol	73.99204	0.730245	10.7316	554.987	21.8499	297.059	24.7549
cm^3	K	mol	8314.510	82.0578	1205.92	62364.1	2455.28	33380.6	2781.72
		lb·mol	3771398	37220.8	546995	28287900	1113700	15141200	1261770
	°R	mol	4619.172	45.5877	669.954	34646.7	1364.04	18544.8	1545.40
		lb·mol	2095221	20678.2	303886	15715500	618720	8411770	700982
L	K	mol	8.314510	0.0820578	1.20592	62.3641	2.45528	33.3806	2.78172
		lb·mol	3771.398	37.2208	546.995	28287.9	1113.70	15141.2	1261.77
	°R	mol	4.619172	0.0455877	0.669954	34.6467	1.36404	18.5448	1.54540
		lb·mol	2095.221	20.6782	303.886	15715.5	618.720	8411.77	700.982
m^3	K	mol	0.008314510	0.0000820578	0.00120592	0.0623641	0.00245528	0.0333806	0.00278172
		lb·mol	3.771398	0.0372208	0.546995	28.2879	1.11370	15.1412	1.26177
	°R	mol	0.004619172	0.0000455877	0.000669954	0.0346467	0.00136404	0.0185448	0.00154540
		lb·mol	2.095221	0.0206782	0.303886	15.7155	0.618720	8.41177	0.700982

PERIODIC TABLE OF THE ELEMENTS

Key to Chart

Atomic Number	Symbol	1995 Atomic Weight	Electron Configuration	Oxidation States
50	Sn	118.710	-18-18-4	+2 +4

New Notation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Shell
Previous IUPAC Form	Group IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA			IB	IIB	IIIB	IVB	VB	VIB	VIIB	VIIIA	
CAS Version			IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA		
	1 H +1 -1 1.00794 1																	2 He 0 4.002602 2	K
	3 Li +1 6.941 2-1	4 Be +2 9.012182 2-2											5 B +3 10.811 2-3	6 C +2 +4 -4 12.0107 2-4	7 N +1 +2 +3 +4 +5 -1 -2 -3 14.00674 2-5	8 O -2 15.9994 2-6	9 F -1 18.9984032 2-7	10 Ne 0 20.1797 2-8	K-L
	11 Na +1 22.989770 2-8-1	12 Mg +2 24.3050 2-8-2											13 Al +3 26.981538 2-8-3	14 Si +2 +4 -4 28.0855 2-8-4	15 P +3 +5 -3 30.973761 2-8-5	16 S +4 +6 -2 32.066 2-8-6	17 Cl +1 +5 +7 -1 35.4527 2-8-7	18 Ar 0 39.948 2-8-8	K-L-M
	19 K +1 39.0983 -8-8-1	20 Ca +2 40.078 -8-8-2	21 Sc +3 44.955910 -8-9-2	22 Ti +2 +3 +4 47.867 -8-10-2	23 V +2 +3 +4 +5 50.9415 -8-11-2	24 Cr +2 +3 +6 51.9961 -8-13-1	25 Mn +2 +3 +4 +7 54.938049 -8-13-2	26 Fe +2 +3 55.845 -8-13-2	27 Co +2 +3 58.933200 -8-15-2	28 Ni +2 +3 58.6934 -8-16-2	29 Cu +1 +2 63.546 -8-18-1	30 Zn +2 65.39 -8-18-2	31 Ga +3 69.723 -8-18-3	32 Ge +2 +4 72.61 -8-18-4	33 As +3 +5 -3 74.92160 -8-18-5	34 Se +4 +6 -2 78.96 -8-18-6	35 Br +1 +5 -1 79.904 -8-18-7	36 Kr 0 83.80 -8-18-8	-L-M-N
	37 Rb +1 85.4678 -18-8-1	38 Sr +2 87.62 -18-8-2	39 Y +3 88.90585 -18-9-2	40 Zr +4 91.224 -18-10-2	41 Nb +3 +5 92.90638 -18-12-1	42 Mo +6 95.94 -18-13-1	43 Tc +4 +6 +7 (98) -18-13-2	44 Ru +3 101.07 -18-15-1	45 Rh +3 102.90550 -18-16-1	46 Pd +2 +3 106.42 -18-18-0	47 Ag +1 107.8682 -18-18-1	48 Cd +2 112.411 -18-18-2	49 In +3 114.818 -18-18-3	50 Sn +2 +4 118.710 -18-18 -4	51 Sb +3 +5 -3 121.760 -18-18-5	52 Te +4 +6 -2 127.60 -18-18-6	53 I +1 +5 +7 -1 126.90447 -18-18-7	54 Xe 0 131.29 -18-18-8	-M-N-O
	55 Cs +1 132.90545 -18-8-1	56 Ba +2 137.327 -18-8-2	57* La +3 138.9055 -18-9-2	72 Hf +4 178.49 -32-10-2	73 Ta +5 180.9479 -32-11-2	74 W +6 183.84 -32-12-2	75 Re +4 +6 +7 186.207 -32-13-2	76 Os +3 +4 190.23 -32-14-2	77 Ir +3 +4 192.217 -32-15-2	78 Pt +2 +4 195.078 -32-17-1	79 Au +1 +3 196.96655 -32-18-1	80 Hg +1 +2 200.59 -32-18-2	81 Tl +1 +3 204.3833 -32-18-3	82 Pb +2 +4 207.2 -32-18-4	83 Bi +3 +5 208.98038 -32-18-5	84 Po +2 +4 (209) -32-18-6	85 At (210) -32-18-7	86 Rn 0 (222) -32-18-8	-N-O-P
	87 Fr +1 (223) -18-8-1	88 Ra +2 (226) -18-8-2	89** Ac +3 (227) -18-9-2	104 Rf +4 (261) -32-10-2	105 Db (262) -32-11-2	106 Sg (263) -32-12-2	107 Bh (262) -32-13-2	108 Hs (265) -32-14-2	109 Mt (266) -32-15-2	110 Uun (269) -32-16-2	111 Uuu (272)	112 Uub							-O-P-Q

* Lanthanides	58 Ce +3 +4 140.116 -19-9-2	59 Pr +3 140.90765 -21-8-2	60 Nd +3 144.24 -22-8-2	61 Pm +3 (145) -23-8-2	62 Sm +2 +3 150.36 -24-8-2	63 Eu +2 +3 151.964 -25-8-2	64 Gd +3 157 .25 -25-9-2	65 Tb +3 158.92534 -27-8-2	66 Dy +3 162.50 -28-8-2	67 Ho +3 164.93032 -29-8-2	68 Er +3 167.26 -30-8-2	69 Tm +3 168.93421 -31-8-2	70 Yb +2 +3 173.04 -32-8-2	71 Lu +3 174.967 -32-9-2	-N-O-P
** Actinides	90 Th +4 232.0381 -18-10-2	91 Pa +5 +4 231.03588 -20-9-2	92 U +3 +4 +5 +6 238.0289 -21-9-2	93 Np +3 +4 +5 +6 (237) -22-9-2	94 Pu +3 +4 +5 +6 (244) -24-8-2	95 Am +3 +4 +5 +6 (243) -25-8-2	96 Cm +3 (247) -25-9-2	97 Bk +3 +4 (247) -27-8-2	98 Cf +3 (251) -28-8-2	99 Es +3 (252) -29-8-2	100 Fm +3 (257) -30-8-2	101 Md +2 +3 (258) -31-8-2	102 No +2 +3 (259) -32-8-2	103 Lr +3 (262) -32-9-2	-O-P-Q

The new IUPAC format numbers the groups from 1 to 18. The previous IUPAC numbering system and the system used by Chemical Abstracts Service (CAS) are also shown. For radioactive elements that do not occur in nature, the mass number of the most stable isotope is given in parentheses.

References

1. G. J. Leigh, Editor, *Nomenclature of Inorganic Chemistry*, Blackwell Scientific Publications, Oxford, 1990.
2. *Chemical and Engineering News*, 63(5), 27, 1985.
3. Atomic Weights of the Elements, 1995, *Pure & Appl. Chem.*, 68, 2339, 1996.

UNITS FOR MAGNETIC PROPERTIES

Quantity	Symbol	Gaussian & cgs emu [a]	Conversion factor, C [b]	SI & rationalized mks [c]
Magnetic flux density, magnetic induction	B	gauss (G) [d]	10^{-4}	tesla (T), Wb/m^2
Magnetic flux	Φ	maxwell (Mx), $G\cdot cm^2$	10^{-8}	weber (Wb), volt second (V·s)
Magnetic potential difference, magnetomotive force	U, F	gilbert (Gb)	$10/4\pi$	ampere (A)
Magnetic field strength, magnetizing force	H	oersted (Oe),[e] Gb/cm	$10^3/4\pi$	A/m [f]
(Volume) magnetization [g]	M	emu/cm^3 [h]	10^3	A/m
(Volume) magnetization	$4\pi M$	G	$10^3/4\pi$	A/m
Magnetic polarization, intensity of magnetization	J, I	emu/cm^3	$4\pi \times 10^{-4}$	T, Wb/m^2 [i]
(Mass) magnetization	σ, M	emu/g	1 $4\pi \times 10^{-7}$	$A\cdot m^2/kg$ Wb·m/kg
Magnetic moment	m	emu, erg/G	10^{-3}	$A\cdot m^2$, joule per tesla (J/T)
Magnetic dipole moment	j	emu, erg/G	$4\pi \times 10^{-10}$	Wb·m [i]
(Volume) susceptibility	χ, κ	dimensionless, emu/cm^3	4π $(4\pi)^2 \times 10^{-7}$	dimensionless henry per meter (H/m), Wb/(A·m)
(Mass) susceptibility	χ_ρ, κ_ρ	cm^3/g, emu/g	$4\pi \times 10^{-3}$ $(4\pi)^2 \times 10^{-10}$	m^3/kg $H\cdot m^2/kg$
(Molar) susceptibility	χ_{mol}, κ_{mol}	cm^3/mol, emu/mol	$4\pi \times 10^{-6}$ $(4\pi)^2 \times 10^{-13}$	m^3/mol $H\cdot m^2/mol$
Permeability	μ	dimensionless	$4\pi \times 10^{-7}$	H/m, Wb/(A·m)
Relative permeability [j]	μ_r	not defined		dimensionless
(Volume) energy density, energy product [k]	W	erg/cm^3	10^{-1}	J/m^3
Demagnetization factor	D, N	dimensionless	$1/4\pi$	dimensionless

a. Gaussian units and cgs emu are the same for magnetic properties. The defining relation is $B = H + 4\pi M$.
b. Multiply a number in Gaussian units by C to convert it to SI (e.g., $1\ G \times 10^{-4}\ T/G = 10^{-4}\ T$).
c. SI (*Système International d'Unités*) has been adopted by the National Bureau of Standards. Where two conversion factors are given, the upper one is recognized under, or consistent with, SI and is based on the definition $B = \mu_0(H + M)$, where $\mu_0 = 4\pi \times 10^{-7}$ H/m. The lower one is not recognized under SI and is based on the definition $B = \mu_0 H + J$, where the symbol I is often used in place of J.
d. 1 gauss $= 10^5$ gamma (γ).
e. Both oersted and gauss are expressed as $cm^{-1/2}\cdot g^{1/2}\cdot s^{-1}$ in terms of base units.
f. A/m was often expressed as "ampere-turn per meter" when used for magnetic field strength.
g. Magnetic moment per unit volume.
h. The designation "emu" is not a unit.
i. Recognized under SI, even though based on the definition $B = \mu_0 H + J$. See footnote *c*.
j. $\mu_r = \mu/\mu_0 = 1 + \chi$, all in SI. μ_r is equal to Gaussian μ.
k. $B\cdot H$ and $\mu_0 M\cdot H$ have SI units J/m^3; $M\cdot H$ and $B\cdot H/4\pi$ have Gaussian units erg/cm^3.

R. B. Goldfarb and F. R. Fickett, U.S. Department of Commerce, National Bureau of Standards, Boulder, Colorado 80303, March 1985
NBS Special Publication 696 For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402

SYMBOLS AND TERMINOLOGY FOR PHYSICAL AND CHEMICAL QUANTITIES

The International Organization for Standardization (ISO), International Union of Pure and Applied Chemistry (IUPAC), and the International Union of Pure and Applied Physics (IUPAP) have jointly developed a set of recommended symbols for physical and chemical quantities. Consistent use of these recommended symbols helps assure unambiguous scientific communication. The list below is reprinted from Reference 1 with permission from IUPAC. Full details may be found in the following references:

1. Ian Mills, Ed., *Quantities, Units, and Symbols in Physical Chemistry*, Blackwell Scientific Publications, Oxford, 1988.
2. E. R. Cohen and P. Giacomo, *Symbols, Units, Nomenclature, and Fundamental Constants in Physics*, Document IUPAP-25, 1987; also published in *Physica*, 146A, 1—68, 1987.
3. *ISO Standards Handbook 2: Units of Measurement*, International Organization of Standardization, Geneva, 1982.

GENERAL RULES

The value of a physical quantity is expressed as the product of a numerical value and a unit, e.g.:

$T = 300$ K
$V = 26.2$ cm^3
$C_p = 45.3$ J mol^{-1} K^{-1}

The symbol for a physical quantity is always given in italic (sloping) type, while symbols for units are given in roman type. Column headings in tables and axis labels on graphs may conveniently be written as the physical quantity symbol divided by the unit symbol, e.g.:

T/K
V/cm^3
C_p/J mol^{-1} K^{-1}

The values in the table or graph axis are then pure numbers.

Subscripts to symbols for physical quantities should be italic if the subscript refers to another physical quantity or to a number, e.g.:

C_p — heat capacity at constant pressure
B_n — nth virial coefficient

Subscripts which have other meanings should be in roman type:

m_{p} — mass of the proton
E_{k} — kinetic energy

The following tables give the recommended symbols for the major classes of physical and chemical quantities. The expression in the Definition column is given as an aid in identifying the quantity but is not necessarily the complete or unique definition. The SI Unit gives one (not necessarily unique) expression for the coherent SI unit for the quantity. Other equivalent unit expressions, including those which involve SI prefixes, may be used.

Name	*Symbol*	*Definition*	*SI unit*
SPACE AND TIME			
cartesian space coordinates	x, y, z		m
spherical polar coordinates	r, θ, ϕ		m, 1, 1
generalized coordinate	q, q_i		(varies)
position vector	$\boldsymbol{r}$	$\boldsymbol{r} = x\boldsymbol{i} + y\boldsymbol{j} + z\boldsymbol{k}$	m
length	l		m
special symbols:			
height	h		
breadth	b		
thickness	d, δ		
distance	d		

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Name	*Symbol*	*Definition*	*SI unit*
radius	r		
diameter	d		
path length	s		
length of arc	s		
area	A, A_s, S		m^2
volume	$V, (v)$		m^3
plane angle	$\alpha, \beta, \gamma, \theta, \phi \ldots$	$\alpha = s/r$	rad, 1
solid angle	ω, Ω	$\omega = A/r^2$	sr, 1
time	t		s
period	T	$T = t/N$	s
frequency	ν, f	$\nu = 1/T$	Hz
circular frequency, angular frequency	ω	$\omega = 2\pi\nu$	rad s^{-1}, s^{-1}
characteristic time interval, relaxation time, time constant	τ, T	$\tau = \lvert dt/d\ln x \rvert$	s
angular velocity	ω	$\omega = d\phi/dt$	rad s^{-1}, s^{-1}
velocity	$\boldsymbol{v}, \boldsymbol{u}, \boldsymbol{w}, \boldsymbol{c}, \dot{\boldsymbol{r}}$	$\boldsymbol{v} = d\boldsymbol{r}/dt$	m s^{-1}
speed	v, u, w, c	$v = \lvert \boldsymbol{v} \rvert$	m s^{-1}
acceleration	$\boldsymbol{a}, (g)$	$\boldsymbol{a} = d\boldsymbol{v}/dt$	m s^{-2}

CLASSICAL MECHANICS

Name	*Symbol*	*Definition*	*SI unit*
mass	m		kg
reduced mass	μ	$\mu = m_1 m_2/(m_1 + m_2)$	kg
density, mass density	ρ	$\rho = m/V$	kg m^{-3}
relative density	d	$d = \rho/\rho^{\circ}$	1
surface density	ρ_A, ρ_S	$\rho_A = m/A$	kg m^{-2}
specific volume	v	$v = V/m = 1/\rho$	m^3 kg^{-1}
momentum	$\boldsymbol{p}$	$\boldsymbol{p} = m\boldsymbol{v}$	kg m s^{-1}
angular momentum, action	$\boldsymbol{L}$	$\boldsymbol{L} = \boldsymbol{r} \times \boldsymbol{p}$	J s
moment of inertia	I, J	$I = \sum m_i r_i^2$	kg m^2
force	$\boldsymbol{F}$	$\boldsymbol{F} = d\boldsymbol{p}/dt = m\boldsymbol{a}$	N
torque, moment of a force	$\boldsymbol{T}, (\boldsymbol{M})$	$\boldsymbol{T} = \boldsymbol{r} \times \boldsymbol{F}$	N m
energy	E		J
potential energy	E_p, V, Φ	$E_p = -\int \boldsymbol{F} \cdot d\boldsymbol{s}$	J
kinetic energy	E_k, T, K	$E_k = \frac{1}{2}mv^2$	J
work	W, w	$W = \int \boldsymbol{F} \cdot d\boldsymbol{s}$	J
Hamilton function	H	$H(q, p) = T(q, p) + V(q)$	J
Lagrange function	L	$L(q, \dot{q}) = T(q, \dot{q}) - V(q)$	J

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Name	*Symbol*	*Definition*	*SI unit*
pressure	p, P	$p=F/A$	Pa, N m^{-2}
surface tension	γ, σ	$\gamma=dW/dA$	N m^{-1}, J m^{-2}
weight	$G, (W, P)$	$G=mg$	N
gravitational constant	G	$F=Gm_1 m_2/r^2$	N m^2 kg^{-2}
normal stress	σ	$\sigma=F/A$	Pa
shear stress	τ	$\tau=F/A$	Pa
linear strain, relative elongation	ε, e	$\varepsilon=\Delta l/l$	1
modulus of elasticity, Young's modulus	E	$E=\sigma/\varepsilon$	Pa
shear strain	γ	$\gamma=\Delta x/d$	1
shear modulus	G	$G=\tau/\gamma$	Pa
volume strain, bulk strain	θ	$\theta=\Delta V/V_0$	1
bulk modulus, compression modulus	K	$K=-V_0(dp/dV)$	Pa
viscosity, dynamic viscosity	η, μ	$\tau_{x,z}=\eta(dv_x/dz)$	Pa s
fluidity	ϕ	$\phi=1/\eta$	m kg^{-1} s
kinematic viscosity	ν	$\nu=\eta/\rho$	m^2 s^{-1}
friction coefficient	$\mu, (f)$	$F_{frict}=\mu F_{norm}$	1
power	P	$P=dW/dt$	W
sound energy flux	P, P_a	$P=dE/dt$	W
acoustic factors,			
reflection factor	ρ	$\rho=P_r/P_0$	1
acoustic absorption factor	$\alpha_a, (\alpha)$	$\alpha_a=1-\rho$	1
transmission factor	τ	$\tau=P_{tr}/P_0$	1
dissipation factor	δ	$\delta=\alpha_a-\tau$	1
		ELECTRICITY AND MAGNETISM	
quantity of electricity, electric charge	Q		C
charge density	ρ	$\rho=Q/V$	C m^{-3}
surface charge density	σ	$\sigma=Q/A$	C m^{-2}
electric potential	V, ϕ	$V=dW/dQ$	V, J C^{-1}
electric potential difference	$U, \Delta V, \Delta\phi$	$U=V_2-V_1$	V
electromotive force	E	$E=\int(\mathbf{F}/Q)\cdot d\mathbf{s}$	V
electric field strength	$\mathbf{E}$	$\mathbf{E}=\mathbf{F}/Q=-\text{grad } V$	V m^{-1}
electric flux	Ψ	$\Psi=\int \mathbf{D}\cdot d\mathbf{A}$	C
electric displacement	$\mathbf{D}$	$\mathbf{D}=\varepsilon\mathbf{E}$	C m^{-2}
capacitance	C	$C=Q/U$	F, C V^{-1}
permittivity	ε	$\mathbf{D}=\varepsilon\mathbf{E}$	F m^{-1}

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SYMBOLS AND TERMINOLOGY FOR PHYSICAL AND CHEMICAL QUANTITIES (continued)

Name	*Symbol*	*Definition*	*SI unit*
permittivity of vacuum	ε_0	$\varepsilon_0 = \mu_0^{-1} c_0^{-2}$	$\mathrm{F\,m^{-1}}$
relative permittivity	ε_r	$\varepsilon_r = \varepsilon/\varepsilon_0$	1
dielectric polarization (dipole moment per volume)	$\boldsymbol{P}$	$\boldsymbol{P} = \boldsymbol{D} - \varepsilon_0 \boldsymbol{E}$	$\mathrm{C\,m^{-2}}$
electric susceptibility	χ_e	$\chi_e = \varepsilon_r - 1$	1
electric dipole moment	$\boldsymbol{p}, \boldsymbol{\mu}$	$\boldsymbol{p} = Q\boldsymbol{r}$	C m
electric current	I	$I = \mathrm{d}Q/\mathrm{d}t$	A
electric current density	$\boldsymbol{j}, \boldsymbol{J}$	$I = \int \boldsymbol{j} \cdot \mathrm{d}\boldsymbol{A}$	$\mathrm{A\,m^{-2}}$
magnetic flux density, magnetic induction	$\boldsymbol{B}$	$\boldsymbol{F} = Q\boldsymbol{v} \times \boldsymbol{B}$	T
magnetic flux	Φ	$\Phi = \int \boldsymbol{B} \cdot \mathrm{d}\boldsymbol{A}$	Wb
magnetic field strength	$\boldsymbol{H}$	$\boldsymbol{B} = \mu \boldsymbol{H}$	$\mathrm{A\,m^{-1}}$
permeability	μ	$\boldsymbol{B} = \mu \boldsymbol{H}$	$\mathrm{N\,A^{-2}}$, $\mathrm{H\,m^{-1}}$
permeability of vacuum	μ_0		$\mathrm{H\,m^{-1}}$
relative permeability	μ_r	$\mu_r = \mu/\mu_0$	1
magnetization (magnetic dipole moment per volume)	$\boldsymbol{M}$	$\boldsymbol{M} = \boldsymbol{B}/\mu_0 - \boldsymbol{H}$	$\mathrm{A\,m^{-1}}$
magnetic susceptibility	$\chi, \kappa, (\chi_m)$	$\chi = \mu_r - 1$	1
molar magnetic susceptibility	χ_m	$\chi_m = V_m \chi$	$\mathrm{m^3\,mol^{-1}}$
magnetic dipole moment	$\boldsymbol{m}, \boldsymbol{\mu}$	$E_p = -\boldsymbol{m} \cdot \boldsymbol{B}$	$\mathrm{A\,m^2}$, $\mathrm{J\,T^{-1}}$
electrical resistance	R	$R = U/I$	Ω
conductance	G	$G = 1/R$	S
loss angle	δ	$\delta = (\pi/2) + \phi_I - \phi_U$	1, rad
reactance	X	$X = (U/I)\sin\delta$	Ω
impedance (complex impedance)	Z	$Z = R + \mathrm{i}X$	Ω
admittance (complex admittance)	Y	$Y = 1/Z$	S
susceptance	B	$Y = G + \mathrm{i}B$	S
resistivity	ρ	$\rho = E/j$	Ω m
conductivity	κ, γ, σ	$\kappa = 1/\rho$	$\mathrm{S\,m^{-1}}$
self-inductance	L	$E = -L(\mathrm{d}I/\mathrm{d}t)$	H
mutual inductance	M, L_{12}	$E_1 = L_{12}(\mathrm{d}I_2/\mathrm{d}t)$	H
magnetic vector potential	$\boldsymbol{A}$	$\boldsymbol{B} = \nabla \times \boldsymbol{A}$	$\mathrm{Wb\,m^{-1}}$
Poynting vector	$\boldsymbol{S}$	$\boldsymbol{S} = \boldsymbol{E} \times \boldsymbol{H}$	$\mathrm{W\,m^{-2}}$

QUANTUM MECHANICS

Name	*Symbol*	*Definition*	*SI unit*
momentum operator	$\hat{p}$	$\hat{p} = -\mathrm{i}\hbar\nabla$	$\mathrm{m^{-1}\,J\,s}$
kinetic energy operator	$\hat{T}$	$\hat{T} = -(\hbar^2/2m)\nabla^2$	J

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Name	*Symbol*	*Definition*	*SI unit*
hamiltonian operator	$\hat{H}$	$\hat{H}=\hat{T}+V$	J
wavefunction, state function	Ψ, ψ, ϕ	$\hat{H}\psi=E\psi$	($m^{-3/2}$)
probability density	P	$P=\psi^*\psi$	(m^{-3})
charge density of electrons	ρ	$\rho=-eP$	($C\ m^{-3}$)
probability current density	S	$S=-i\hbar(\psi^*\nabla\psi-\psi\nabla\psi^*)/2m_e$	($m^{-2}\ s^{-1}$)
electric current density of electrons	j	$j=-eS$	($A\ m^{-2}$)
matrix element of operator $\hat{A}$	$A_{ij}, \langle i\|\hat{A}\|j\rangle$	$A_{ij}=\int\psi_i^*\hat{A}\psi_j\mathrm{d}\tau$	(varies)
expectation value of operator $\hat{A}$	$\langle A\rangle, \bar{A}$	$\langle A\rangle=\int\psi^*\hat{A}\psi\mathrm{d}\tau$	(varies)
hermitian conjugate of $\hat{A}$	$\hat{A}^\dagger$	$(\hat{A}^\dagger)_{ij}=(A_{ji})^*$	(varies)
commutator of $\hat{A}$ and $\hat{B}$	$[\hat{A},\hat{B}], [\hat{A},\hat{B}]_-$	$[\hat{A},\hat{B}]=\hat{A}\hat{B}-\hat{B}\hat{A}$	(varies)
anticommutator	$[\hat{A},\hat{B}]_+$	$[\hat{A},\hat{B}]_+=\hat{A}\hat{B}+\hat{B}\hat{A}$	(varies)
spin wavefunction	$\alpha; \beta$		1
coulomb integral	H_{AA}	$H_{AA}=\int\psi_A{}^*\hat{H}\psi_A\mathrm{d}\tau$	J
resonance integral	H_{AB}	$H_{AB}=\int\psi_A{}^*\hat{H}\psi_B\mathrm{d}\tau$	J
overlap integral	S_{AB}	$S_{AB}=\int\psi_A{}^*\psi_B\mathrm{d}\tau$	1

ATOMS AND MOLECULES

nucleon number, mass number	A		1
proton number, atomic number	Z		1
neutron number	N	$N=A-Z$	1
electron rest mass	m_e		kg
mass of atom, atomic mass	m_a, m		kg
atomic mass constant	m_u	$m_u=m_a(^{12}C)/12$	kg
mass excess	Δ	$\Delta=m_a-Am_u$	kg
elementary charge, proton charge	e		C
Planck constant	h		J s
Planck constant/2π	$\hbar$	$\hbar=h/2\pi$	J s
Bohr radius	a_0	$a_0=4\pi\varepsilon_0\hbar^2/m_ee^2$	m
Hartree energy	E_h	$E_h=\hbar^2/m_ea_0{}^2$	J
Rydberg constant	R_∞	$R_\infty=E_h/2hc$	m^{-1}
fine structure constant	α	$\alpha=e^2/4\pi\varepsilon_0\hbar c$	1
ionization energy	E_i		J

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Name	*Symbol*	*Definition*	*SI unit*
electron affinity	E_{ea}		J
dissociation energy	E_d, D		J
from the ground state	D_0		J
from the potential minimum	D_e		J
principal quantum number (H atom)	n	$E = -hcR/n^2$	1
angular momentum quantum numbers	see under Spectroscopy		
magnetic dipole moment of a molecule	$\boldsymbol{m}$, $\boldsymbol{\mu}$	$E_p = -\boldsymbol{m} \cdot \boldsymbol{B}$	$J\,T^{-1}$
magnetizability of a molecule	ξ	$\boldsymbol{m} = \xi \boldsymbol{B}$	$J\,T^{-2}$
Bohr magneton	μ_B	$\mu_B = e\hbar/2m_e$	$J\,T^{-1}$
nuclear magneton	μ_N	$\mu_N = (m_e/m_p)\mu_B$	$J\,T^{-1}$
magnetogyric ratio (gyromagnetic ratio)	γ	$\gamma = \mu/L$	$C\,kg^{-1}$
g factor	g		1
Larmor circular frequency	ω_L	$\omega_L = (e/2m)B$	s^{-1}
Larmor frequency	ν_L	$\nu_L = \omega_L/2\pi$	Hz
longitudinal relaxation time	T_1		s
transverse relaxation time	T_2		s
electric dipole moment of a molecule	$\boldsymbol{p}$, $\boldsymbol{\mu}$	$E_p = -\boldsymbol{p} \cdot \boldsymbol{E}$	C m
quadrupole moment of a molecule	$\boldsymbol{Q}$; $\boldsymbol{\Theta}$	$E_p = \frac{1}{2}\boldsymbol{Q} : \boldsymbol{V}'' = \frac{1}{3}\boldsymbol{\Theta} : \boldsymbol{V}''$	$C\,m^2$
quadrupole moment of a nucleus	eQ	$eQ = 2\langle\Theta_{zz}\rangle$	$C\,m^2$
electric field gradient tensor	$\boldsymbol{q}$	$q_{\alpha\beta} = -\partial^2 V/\partial\alpha\partial\beta$	$V\,m^{-2}$
quadrupole interaction energy tensor	$\boldsymbol{\chi}$	$\chi_{\alpha\beta} = eQq_{\alpha\beta}$	J
electric polarizability of a molecule	α	p (induced) $= \alpha E$	$C\,m^2\,V^{-1}$
activity (of a radioactive substance)	A	$A = -dN_B/dt$	Bq
decay (rate) constant, disintegration (rate) constant	λ	$A = \lambda N_B$	s^{-1}
half life	$t_{\frac{1}{2}}$, $T_{\frac{1}{2}}$		s
mean life	τ		s
level width	Γ	$\Gamma = \hbar/\tau$	J

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Name	*Symbol*	*Definition*	*SI unit*
disintegration energy	Q		J
cross section (of a nuclear reaction)	σ		m^2
SPECTROSCOPY			
total term	T	$T = E_{tot}/hc$	m^{-1}
transition wavenumber	$\tilde{\nu}, (\nu)$	$\tilde{\nu} = T' - T''$	m^{-1}
transition frequency	ν	$\nu = (E' - E'')/h$	Hz
electronic term	T_e	$T_e = E_e/hc$	m^{-1}
vibrational term	G	$G = E_{vib}/hc$	m^{-1}
rotational term	F	$F = E_{rot}/hc$	m^{-1}
spin orbit coupling constant	A	$T_{s.o.} = A\langle \hat{L} \cdot \hat{S} \rangle$	m^{-1}
principal moments of inertia	$I_A; I_B; I_C$	$I_A \leqslant I_B \leqslant I_C$	$kg\ m^2$
rotational constants,			
in wavenumber	$\tilde{A}; \tilde{B}; \tilde{C}$	$\tilde{A} = h/8\pi^2 c I_A$	m^{-1}
in frequency	$A; B; C$	$A = h/8\pi^2 I_A$	Hz
inertial defect	Δ	$\Delta = I_C - I_A - I_B$	$kg\ m^2$
asymmetry parameter	κ	$\kappa = \dfrac{(2B - A - C)}{(A - C)}$	1
centrifugal distortion constants,			
S reduction	$D_J; D_{JK}; D_K; d_1; d_2$		m^{-1}
A reduction	$\Delta_J; \Delta_{JK}; \Delta_K; \delta_J; \delta_K$		m^{-1}
harmonic vibration wavenumber	$\omega_e; \omega_r$		m^{-1}
vibrational anharmonicity constant	$\omega_e x_e; x_{rs}; g_{tt'}$		m^{-1}
vibrational quantum numbers	$v_r; l_t$		1
Coriolis zeta constant	ζ_{rs}^{α}		1
angular momentum quantum numbers	see additional information below		
degeneracy, statistical weight	g, d, β		1
electric dipole moment of a molecule	p, μ	$E_p = -p \cdot E$	C m
transition dipole moment of a molecule	M, R	$M = \int \psi' p \psi'' d\tau$	C m
molecular geometry, interatomic distances,			
equilibrium distance	r_e		m
zero-point average distance	r_z		m
ground state distance	r_0		m

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Name	*Symbol*	*Definition*	*SI unit*
substitution structure distance	r_s		m
vibrational coordinates,			
internal coordinates	R_i, r_i, θ_j, etc.		(varies)
symmetry coordinates	S_i		(varies)
normal coordinates			
mass adjusted	Q_r		$kg^{\frac{1}{2}}$ m
dimensionless	q_r		1
vibrational force constants,			
diatomic	f, (k)	$f = \partial^2 V/\partial r^2$	$J\ m^{-2}$
polyatomic,			
internal coordinates	f_{ij}	$f_{ij} = \partial^2 V/\partial r_i \partial r_j$	(varies)
symmetry coordinates	F_{ij}	$F_{ij} = \partial^2 V/\partial S_i \partial S_j$	(varies)
dimensionless normal coordinates	$\phi_{rst\ldots}$, $k_{rst\ldots}$		m^{-1}
nuclear magnetic resonance (NMR),			
magnetogyric ratio	γ	$\gamma = \mu/I\hbar$	$C\ kg^{-1}$
shielding constant	σ_A	$B_A = (1-\sigma_A)B$	1
chemical shift, δ scale	δ	$\delta = 10^6(\nu - \nu_0)/\nu_0$	1
(indirect) spin–spin coupling constant	J_{AB}	$\hat{H}/h = J_{AB}\hat{I}_A \cdot \hat{I}_B$	Hz
direct (dipolar) coupling constant	D_{AB}		Hz
longitudinal relaxation time	T_1		s
transverse relaxation time	T_2		s
electron spin resonance, electron paramagnetic resonance (ESR, EPR),			
magnetogyric ratio	γ	$\gamma = \mu/s\hbar$	$C\ kg^{-1}$
g factor	g	$h\nu = g\mu_B B$	1
hyperfine coupling constant,			
in liquids	a, A	$\hat{H}_{hfs}/h = a\hat{S}\cdot\hat{I}$	Hz
in solids	T	$\hat{H}_{hfs}/h = \hat{S}\cdot T\cdot\hat{I}$	Hz

Angular momentum	*Operator symbol*	*Quantum number symbol Total*	*Z-axis*	*z-axis*
electron orbital	$\hat{L}$	L	M_L	Λ
one electron only	$\hat{l}$	l	m_l	λ

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Angular momentum	Operator symbol	Quantum number symbol Total	Z-axis	z-axis
electron spin	$\hat{S}$	S	M_S	Σ
one electron only	$\hat{s}$	s	m_s	σ
electron orbital + spin	$\hat{L}+\hat{S}$			$\Omega=\Lambda+\Sigma$
nuclear orbital (rotational)	$\hat{R}$	R		K_R, k_R
nuclear spin	$\hat{I}$	I	M_I	
internal vibrational				
spherical top	$\hat{l}$	$l(l\zeta)$		K_l
other	$\hat{j}$, $\hat{\pi}$			$l(l\zeta)$
sum of $R+L(+j)$	$\hat{N}$	N		K, k
sum of $N+S$	$\hat{J}$	J	M_J	K, k
sum of $J+I$	$\hat{F}$	F	M_F	

ELECTROMAGNETIC RADIATION

Name	Symbol	Definition	SI unit
wavelength	λ		m
speed of light			
in vacuum	c_0		$m\ s^{-1}$
in a medium	c	$c=c_0/n$	$m\ s^{-1}$
wavenumber in vacuum	$\tilde{\nu}$	$\tilde{\nu}=\nu/c_0=1/n\lambda$	m^{-1}
wavenumber (in a medium)	σ	$\sigma=1/\lambda$	m^{-1}
frequency	ν	$\nu=c/\lambda$	Hz
circular frequency, pulsatance	ω	$\omega=2\pi\nu$	s^{-1}, rad s^{-1}
refractive index	n	$n=c_0/c$	1
Planck constant	h		J s
Planck constant/2π	$\hbar$	$\hbar=h/2\pi$	J s
radiant energy	Q, W		J
radiant energy density	ρ, w	$\rho=Q/V$	$J\ m^{-3}$
spectral radiant energy density			
in terms of frequency	ρ_ν, w_ν	$\rho_\nu=d\rho/d\nu$	$J\ m^{-3}\ Hz^{-1}$
in terms of wavenumber	$\rho_{\tilde{\nu}}$, $w_{\tilde{\nu}}$	$\rho_{\tilde{\nu}}=d\rho/d\tilde{\nu}$	$J\ m^{-2}$
in terms of wavelenglth	ρ_λ, w_λ	$\rho_\lambda=d\rho/d\lambda$	$J\ m^{-4}$
Einstein transition probabilities			
spontaneous emission	A_{nm}	$dN_n/dt=-A_{nm}N_n$	s^{-1}
stimulated emission	B_{nm}	$dN_n/dt=-\rho_{\tilde{\nu}}(\tilde{\nu}_{nm})\times B_{nm}N_n$	$s\ kg^{-1}$
stimulated absorption	B_{mn}	$dN_n/dt=\rho_{\tilde{\nu}}(\tilde{\nu}_{nm})B_{mn}N_m$	$s\ kg^{-1}$
radiant power, radiant energy per time	Φ, P	$\Phi=dQ/dt$	W

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Name	*Symbol*	*Definition*	*SI unit*
radiant intensity	I	$I = \mathrm{d}\Phi/\mathrm{d}\Omega$	$\mathrm{W\ sr^{-1}}$
radiant exitance, (emitted radiant flux)	M	$M = \mathrm{d}\Phi/\mathrm{d}A_{\mathrm{source}}$	$\mathrm{W\ m^{-2}}$
irradiance, (radiant flux received)	E, (I)	$E = \mathrm{d}\Phi/\mathrm{d}A$	$\mathrm{W\ m^{-2}}$
emittance	ε	$\varepsilon = M/M_{\mathrm{bb}}$	1
Stefan–Boltzmann constant	σ	$M_{\mathrm{bb}} = \sigma T^4$	$\mathrm{W\ m^{-2}\ K^{-4}}$
first radiation constant	c_1	$c_1 = 2\pi h c_0{}^2$	$\mathrm{W\ m^2}$
second radiation constant	c_2	$c_2 = hc_0/k$	K m
transmittance, transmission factor	τ, T	$\tau = \Phi_{\mathrm{tr}}/\Phi_0$	1
absorptance, absorption factor	α	$\alpha = \Phi_{\mathrm{abs}}/\Phi_0$	1
reflectance, reflection factor	ρ	$\rho = \Phi_{\mathrm{refl}}/\Phi_0$	1
(decadic) absorbance	A	$A = -\lg(1-\alpha_{\mathrm{i}})$	1
napierian absorbance	B	$B = -\ln(1-\alpha_{\mathrm{i}})$	1
absorption coefficient			
(linear) decadic	a, K	$a = A/l$	$\mathrm{m^{-1}}$
(linear) napierian	α	$\alpha = B/l$	$\mathrm{m^{-1}}$
molar (decadic)	ε	$\varepsilon = a/c = A/cl$	$\mathrm{m^2\ mol^{-1}}$
molar napierian	κ	$\kappa = \alpha/c = B/cl$	$\mathrm{m^2\ mol^{-1}}$
absorption index	k	$k = \alpha/4\pi\tilde{\nu}$	1
complex refractive index	$\hat{n}$	$\hat{n} = n + \mathrm{i}k$	1
molar refraction	R, R_{m}	$R = \dfrac{(n^2-1)}{(n^2+2)} V_{\mathrm{m}}$	$\mathrm{m^3\ mol^{-1}}$
angle of optical rotation	α		1, rad

SOLID STATE

Name	*Symbol*	*Definition*	*SI unit*
lattice vector	$\boldsymbol{R}$, $\boldsymbol{R}_0$		m
fundamental translation vectors for the crystal lattice	$\boldsymbol{a}_1$; $\boldsymbol{a}_2$; $\boldsymbol{a}_3$, $\boldsymbol{a}$; $\boldsymbol{b}$; $\boldsymbol{c}$	$\boldsymbol{R} = n_1\boldsymbol{a}_1 + n_2\boldsymbol{a}_2 + n_3\boldsymbol{a}_3$	m
(circular) reciprocal lattice vector	$\boldsymbol{G}$	$\boldsymbol{G} \cdot \boldsymbol{R} = 2\pi m$	$\mathrm{m^{-1}}$
(circular) fundamental translation vectors for the reciprocal lattice	$\boldsymbol{b}_1$; $\boldsymbol{b}_2$; $\boldsymbol{b}_3$, $\boldsymbol{a}^*$; $\boldsymbol{b}^*$; $\boldsymbol{c}^*$	$\boldsymbol{a}_i \cdot \boldsymbol{b}_k = 2\pi\delta_{ik}$	$\mathrm{m^{-1}}$
lattice plane spacing	d		m
Bragg angle	θ	$n\lambda = 2d\sin\theta$	1, rad

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Name	*Symbol*	*Definition*	*SI unit*
order of reflection	n		1
order parameters			
short range	σ		1
long range	s		1
Burgers vector	$\boldsymbol{b}$		m
particle position vector	$\boldsymbol{r}, \boldsymbol{R}_j$		m
equilibrium position vector of an ion	$\boldsymbol{R}_0$		m
displacement vector of an ion	$\boldsymbol{u}$	$\boldsymbol{u} = \boldsymbol{R} - \boldsymbol{R}_0$	m
Debye–Waller factor	B, D		1
Debye circular wavenumber	q_D		m^{-1}
Debye circular frequency	ω_D		s^{-1}
Grüneisen parameter	γ, Γ	$\gamma = \alpha V/\kappa C_V$	1
Madelung constant	$\alpha, \mathcal{M}$	$E_{coul} = \dfrac{\alpha N_A z_+ z_- e^2}{4\pi\varepsilon_0 R_0}$	1
density of states	N_E	$N_E = dN(E)/dE$	$J^{-1}\ m^{-3}$
(spectral) density of vibrational modes	N_ω, g	$N_\omega = dN(\omega)/d\omega$	$s\ m^{-3}$
resistivity tensor	ρ_{ik}	$\boldsymbol{E} = \boldsymbol{\rho} \cdot \boldsymbol{j}$	$\Omega\ m$
conductivity tensor	σ_{ik}	$\boldsymbol{\sigma} = \boldsymbol{\rho}^{-1}$	$S\ m^{-1}$
thermal conductivity tensor	λ_{ik}	$\boldsymbol{J}_q = -\boldsymbol{\lambda} \cdot \text{grad}\ T$	$W\ m^{-1}\ K^{-1}$
residual resistivity	ρ_R		$\Omega\ m$
relaxation time	τ	$\tau = l/v_F$	s
Lorenz coefficient	L	$L = \lambda/\sigma T$	$V^2\ K^{-2}$
Hall coefficient	A_H, R_H	$\boldsymbol{E} = \boldsymbol{\rho} \cdot \boldsymbol{j} + R_H(\boldsymbol{B} \times \boldsymbol{j})$	$m^3\ C^{-1}$
thermoelectric force	E		V
Peltier coefficient	Π		V
Thomson coefficient	$\mu, (\tau)$		$V\ K^{-1}$
work function	Φ	$\Phi = E_\infty - E_F$	J
number density, number concentration	$n, (p)$		m^{-3}
gap energy	E_g		J
donor ionization energy	E_d		J
acceptor ionization energy	E_a		J
Fermi energy	E_F, ε_F		J
circular wave vector, propagation vector	$\boldsymbol{k}, \boldsymbol{q}$	$k = 2\pi/\lambda$	m^{-1}
Bloch function	$u_k(\boldsymbol{r})$	$\psi(\boldsymbol{r}) = u_k(\boldsymbol{r}) \exp(i\boldsymbol{k} \cdot \boldsymbol{r})$	$m^{-3/2}$
charge density of electrons	ρ	$\rho(\boldsymbol{r}) = -e\psi^*(\boldsymbol{r})\psi(\boldsymbol{r})$	$C\ m^{-3}$

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Name	*Symbol*	*Definition*	*SI unit*
effective mass	m^*		kg
mobility	μ	$\mu = v_{\mathrm{drift}}/E$	$\mathrm{m^2\,V^{-1}\,s^{-1}}$
mobility ratio	b	$b = \mu_n/\mu_p$	1
diffusion coefficient	D	$\mathrm{d}N/\mathrm{d}t = -DA(\mathrm{d}n/\mathrm{d}x)$	$\mathrm{m^2\,s^{-1}}$
diffusion length	L	$L = \sqrt{D\tau}$	m
characteristic (Weiss) temperature	θ, θ_W		K
Curie temperature	T_C		K
Néel temperature	T_N		K
	STATISTICAL THERMODYNAMICS		
number of entities	N		1
number density of entities, number concentration	n, C	$n = N/V$	$\mathrm{m^{-3}}$
Avogadro constant	L, N_A		$\mathrm{mol^{-1}}$
Boltzmann constant	k, k_B		$\mathrm{J\,K^{-1}}$
gas constant (molar)	R	$R = Lk$	$\mathrm{J\,K^{-1}\,mol^{-1}}$
molecular position vector	$\boldsymbol{r}\ (x, y, z)$		m
molecular velocity vector	$\boldsymbol{c}(c_x, c_y, c_z)$, $\boldsymbol{u}(u_x, u_y, u_z)$	$\boldsymbol{c} = \mathrm{d}\boldsymbol{r}/\mathrm{d}t$	$\mathrm{m\,s^{-1}}$
molecular momentum vector	$\boldsymbol{p}(p_x, p_y, p_z)$	$\boldsymbol{p} = m\boldsymbol{c}$	$\mathrm{kg\,m\,s^{-1}}$
velocity distribution function (Maxwell)	$f(c_x)$	$f(c_x) = (m/2\pi kT)^{\frac{1}{2}} \times \exp(-mc_x^2/2kT)$	$\mathrm{m^{-1}\,s}$
speed distribution function (Maxwell–Boltzmann)	$F(c)$	$F(c) = (m/2\pi kT)^{3/2} \times 4\pi c^2 \exp(-mc^2/2kT)$	$\mathrm{m^{-1}\,s}$
average speed	$\bar{c}$, $\bar{u}$, $\langle c \rangle$, $\langle u \rangle$	$\bar{c} = \int cF(c)\mathrm{d}c$	$\mathrm{m\,s^{-1}}$
generalized coordinate	q		(m)
generalized momentum	p	$p = \partial L/\partial \dot{q}$	$(\mathrm{kg\,m\,s^{-1}})$
volume in phase space	Ω	$\Omega = (1/h)\int p\,\mathrm{d}q$	1
probability	P		1
statistical weight, degeneracy	g, d, W, ω, β		1
density of states	$\rho(E)$	$\rho(E) = \mathrm{d}N/\mathrm{d}E$	$\mathrm{J^{-1}}$
partition function, sum over states,			
for a single molecule	q, z	$q = \sum_i g_i \exp(-\varepsilon_i/kT)$	1
for a canonical ensemble (system, or assembly)	Q, Z		1

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Name	*Symbol*	*Definition*	*SI unit*
microcanonical ensemble	Ω		1
grand (canonical ensemble)	Ξ		1
symmetry number	σ, s		1
reciprocal temperature parameter	β	$\beta = 1/kT$	J^{-1}
characteristic temperature	Θ		K

GENERAL CHEMISTRY

Name	*Symbol*	*Definition*	*SI unit*
number of entities (e.g. molecules, atoms, ions, formula units)	N		1
amount (of substance)	n	$n_B = N_B/L$	mol
Avogadro constant	L, N_A		mol^{-1}
mass of atom, atomic mass	m_a, m		kg
mass of entity (molecule, or formula unit)	m_f, m		kg
atomic mass constant	m_u	$m_u = m_a(^{12}C)/12$	kg
molar mass	M	$M_B = m/n_B$	$kg\ mol^{-1}$
relative molecular mass (relative molar mass, molecular weight)	M_r	$M_{r,B} = m_B/m_u$	1
molar volume	V_m	$V_{m,B} = V/n_B$	$m^3\ mol^{-1}$
mass fraction	w	$w_B = m_B/\Sigma m_i$	1
volume fraction	ϕ	$\phi_B = V_B/\Sigma V_i$	1
mole fraction, amount fraction, number fraction	x, y	$x_B = n_B/\Sigma n_i$	1
(total) pressure	p, P		Pa
partial pressure	p_B	$p_B = y_B p$	Pa
mass concentration (mass density)	γ, ρ	$\gamma_B = m_B/V$	$kg\ m^{-3}$
number concentration, number density of entities	C, n	$C_B = N_B/V$	m^{-3}
amount concentration, concentration	c	$c_B = n_B/V$	$mol\ m^{-3}$
solubility	s	$s_B = c_B$ (saturated solution)	$mol\ m^{-3}$
molality (of a solute)	m, (b)	$m_B = n_B/m_A$	$mol\ kg^{-1}$

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Name	*Symbol*	*Definition*	*SI unit*
surface concentration	Γ	$\Gamma_B = n_B/A$	$mol\ m^{-2}$
stoichiometric number	ν		1
extent of reaction, advancement	ξ	$\Delta\xi = \Delta n_B/\nu_B$	mol
degree of dissociation	α		1
	CHEMICAL THERMODYNAMICS		
heat	q, Q		J
work	w, W		J
internal energy	U	$\Delta U = q + w$	J
enthalpy	H	$H = U + pV$	J
thermodynamic temperature	T		K
Celsius temperature	θ, t	$\theta/°C = T/K - 273.15$	°C
entropy	S	$dS \geqslant dq/T$	$J\ K^{-1}$
Helmholtz energy, (Helmholtz function)	A	$A = U - TS$	J
Gibbs energy, (Gibbs function)	G	$G = H - TS$	J
Massieu function	J	$J = -A/T$	$J\ K^{-1}$
Planck function	Y	$Y = -G/T$	$J\ K^{-1}$
surface tension	γ, σ	$\gamma = (\partial G/\partial A_s)_{T,p}$	$J\ m^{-2}, N\ m^{-1}$
molar quantity X	X_m	$X_m = X/n$	(varies)
specific quantity X	x	$x = X/m$	(varies)
pressure coefficient	β	$\beta = (\partial p/\partial T)_V$	$Pa\ K^{-1}$
relative pressure coefficient	α_p	$\alpha_p = (1/p)(\partial p/\partial T)_V$	K^{-1}
compressibility,			
isothermal	κ_T	$\kappa_T = -(1/V)(\partial V/\partial p)_T$	Pa^{-1}
isentropic	κ_S	$\kappa_S = -(1/V)(\partial V/\partial p)_S$	Pa^{-1}
linear expansion coefficient	α_l	$\alpha_l = (1/l)(\partial l/\partial T)$	K^{-1}
cubic expansion coefficient	α, α_V, γ	$\alpha = (1/V)(\partial V/\partial T)_p$	K^{-1}
heat capacity,			
at constant pressure	C_p	$C_p = (\partial H/\partial T)_p$	$J\ K^{-1}$
at constant volume	C_V	$C_V = (\partial U/\partial T)_V$	$J\ K^{-1}$
ratio of heat capacities	$\gamma, (\kappa)$	$\gamma = C_p/C_V$	1
Joule–Thomson coefficient	μ, μ_{JT}	$\mu = (\partial T/\partial p)_H$	$K\ Pa^{-1}$
second virial coefficient	B	$pV_m = RT(1 + B/V_m + \cdots)$	$m^3\ mol^{-1}$
compression factor (compressibility factor)	Z	$Z = pV_m/RT$	1

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SYMBOLS AND TERMINOLOGY FOR PHYSICAL AND CHEMICAL QUANTITIES (continued)

Name	*Symbol*	*Definition*	*SI unit*
partial molar quantity X	X_B, (X'_B)	$X_B = (\partial X/\partial n_B)_{T,p,n_{j\neq B}}$	(varies)
chemical potential (partial molar Gibbs energy)	μ	$\mu_B = (\partial G/\partial n_B)_{T,p,n_{j\neq B}}$	$J\,mol^{-1}$
absolute activity	λ	$\lambda_B = \exp(\mu_B/RT)$	1
standard chemical potential	μ°, μ^o		$J\,mol^{-1}$
standard partial molar enthalpy	$H_B{}^\circ$	$H_B{}^\circ = \mu_B{}^\circ + TS_B{}^\circ$	$J\,mol^{-1}$
standard partial molar entropy	$S_B{}^\circ$	$S_B{}^\circ = -(\partial\mu_B{}^\circ/\partial T)_p$	$J\,mol^{-1}\,K^{-1}$
standard reaction Gibbs energy (function)	$\Delta_r G^\circ$	$\Delta_r G^\circ = \sum_B \nu_B \mu_B{}^\circ$	$J\,mol^{-1}$
affinity of reaction	A, $(\mathcal{A})$	$A = -(\partial G/\partial\xi)_{p,T} = -\sum_B \nu_B\mu_B$	$J\,mol^{-1}$
standard reaction enthalpy	$\Delta_r H^\circ$	$\Delta_r H^\circ = \sum_B \nu_B H_B{}^\circ$	$J\,mol^{-1}$
standard reaction entropy	$\Delta_r S^\circ$	$\Delta_r S^\circ = \sum_B \nu_B S_B{}^\circ$	$J\,mol^{-1}\,K^{-1}$
equilibrium constant	K°, K	$K^\circ = \exp(-\Delta_r G^\circ/RT)$	1
equilibrium constant,			
pressure basis	K_p	$K_p = \prod_B p_B{}^{\nu_B}$	$Pa^{\Sigma\nu}$
concentration basis	K_c	$K_c = \prod_B c_B{}^{\nu_B}$	$(mol\,m^{-3})^{\Sigma\nu}$
molality basis	K_m	$K_m = \prod_B m_B{}^{\nu_B}$	$(mol\,kg^{-1})^{\Sigma\nu}$
fugacity	f, $\tilde{p}$	$f_B = \lambda_B \lim_{p\to 0}(p_B/\lambda_B)_T$	Pa
fugacity coefficient	ϕ	$\phi_B = f_B/p_B$	1
activity and activity coefficient referenced to Raoult's law,			
(relative) activity	a	$a_B = \exp\left[\frac{\mu_B - \mu_B{}^*}{RT}\right]$	1
activity coefficient	f	$f_B = a_B/x_B$	1
activities and activity coefficients referenced to Henry's law, (relative) activity,			
molality basis	a_m	$a_{m,B} = \exp\left[\frac{\mu_B - \mu_B{}^\circ}{RT}\right]$	1
concentration basis	a_c	$a_{c,B} = \exp\left[\frac{\mu_B - \mu_B{}^\circ}{RT}\right]$	1

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Name	*Symbol*	*Definition*	*SI Unit*
mole fraction basis	a_x	$a_{x,\mathrm{B}} = \exp\left[\frac{\mu_\mathrm{B} - \mu_\mathrm{B}^*}{RT}\right]$	1
activity coefficient,			
molality basis	γ_m	$a_{m,\mathrm{B}} = \gamma_{m,\mathrm{B}} m_\mathrm{B}/m^\ominus$	1
concentration basis	γ_c	$a_{c,\mathrm{B}} = \gamma_{c,\mathrm{B}} c_\mathrm{B}/c^\ominus$	1
mole fraction basis	γ_x	$a_{x,\mathrm{B}} = \gamma_{x,\mathrm{B}} x_\mathrm{B}$	1
ionic strength,			
molality basis	I_m, I	$I_m = \frac{1}{2}\Sigma m_\mathrm{B} z_\mathrm{B}^2$	$\mathrm{mol\,kg^{-1}}$
concentration basis	I_c, I	$I_c = \frac{1}{2}\Sigma c_\mathrm{B} z_\mathrm{B}^2$	$\mathrm{mol\,m^{-3}}$
osmotic coefficient,			
molality basis	ϕ_m	$\phi_m = (\mu_\mathrm{A}^* - \mu_\mathrm{A})/(RTM_\mathrm{A}\Sigma m_\mathrm{B})$	1
mole fraction basis	ϕ_x	$\phi_x = (\mu_\mathrm{A} - \mu_\mathrm{A}^*)/(RT \ln x_\mathrm{A})$	1
osmotic pressure	Π	$\Pi = c_\mathrm{B} RT$ (ideal dilute solution)	Pa

(i) *Symbols used as subscripts to denote a chemical process or reaction*

These symbols should be printed in roman (upright) type, without a full stop (period).

vaporization, evaporation (liquid→gas)	vap
sublimation (solid→gas)	sub
melting, fusion (solid→liquid)	fus
transition (between two phases)	trs
mixing of fluids	mix
solution (of solute in solvent)	sol
dilution (of a solution)	dil
adsorption	ads
displacement	dpl
immersion	imm
reaction in general	r
atomization	at
combustion reaction	c
formation reaction	f

(ii) *Recommended superscripts*

standard	$\ominus$, o
pure substance	*
infinite dilution	∞
ideal	id
activated complex, transition state	‡
excess quantity	E

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Name	*Symbol*	*Definition*	*SI unit*
		CHEMICAL KINETICS	
rate of change of quantity X	$\dot{X}$	$\dot{X} = \mathrm{d}X/\mathrm{d}t$	(varies)
rate of conversion	$\dot{\xi}$	$\dot{\xi} = \mathrm{d}\xi/\mathrm{d}t$	$\mathrm{mol\ s^{-1}}$
rate of concentration change (due to chemical reaction)	r_B, v_B	$r_B = \mathrm{d}c_B/\mathrm{d}t$	$\mathrm{mol\ m^{-3}\ s^{-1}}$
rate of reaction (based on amount concentration)	v	$v = \dot{\xi}/V$ $= \nu_B^{-1}\mathrm{d}c_B/\mathrm{d}t$	$\mathrm{mol\ m^{-3}\ s^{-1}}$
partial order of reaction	n_B	$v = k\Pi c_B^{n_B}$	1
overall order of reaction	n	$n = \Sigma n_B$	1
rate constant, rate coefficient	k	$v = k\Pi c_B^{n_B}$	$(\mathrm{mol^{-1}\,m^3})^{n-1}\mathrm{s^{-1}}$
Boltzmann constant	k, k_B		$\mathrm{J\,K^{-1}}$
half life	$t_{\frac{1}{2}}$	$c(t_{\frac{1}{2}}) = c_0/2$	s
relaxation time	τ	$\tau = 1/(k_1 + k_{-1})$	s
energy of activation, activation energy	E_a, E	$E_a = RT^2\,\mathrm{d}\ln k/\mathrm{d}T$	$\mathrm{J\,mol^{-1}}$
pre-exponential factor	A	$k = A\exp(-E_a/RT)$	$(\mathrm{mol^{-1}\,m^3})^{n-1}\mathrm{s^{-1}}$
volume of activation	$\Delta^{\ddagger}V$	$\Delta^{\ddagger}V = -RT\times$ $(\partial\ln k/\partial p)_T$	$\mathrm{m^3\,mol^{-1}}$
collision diameter	d	$d_{AB} = r_A + r_B$	m
collision cross-section	σ	$\sigma_{AB} = \pi d_{AB}^2$	$\mathrm{m^2}$
collision frequency	Z_A		$\mathrm{s^{-1}}$
collision number	Z_{AB}, Z_{AA}		$\mathrm{m^{-3}\,s^{-1}}$
collision frequency factor	z_{AB}, z_{AA}	$z_{AB} = Z_{AB}/Lc_Ac_B$	$\mathrm{m^3\,mol^{-1}\,s^{-1}}$
standard enthalpy of activation	$\Delta^{\ddagger}H^{\circ}, \Delta H^{\ddagger}$		$\mathrm{J\,mol^{-1}}$
standard entropy of activation	$\Delta^{\ddagger}S^{\circ}, \Delta S^{\ddagger}$		$\mathrm{J\,mol^{-1}\,K^{-1}}$
standard Gibbs energy of activation	$\Delta^{\ddagger}G^{\circ}, \Delta G^{\ddagger}$		$\mathrm{J\,mol^{-1}}$
quantum yield, photochemical yield	ϕ		1
		ELECTROCHEMISTRY	
elementary charge (proton charge)	e		C
Faraday constant	F	$F = eL$	$\mathrm{C\,mol^{-1}}$

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Name	*Symbol*	*Definition*	*SI unit*
charge number of an ion	z	$z_B = Q_B/e$	1
ionic strength	I_c, I	$I_c = \frac{1}{2}\sum c_i z_i^2$	$mol\ m^{-3}$
mean ionic activity	$a_\pm$	$a_\pm = m_\pm \gamma_\pm / m^\circ$	1
mean ionic molality	$m_\pm$	$m_\pm^{(\nu_+ + \nu_-)} = m_+^{\nu_+} m_-^{\nu_-}$	$mol\ kg^{-1}$
mean ionic activity coefficient	$\gamma_\pm$	$\gamma_\pm^{(\nu_+ + \nu_-)} = \gamma_+^{\nu_+} \gamma_-^{\nu_-}$	1
charge number of electrochemical cell reaction	n, (z)		1
electric potential difference (of a galvanic cell)	$\Delta V, E, U$	$\Delta V = V_R - V_L$	V
emf, electromotive force	E	$E = \lim_{I \to 0} \Delta V$	V
standard emf, standard potential of the electrochemical cell reaction	E°	$E^\circ = -\Delta_r G^\circ / nF$ $= (RT/nF) \ln K^\circ$	V
standard electrode potential	E°		V
emf of the cell, potential of the electro-chemical cell reaction	E	$E = E^\circ - (RT/nF) \times \sum \nu_i \ln a_i$	V
pH	pH	$\mathrm{pH} \approx -\lg\left[\frac{c(\mathrm{H}^+)}{\mathrm{mol\ dm}^{-3}}\right]$	1
inner electric potential	ϕ	$\nabla\phi = -\boldsymbol{E}$	V
outer electric potential	ψ	$\psi = Q/4\pi\varepsilon_0 r$	V
surface electric potential	χ	$\chi = \phi - \psi$	V
Galvani potential difference	$\Delta\phi$	$\Delta_\alpha^\beta \phi = \phi^\beta - \phi^\alpha$	V
volta potential difference	$\Delta\psi$	$\Delta_\alpha^\beta \psi = \psi^\beta - \psi^\alpha$	V
electrochemical potential	$\tilde{\mu}$	$\tilde{\mu}_B^\alpha = (\partial G/\partial n_B^\alpha)$	$J\ mol^{-1}$
electric current	I	$I = dQ/dt$	A
(electric) current density	j	$j = I/A$	$A\ m^{-2}$
(surface) charge density	σ	$\sigma = Q/A$	$C\ m^{-2}$
electrode reaction rate constant	k	$k_{ox} = I_a / (nFA \prod_i c_i^{n_i})$	(varies)
mass transfer coefficient, diffusion rate constant	k_d	$k_{d,B} = \lvert\nu_B\rvert I_{l,B} / nFcA$	$m\ s^{-1}$
thickness of diffusion layer	δ	$\delta_B = D_B / k_{d,B}$	m

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Name	*Symbol*	*Definition*	*SI unit*
transfer coefficient (electrochemical)	α	$\alpha_c = \frac{-\lvert\nu\rvert RT}{nF}\frac{\partial \ln\lvert I_c\rvert}{\partial E}$	1
overpotential	η	$\eta = E_I - E_{I=0} - IR_u$	V
electrokinetic potential (zeta potential)	ζ		V
conductivity	$\kappa, (\sigma)$	$\kappa = j/E$	$S\,m^{-1}$
conductivity cell constant	K_{cell}	$K_{cell} = \kappa R$	m^{-1}
molar conductivity (of an electrolyte)	Λ	$\Lambda_B = \kappa/c_B$	$S\,m^2\,mol^{-1}$
ionic conductivity, molar conductivity of an ion	λ	$\lambda_B = \lvert z_B\rvert F u_B$	$S\,m^2\,mol^{-1}$
electric mobility	$u, (\mu)$	$u_B = v_B/E$	$m^2\,V^{-1}\,s^{-1}$
transport number	t	$t_B = j_B/\Sigma j_i$	1
reciprocal radius of ionic atmosphere	κ	$\kappa = (2F^2 I/\varepsilon RT)^{\frac{1}{2}}$	m^{-1}

COLLOID AND SURFACE CHEMISTRY

Name	*Symbol*	*Definition*	*SI unit*
specific surface area	a, a_s, s	$a = A/m$	$m^2\,kg^{-1}$
surface amount of B, adsorbed amount of B	$n_B{}^s, n_B{}^a$		mol
surface excess of B	$n_B{}^\sigma$		mol
surface excess concentration of B	$\Gamma_B, (\Gamma_B{}^\sigma)$	$\Gamma_B = n_B{}^\sigma/A$	$mol\,m^{-2}$
total surface excess concentration	$\Gamma, (\Gamma^\sigma)$	$\Gamma = \sum_i \Gamma_i$	$mol\,m^{-2}$
area per molecule	a, σ	$a_B = A/N_B{}^\sigma$	m^2
area per molecule in a filled monolayer	a_m, σ_m	$a_{m,B} = A/N_{m,B}$	m^2
surface coverage	θ	$\theta = N_B{}^\sigma/N_{m,B}$	1
contact angle	θ		1, rad
film thickness	t, h, δ		m
thickness of (surface or interfacial) layer	τ, δ, t		m
surface tension, interfacial tension	γ, σ	$\gamma = (\partial G/\partial A_s)_{T,p}$	$N\,m^{-1}$, $J\,m^{-2}$
film tension	Σ_f	$\Sigma_f = 2\gamma_f$	$N\,m^{-1}$
reciprocal thickness of the double layer	κ	$\kappa = [2F^2 I_c/\varepsilon RT]^{\frac{1}{2}}$	m^{-1}
average molar masses			
number-average	M_n	$M_n = \Sigma n_i M_i/\Sigma n_i$	$kg\,mol^{-1}$
mass-average	M_m	$M_m = \Sigma n_i M_i{}^2/\Sigma n_i M_i$	$kg\,mol^{-1}$

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Name	*Symbol*	*Definition*	*SI unit*
Z-average	M_Z	$M_Z = \Sigma n_i M_i^3 / \Sigma n_i M_i^2$	kg mol^{-1}
sedimentation coefficient	s	$s = v/a$	s
van der Waals constant	λ		J
retarded van der Waals constant	β, B		J
van der Waals–Hamaker constant	A_H		J
surface pressure	π^s, π	$\pi^s = \gamma^0 - \gamma$	N m^{-1}

TRANSPORT PROPERTIES

flux (of a quantity X)	J_X, J	$J_X = A^{-1}\, \mathrm{d}X/\mathrm{d}t$	(varies)
volume flow rate	q_V, $\dot{V}$	$q_v = \mathrm{d}V/\mathrm{d}t$	m^3 s^{-1}
mass flow rate	q_m, $\dot{m}$	$q_m = \mathrm{d}m/\mathrm{d}t$	kg s^{-1}
mass transfer coefficient	k_d		m s^{-1}
heat flow rate	ϕ	$\phi = \mathrm{d}q/\mathrm{d}t$	W
heat flux	J_q	$J_q = \phi/A$	W m^{-2}
thermal conductance	G	$G = \phi/\Delta T$	W K^{-1}
thermal resistance	R	$R = 1/G$	K W^{-1}
thermal conductivity	λ, k	$\lambda = J_q/(\mathrm{d}T/\mathrm{d}l)$	W m^{-1} K^{-1}
coefficient of heat transfer	h, (k, K, α)	$h = J_q/\Delta T$	W m^{-2} K^{-1}
thermal diffusivity	a	$a = \lambda/\rho c_p$	m^2 s^{-1}
diffusion coefficient	D	$D = J_n/(\mathrm{d}c/\mathrm{d}l)$	m^2 s^{-1}

The following symbols are used in the definitions of the dimensionless quantities: mass (m), time (t), volume (V), area (A), density (ρ), speed (v), length (l), viscosity (η), pressure (p), acceleration of free fall (g), cubic expansion coefficient (α), temperature (T), surface tension (γ), speed of sound (c), mean free path (λ), frequency (f), thermal diffusivity (a), coefficient of heat transfer (h), thermal conductivity (k), specific heat capacity at constant pressure (c_p), diffusion coefficient (D), mole fraction (x), mass transfer coefficient (k_d), permeability (μ), electric conductivity (κ), and magnetic flux density (B).

Name	*Symbol*	*Definition*	*SI unit*
Reynolds number	Re	$Re = \rho v l/\eta$	1
Euler number	Eu	$Eu = \Delta p/\rho v^2$	1
Froude number	Fr	$Fr = v/(lg)^{\frac{1}{2}}$	1
Grashof number	Gr	$Gr = l^3 g \alpha \Delta T \rho^2/\eta^2$	1
Weber number	We	$We = \rho v^2 l/\gamma$	1
Mach number	Ma	$Ma = v/c$	1
Knudsen number	Kn	$Kn = \lambda/l$	1
Strouhal number	Sr	$Sr = lf/v$	1
Fourier number	Fo	$Fo = at/l^2$	1
Péclet number	Pe	$Pe = vl/a$	1
Rayleigh number	Ra	$Ra = l^3 g \alpha \Delta T \rho/\eta a$	1
Nusselt number	Nu	$Nu = hl/k$	1
Stanton number	St	$St = h/\rho v c_p$	1

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Name	*Symbol*	*Definition*	*SI units*
Fourier number for mass transfer	Fo^*	$Fo^* = Dt/l^2$	1
Péclet number for mass transfer	Pe^*	$Pe^* = vl/D$	1
Grashof number for mass transfer	Gr^*	$Gr^* = l^3 g\left(\frac{\partial \rho}{\partial x}\right)_{T,p}\left(\frac{\Delta x \rho}{\eta}\right)$	1
Nusselt number for mass transfer	Nu^*	$Nu^* = k_d l/D$	1
Stanton number for mass transfer	St^*	$St^* = k_d/v$	1
Prandtl number	Pr	$Pr = \eta/\rho a$	1
Schmidt number	Sc	$Sc = \eta/\rho D$	1
Lewis number	Le	$Le = a/D$	1
magnetic Reynolds number	Rm, Re_m	$Rm = v\mu\kappa l$	1
Alfvén number	Al	$Al = v(\rho\mu)^{\frac{1}{2}}/B$	1
Hartmann number	Ha	$Ha = Bl(\kappa/\eta)^{\frac{1}{2}}$	1
Cowling number	Co	$Co = B^2/\mu\rho v^2$	1

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NOMENCLATURE OF CHEMICAL COMPOUNDS

The International Union of Pure and Applied Chemistry (IUPAC) maintains several commissions that deal with the naming of chemical substances. In general, the approach of IUPAC is to present rules for arriving at names in a systematic manner, rather than recommending a unique name for each compound. Thus there are often several alternative "IUPAC names", depending on which nomenclature system is used, each of which may have advantages in specific applications. However, each of these names will be unambiguous.

Organizations such as the Chemical Abstacts Service and the Beilstein Institute that prepare indexes to the chemical literature must adopt a system for selecting unique names in order to avoid excessive cross referencing. Chemical Abstracts Service uses a system which groups together compounds derived from a single parent compound. Thus most index names are inverted (e.g., Benzene, bromo rather than bromobenzene; Acetic acid, sodium salt rather than sodium acetate). In this *Handbook* the CAS Index Names are used only in the table "Physical Constants of Organic Compounds". Other tables use more familiar names which, with a few possible exceptions, conform to one of the IUPAC naming systems.

Recommended names for the most common substituent groups, ligands, ions, and organic rings are given in the two following tables, "Nomenclature for Inorganic Ions and Ligands" and "Organic Substituent Groups and Ring Systems". For the basics of macromolecular nomenclature, see "Naming Organic Polymers" in Section 13.

Some of the most useful recent guides to chemical nomenclature, prepared by IUPAC and other organizations such as the International Union of Biochemistry and Molecular Biology (IUBMB) and the American Chemical Society are listed below . These books contain citations to the more detailed nomenclature documents in each area.

Inorganic Chemistry

International Union of Pure and Applied Chemistry, *Nomenclature of Inorganic Chemistry, Recommendations 1990,* edited by Leigh, G.J., Blackwell Scientific Publications, Oxford, 1990.

Block, B.P., Powell, W.H., and Fernelius, W.C., *Inorganic Chemical Nomenclature, Principles and Practice*, American Chemical Society, Washington, 1990.

Organic Chemistry

International Union of Pure and Applied Chemistry, *A Guide to IUPAC Nomenclature of Organic Compounds, Recommendations 1993,* edited by Panico, R., Powell, W.H., and Richer, J.-C., Blackwell Scientific Publications, Oxford, 1993.

International Union of Pure and Applied Chemistry, *Glossary of Class Names of Organic Compounds and Reactive Intermediates Based on Structure*, edited by Moss, G.P., Smith, P.A.S., and Tavernier, D., *Pure & Appl. Chem*, 67, 1307, 1995.

Rhodes, P.H., *The Organic Chemist's Desk Reference*, Chapman & Hall, London, 1995.

International Union of Pure and Applied Chemistry, *Basic Terminology of Stereochemistry*, edited by Moss, G.P., *Pure & Applied Chemistry*, 68, 2193, 1966.

Macromolecular Chemistry

International Union of Pure and Applied Chemistry, *Compendium of Macromolecular Nomenclature*, edited by, Metanomski, W.V., Blackwell Scientific Publications, Oxford, 1991.

International Union of Pure and Applied Chemistry, *Glossary of Basic Terms in Polymer Science*, edited by Jenkins, A.D., Kratochvil, P., Stepto, R.F.T., and Suter, U.W., *Pure & Appl. Chem*, 68, in press.

Biochemistry

International Union of Biochemistry and Molecular Biology, *Biochemical Nomenclature and Related Documents*, *2nd Edition, 1992,* Portland Press, London, 1993; includes recommendations of the IUPAC-IUBMB Joint Commission on Biochemical Nomenclature.

International Union of Biochemistry and Molecular Biology, *Enzyme Nomenclature*, *1992*, Academic Press, Orlando, FL, 1992.

IUPAC-IUBMB Joint Commission on Biochemical Nomenclature, *Nomenclature of Carbohydrates*, *Recommendations 1996*, edited by McNaught, A.D., *Pure & Appl. Chem*., 68, 1919, 1996.

General

Chemical Abstracts Service, *Naming and Indexing Chemical Substances for Chemical Abstracts, Appendix IV, Chemical Abstracts 1994 Index Guide.*

NOMENCLATURE FOR INORGANIC IONS AND LIGANDS

See the table *Nomenclature of Chemical Compounds* for references. The assistance of Warren H. Powell in preparing this list is gratefully acknowledged.

Group	As cation	As anion	As ligand	As prefix in organic compounds
H	hydrogen	hydride	hydrido	
F	fluorine	fluoride	fluoro	fluoro
Cl	chlorine	chloride	chloro	chloro
Br	bromine	bromide	bromo	bromo
I	iodine	iodide	iodo	iodo
ClO	chlorosyl	hypochlorite	hypochlorito	chlorosyl
$C1O_2$	chloryl	chlorite	chlorito	chloryl
ClO_3	perchloryl	chlorate	chlorato	perchloryl
$C1O_4$		perchlorate		
IO	iodosyl	hypoiodite		iodoso
IO_2	iodyl			iodyl; iodoxy
O		oxide	oxo	oxo
O_2		peroxide (O_2^{2-}) hyperoxide (O_2^-)	peroxo	peroxy
HO		hydroxide	hydroxo	hydroxy
HO_2		hydrogen peroxide	hydrogen peroxo	hydroperoxy
S		sulfide	thio; sulfido	thio; thioxo
HS		hydrogen sulfide	thiolo	mercapto
S_2		disulfide	disulfido	
SO	sulfinyl; thionyl			sulfinyl
SO_2	sulfonyl; sulfuryl	sulfoxylate		sulfonyl
SO_3		sulfite	sulfito	
HSO_3		hydrogen sulfite	hydrogen sulfito	
S_2O_3		thiosulfate	thiosulfato	
SO_4		sulfate	sulfato	
Se		selenide	seleno	seleno; selenoxo
SeO	seleninyl			seleninyl
SeO_2	selenonyl			selenonyl
SeO_3		selenite	selenito	
SeO_4		selenate	selenato	
Te		telluride	telluro	telluro; telluroxo
CrO_2	chromyl			
UO_2	uranyl			
NpO_2	neptunyl			
PuO_2	plutoryl			
AmO_2	americyl			
N		nitride	nitrido	
N_3		azide	azido	
NH		imide	imido	imino
NH_2		amide	amido	amino
NHOH		hydroxylamide	hydroxylamido	hydroxyamino
N_2H_3		hydrazide	hydrazido	hydrazino; diazanyl
NO	nitrosyl		nitrosyl	nitroso
NO_2	nitryl		nitro	nitro
ONO		nitrite	nitrito	
NS	thionitrosyl			
NO_3		nitrate	nitrato	
N_2O_3		hyponitrite	hyponitrito	
P		phosphide	phosphido	phosphinidyne
PO	phosphoryl			phosphoroso; phosphinylidyne
PO_2	phospho			
PS	thiophosphoryl			phosphinothioylidyne; thiophosphorozo
PH_2O_3		hypophosphite	hypophosphito	
PHO_3		phosphite	phosphito	

NOMENCLATURE FOR INORGANIC IONS AND LIGANDS (continued)

Group	As cation	As anion	As ligand	As prefix in organic compounds
PO_4		phosphate	phosphato	
AsO_4		arsenate	arsenato	
VO	vanadyl			
CO	carbonyl		carbonyl	carbonyl
CS	thiocarbonyl			thiocarbonyl
CH_3O		methanolate	methoxo	methoxy
C_2H_5O		ethanolate	ethoxo	ethoxy
CH_3S		methanethiolate	methanethiolato	methylthio
C_2H_5S		ethanethiolate	ethanethiolato	ethylthio
CN	cyanogen	cyanide	cyano	cyano
OCN		cyanate	cyanato	cyanato
SCN		thiocyanate	thiocyanato	thiocyanato
SeCN		selenocyanate	selenocyanato	selenocyanato
TeCN		tellurocyanate	tellurocyanato	tellurocyanato
CO_3		carbonate	carbonato	
HCO_3		hydrogen carbonate	hydrogen carbonato	carboxycarbonyl
C_2O_4		oxalate	oxalato	

ORGANIC SUBSTITUENT GROUPS AND RING SYSTEMS

The first part of this table lists substituent groups and their line formulas. A substituent group is defined by IUPAC as a group that replaces one or more hydrogen atoms attached to a parent structure. Such groups are sometimes called radicals, but IUPAC now reserves the term radical for a free molecular species with unpaired electrons. IUPAC does not recommend some of these names, which are marked here with asterisks (e.g., amyl*), but they are included in this list because they are often encountered in the older literature. Substituent group names which are formed by systematic rules (e.g., methyl from methane, ethyl from ethane, etc.) are included here only for the first few members of a homologous series.

In the second part of the table a number of common organic ring compounds are shown, with the conventional numbering of the ring positions indicated.

The help of Warren H. Powell in preparing this table is greatly appreciated. Pertinent references may be found in the table *Nomenclature of Chemical Compounds*.

SUBSTITUENT GROUPS

acetamido (acetylamino)	CH_3CONH-
acetoacetyl	CH_3COCH_2CO-
acetonyl	CH_3COCH_2-
acetyl	CH_3CO-
acryloyl* (1-oxo-2-propenyl)	$CH_2{=}CHCO-$
alanyl (from alanine)	$CH_3CH(NH_2)CO-$
β-alanyl	$H_2N(CH_2)_2CO-$
allyl (2-propenyl)	$CH_2{=}CHCH_2-$
allylidene (2-propenylidene)	$CH_2{=}CHCH{=}$
amidino (aminoiminomethyl)	$H_2NC({=}NH)-$
amino	H_2N-
amyl* (pentyl)	$CH_3(CH_2)_4-$
anilino (phenylamino)	C_6H_5NH-
anisidino	$CH_3OC_6H_4NH-$
anthranoyl (2-aminobenzoyl)	$2\text{-}H_2NC_6H_4CO-$
arsino	AsH_2-
azelaoyl (from azelaic acid)	$-OC(CH_2)_7CO-$
azido	N_3-
azino	$=N-N=$
azo	$-N{=}N-$
azoxy	$-N(O){=}N-$
benzal* (benzylidene)	$C_6H_5CH{=}$
benzamido (benzoylamino)	C_6H_5CONH-
benzhydryl (diphenylmethyl)	$(C_6H_5)_2CH-$
benzoxy* (benzoyloxy)	C_6H_5COO-
benzoyl	C_6H_5CO-
benzyl	$C_6H_5CH_2-$
benzylidene	$C_6H_5CH{=}$
benzylidyne	$C_6H_5C{=}$
biphenylyl	$C_6H_5C_6H_5-$
biphenylene	$-C_6H_4-C_6H_4-$
butoxy	C_4H_9O-
sec-butoxy (1-methylpropoxy)	$C_2H_5CH(CH_3)O-$
tert-butoxy (1,1-dimethylethoxy)	$(CH_3)_3CO-$
butyl	$CH_3(CH_2)_3-$
sec-butyl (1-methylpropyl)	$CH_3CH_2CH(CH_3)-$
tert-butyl (1,1-dimethylethyl)	$(CH_3)_3C-$
butyryl (1-oxobutyl)	$CH_3(CH_2)_2CO-$
caproyl* (hexanoyl)	$CH_3(CH_2)_4CO-$
capryl* (decanoyl)	$CH_3(CH_2)_8CO-$
capryloyl* (octanoyl)	$CH_3(CH_2)_6CO-$
carbamido (carbamoylamino)	$H_2NCONH-$
carbamoyl (aminocarbonyl)	H_2NCO-
carbamyl (aminocarbonyl)	H_2NCO-
carbazoyl (hydrazinocarbonyl)	$H_2NNHCO-$
carbethoxy (ethoxycarbonyl)	C_2H_5OCO-
carbonyl	$=C{=}O$
carboxy	$HOOC-$
cetyl* (hexadecyl)	$CH_3(CH_2)_{15}-$
chloroformyl (chlorcarbonyl)	$ClCO-$
cinnamoyl	$C_6H_5CH{=}CHCO-$
cinnamyl (3-phenyl-2-propenyl)	$C_6H_5CH{=}CHCH_2-$
cinnamylidene	$C_6H_5CH{=}CHCH{=}$
cresyl* (hydroxymethylphenyl)	$HO(CH_3)C_6H_4-$
crotonoyl	$CH_3CH{=}CHCO-$
crotyl (2-butenyl)	$CH_3CH{=}CHCH_2-$
cyanamido (cyanoamino)	$NCNH-$
cyanato	$NCO-$
cyano	$NC-$
decanedioyl	$-OC(CH_2)_8CO-$
decanoyl	$CH_3(CH_2)_8CO-$
diazo	$N_2{=}$
diazoamino	$-NHN{=}N-$
disilanyl	H_3SiSiH_2-
disiloxanyloxy	$H_3SiOSiH_2O-$
disulfinyl	$-S(O)S(O)-$
dithio	$-SS-$
enanthoyl* (heptanoyl)	$CH_3(CH_2)_5CO-$
epoxy	$-O-$
ethenyl (vinyl)	$CH_2{=}CH-$
ethynyl	$HC{\equiv}C-$
ethoxy	C_2H_5O-
ethyl	CH_3CH_2-
ethylene	$-CH_2CH_2-$
ethylidene	$CH_3CH{=}$
ethylthio	C_2H_5S-
formamido (formylamino)	$HCONH-$
formyl	$HCO-$
furmaroyl (from fumaric acid)	$-OCCH{=}CHCO-$
furfuryl (2-furanylmethyl)	$OC_4H_3CH_2-$
furfurylidene (2-furanylmethylene)	$OC_4H_3CH{=}$
glutamoyl (from glutamic acid)	$-OC(CH_2)_2CH(NH_2)CO-$
glutaryl (from glutaric acid)	$-OC(CH_2)_3CO-$
glycylamino	H_2NCH_2CONH-
glycoloyl; glycolyl (hydroxyacetyl)	$HOCH_2CO-$
glycyl (aminoacetyl)	H_2NCH_2CO-
glyoxyloyl; glyoxylyl (oxoacetyl)	$HCOCO-$
guanidino	$H_2NC({=}NH)NH-$
guanyl (aminoiminomethyl)	$H_2NC({=}NH)-$
heptadecanoyl	$CH_3(CH_2)_{15}CO-$
heptanamido	$CH_3(CH_2)_5CONH-$
heptanedioyl	$-OC(CH_2)_5CO-$
heptanoyl	$CH_3(CH_2)_5CO-$
hexadecanoyl	$CH_3(CH_2)_{14}CO-$
hexamethylene (1,6-hexanediyl)	$-(CH_2)_6-$
hexanedioyl	$-OC(CH_2)_4CO-$
hippuryl (N-benzoylglycyl)	$C_6H_5CONHCH_2CO-$
hydrazino	H_2NNH-
hydrazo	$-HNNH-$
hydrocinnamoyl	$C_6H_5(CH_2)_2CO-$
hydroperoxy	$HOO-$
hydroxyamino	$HONH-$
hydroxy	$HO-$
imino	$HN{=}$
iodoso* (iodosyl)	$OI-$
iodyl	O_2I-
isoamyl* (isopentyl; 3-methylbutyl)	$(CH_3)_2CH(CH_2)_2-$
isobutenyl (2-methyl-1-propenyl)	$(CH_3)_2C{=}CH-$
isobutoxy (2-methylpropoxy)	$(CH_3)_2CHCH_2O-$
isobutyl (2-methylpropyl)	$(CH_3)_2CHCH_2-$
isobutylidene (3-methylpropylidene)	$(CH_3)_2CHCH{=}$
isobutyryl (2-methyl-1-oxopropyl)	$(CH_3)_2CHCO-$

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isocyanato	$OCN-$
isocyano	$CN-$
isohexyl (4-methylpentyl)	$(CH_3)_2CH(CH_2)_3-$
isoleucyl (from isoleucine)	$C_2H_5CH(CH_3)CH(NH_2)CO-$
isonitroso* (hydroxyamino)	$HON=$
isopentyl (3-methylbutyl)	$(CH_3)_2CH(CH_2)_2-$
isopentylidene (3-methylbutylidene)	$(CH_3)_2CHCH_2CH=$
isopropenyl (1-methylethenyl)	$CH_2=C(CH_3)-$
isopropoxy (1-methylethoxy)	$(CH_3)_2CHO-$
isopropyl (1-methylethyl)	$(CH_3)_2CH-$
isopropylidene (1-methylethylidene)	$(CH_3)_2C=$
isothiocyanato (isothiocyano)	$SCN-$
isovaleryl* (3-methyl-1-oxobutyl)	$(CH_3)_2CHCH_2CO-$
lactoyl (from lactic acid)	$CH_3CH(OH)CO-$
lauroyl (from lauric acid)	$CH_3(CH_2)_{10}CO-$
lauryl (dodecyl)	$CH_3(CH_2)_{11}-$
leucyl (from leucine)	$(CH_3)_2CHCH_2CH(NH_2)CO-$
levulinoyl (from levulinic acid)	$CH_3CO(CH_2)_2CO-$
malonyl (from malonic acid)	$-OCCH_2CO-$
mandeloyl (from mandelic acid)	$C_6H_5CH(OH)CO-$
mercapto	$HS-$
mesityl	$2,4,6-(CH_3)_3C_6H_2-$
methacryloyl (from methacrylic acid)	$CH_2=C(CH_3)CO-$
methallyl (2-methyl-2-propenyl)	$CH_2=C(CH_3)CH_2-$
methionyl (from methionine)	$CH_3SCH_2CH_2CH(NH_2)CO-$
methoxy	CH_3O-
methyl	H_3C-
methylene	$H_2C=$
methylthio	CH_3S-
myristoyl (from myristic acid)	$CH_3(CH_2)_{12}CO-$
myristyl (tetradecyl)	$CH_3(CH_2)_{13}-$
naphthyl	$(C_{10}H_7)-$
naphthylene	$-(C_{10}H_6)-$
neopentyl (2,2-dimethylpropyl)	$(CH_3)_3CCH_2-$
nitramino (nitroamino)	O_2NNH-
nitro	O_2N-
nitrosamino (nitrosoamino)	$ONNH-$
nitrosimino (nitrosoimino)	$ONN=$
nitroso	$ON-$
nonanoyl (from nonanoic acid)	$CH_3(CH_2)_7CO-$
oleoyl (from oleic acid)	$CH_3(CH_2)_7CH=CH(CH_2)_7CO-$
oxalyl (from oxalic acid)	$-OCCO-$
oxo	$O=$
palmitoyl (from palmitic acid)	$CH_3(CH_2)_{14}CO-$
pentamethylene (1,5-pentanediyl)	$-(CH_2)_5-$
pentyl	$CH_3(CH_2)_4-$
tert-pentyl	$CH_3CH_2C(CH_3)_2-$
phenacyl	$C_6H_5COCH_2-$
phenacylidene	$C_6H_5COCH=$
phenethyl (2-phenylethyl)	$C_6H_5CH_2CH_2-$
phenoxy	C_6H_5O-
phenyl	C_6H_5-
phenylene (benzenediyl)	$-C_6H_4-$
phosphino* (phosphanyl)	H_2P-
phosphinyl* (phosphinoyl)	$H_2P(O)-$
phospho	O_2P-
phosphono	$(HO)_2P(O)-$
phthaloyl (from phthalic acid)	$1,2-C_6H_4(CO-)_2$
picryl (2,4,6-trinitrophenyl)	$2,4,6-(NO_2)_3C_6H_2-$
pimeloyl (from pimelic acid)	$-OC(CH_2)_5CO-$
piperidino (1-piperidinyl)	$C_5H_{10}N-$
pivaloyl (from pivalic acid)	$(CH_3)_3CCO-$
prenyl (3-methyl-2-butenyl)	$(CH_3)_2C=CHCH_2-$
propargyl (2-propynyl)	$HC\equiv CCH_2-$
1-propenyl	$-CH=CHCH_2$
2-propenyl (allyl)	$CH_2=CHCH_2-$
propionyl* (propanyl)	CH_3CH_2CO-
propoxy	$CH_3CH_2CH_2O-$
propyl	$CH_3CH_2CH_2-$
propylidene	$CH_3CH_2CH=$
pyrryl (pyrrolyl)	C_3H_4N-
salicyloyl (2-hydroxybenzoyl)	$2-HOC_6H_4CO-$
selenyl* (selanyl; hydroseleno)	$HSe-$
seryl (from serine)	$HOCH_2CH(NH_2)CO-$
siloxy	H_3SiO-
silyl	H_3Si-
silylene	$H_2Si=$
sorboyl (from sorbic acid)	$CH_3CH=CHCH=CHCO-$
stearoyl (from stearic acid)	$CH_3(CH_2)_{14}CO-$
stearyl (octadecyl)	$CH_3(CH_2)_{17}-$
styryl (2-phenylethenyl)	$C_6H_5CH=CH-$
suberoyl (from suberic acid)	$-OC(CH_2)_6CO-$
succinyl (from succinic acid)	$-OCCH_2CH_2CO-$
sulfamino (sulfoamino)	$HOSO_2NH-$
sulfamoyl (sulfamyl)	H_2NSO_2-
sulfanilyl [(4-aminophenyl)sulfonyl]	$4-H_2NC_6H_4SO_2-$
sulfeno	$HOS-$
sulfhydryl (mercapto)	$HS-$
sulfinyl	$OS=$
sulfo	HO_3S-
sulfonyl (sulfuryl)	$-SO_2-$
terephthaloyl	$1,4-C_6H_4(CO-)_2$
tetramethylene	$-(CH_2)_4-$
thienyl (from thiophene)	$(C_4H_3S)-$
thiocarbonyl (carbothionyl)	$=CS$
thiocarboxy	$HOSC-$
thiocyanato (thiocyano)	$NCS-$
thionyl* (sulfinyl)	$-SO-$
threonyl (from threonine)	$CH_3CH(OH)CH(NH_2)CO-$
toluidino [(methylphenyl)amino]	$CH_3C_6H_4NH-$
toluoyl (methylbenzoyl)	$CH_3C_6H_4CO-$
tolyl (methylphenyl)	$CH_3C_6H_4-$
α-tolyl (benzyl)	$C_6H_5CH_2-$
tolylene (methylphenylene)	$-(CH_3C_6H_3)-$
tosyl [(4-methylphenyl) sulfonyl)]	$4-CH_3C_6H_4SO_2-$
triazano	$H_2NNHNH-$
trimethylene (1,3-propanediyl)	$-(CH_2)_3-$
trityl (triphenylmethyl)	$(C_6H_5)_3C-$
valeryl* (pentanoyl)	$CH_3(CH_2)_3CO-$
valyl (from valine)	$(CH_3)_2CHCH(NH_2)CO-$
vinyl (ethenyl)	$CH_2=CH-$
vinylidene (ethenylidene)	$CH_2=C=$
xylidino [(dimethylphenyl)amino]	$(CH_3)_2C_6H_3NH-$
xylyl (dimethylphenyl)	$(CH_3)_2C_6H_3-$
xylylene [phenelenebis(methylene)]	$-CH_2C_6H_4CH_2-$

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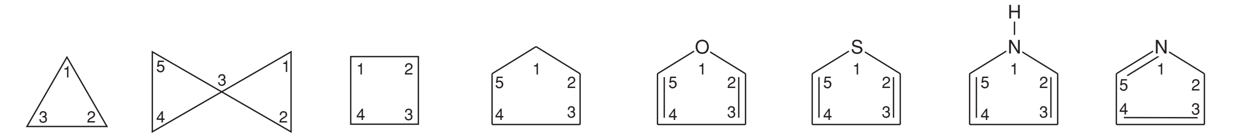
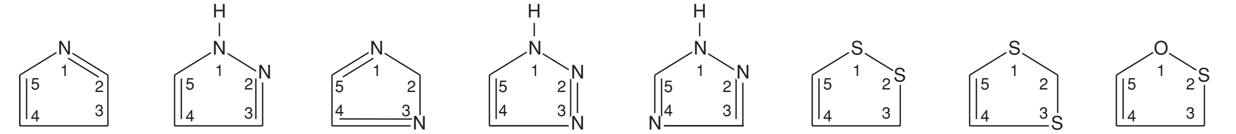
ORGANIC SUBSTITUENT GROUPS AND RING SYSTEMS (continued)

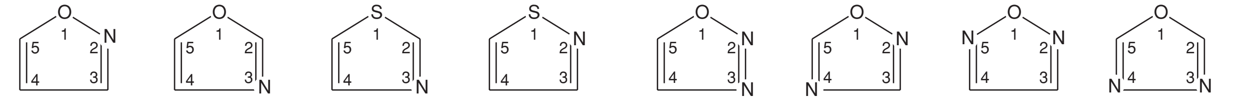
ORGANIC RING COMPOUNDS



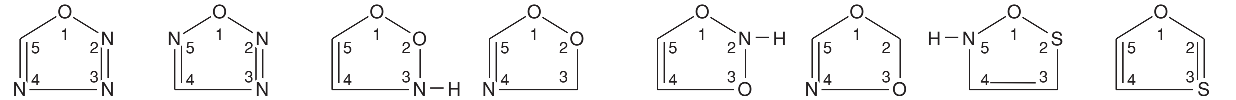
Cyclopropane; Spiropentane; Cyclobutane; Cyclopentane; Furan; Thiophene; Pyrrole (Azole); 2*H*-Pyrrole (2*H*-Azole)



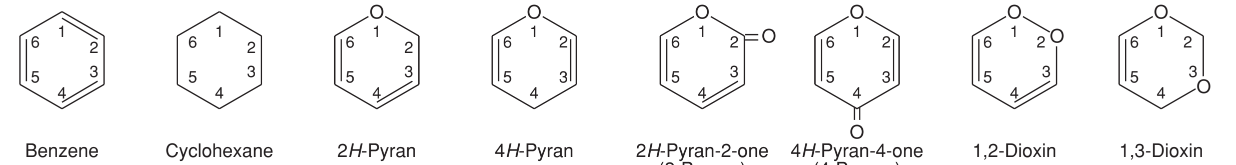
3*H*-Pyrrole (3*H*-Azole); Pyrazole (1,2-Diazole); 2*H*-Imidazole (1,3-Diazole); 1,2,3-Triazole; 1,2,4-Triazole; 1,2-Dithiole; 1,3-Dithiole; 3*H*-1,2-Oxathiole



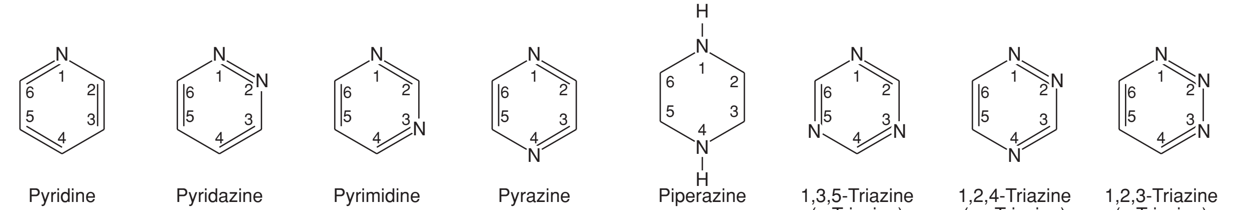
Isoxazole (1,2-Oxazole); Oxazole (1,3-Oxazole); Thiazole (1,3-Thiazole); Isothiazole (1,2-Thiazole); 1,2,3-Oxadiazole; 1,2,4-Oxadiazole; 1,2,5-Oxadiazole (Furazan); 1,3,4-Oxadiazole



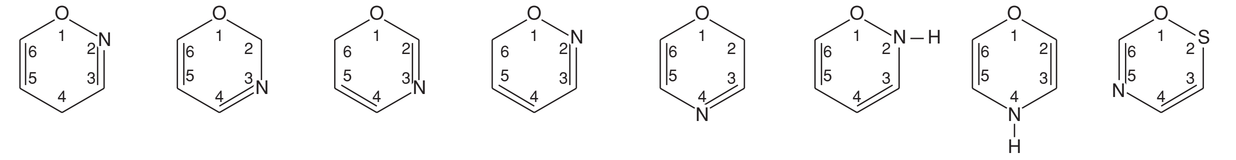
1,2,3,4-Oxatriazole; 1,2,3,5-Oxatriazole; 3*H*-1,2,3-Dioxazole; 1,2,4-Dioxazole; 1,3,2-Dioxazole; 1,3,4-Dioxazole; 5*H*-1,2,5-Oxathiazole; 1,3-Oxathiole



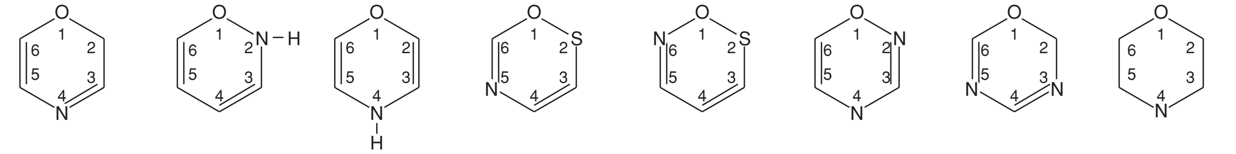
Benzene; Cyclohexane; 2*H*-Pyran; 4*H*-Pyran; 2*H*-Pyran-2-one (2-Pyrone); 4*H*-Pyran-4-one (4-Pyrone); 1,2-Dioxin; 1,3-Dioxin



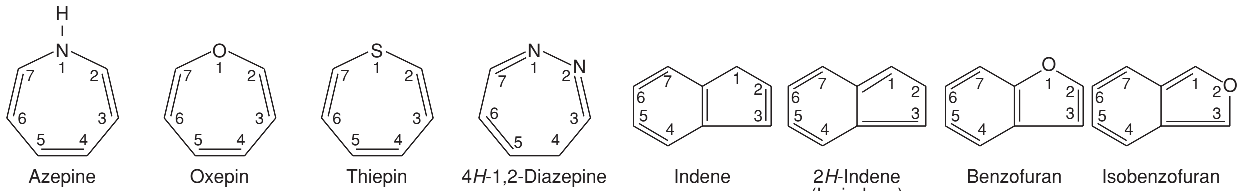
Pyridine; Pyridazine; Pyrimidine; Pyrazine; Piperazine; 1,3,5-Triazine (*s*-Triazine); 1,2,4-Triazine (*as*-Triazine); 1,2,3-Triazine (*v*-Triazine)



4*H*-1,2-Oxazine; 2*H*-1,3-Oxazine; 6*H*-1,3-Oxazine; 6*H*-1,2-Oxazine; 1,4-Oxazine; 2*H*-1,2-Oxazine; 4*H*-1,4-Oxazine; 1,2,5-Oxathiazine



1,4-Oxazine; 2*H*-1,2-Oxazine; 4*H*-1,4-Oxazine; 1,2,5-Oxathiazine; 1,2,6-Oxathiazine; 1,2,4-Oxadiazine; 1,3,5-Oxadiazine; Morpholine



Azepine; Oxepin; Thiepin; 4*H*-1,2-Diazepine; Indene; 2*H*-Indene (Isoindene); Benzofuran; Isobenzofuran

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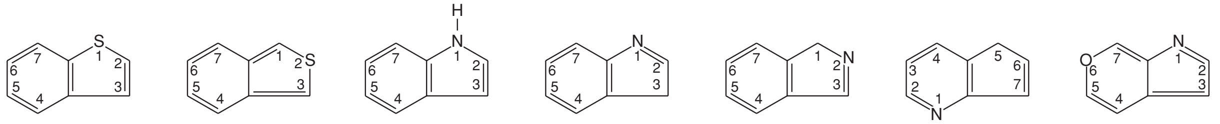
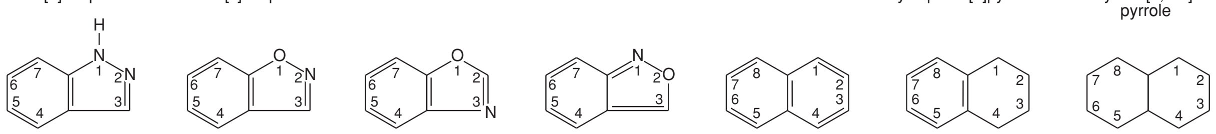
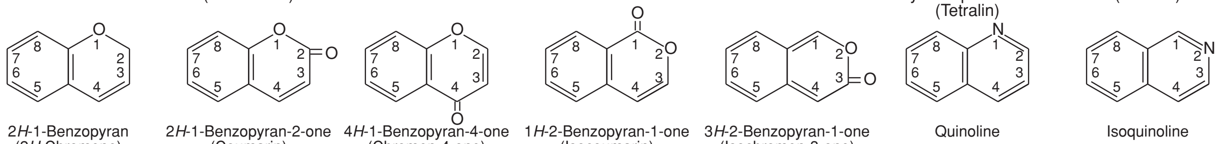
ORGANIC RING COMPOUNDS (continued)



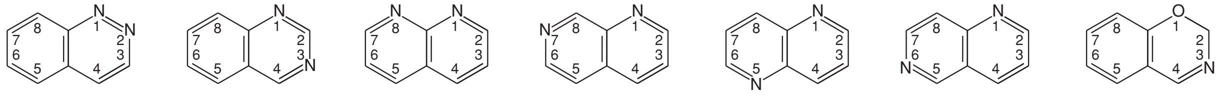
Benzo[b]thiophene | Benzo[c]thiophene | Indole | 3*H*-Indole | 1*H*-Indole | Cyclopenta[*b*]pyridine | Pyrano[3,4-b]-pyrrole



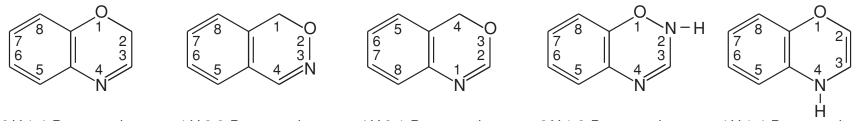
Indazole | Benzisoxazole (Indoxazine) | Benzoxazole | 2,1-Benzisoxazole | Naphthalene | 1,2,3,4-Tetra-hydronaphthalene (Tetralin) | Octahydronaphthalene (Decalin)



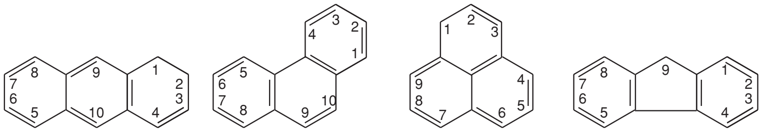
2*H*-1-Benzopyran (2*H*-Chromene) | 2*H*-1-Benzopyran-2-one (Coumarin) | 4*H*-1-Benzopyran-4-one (Chromen-4-one) | 1*H*-2-Benzopyran-1-one (Isocoumarin) | 3*H*-2-Benzopyran-1-one (Isochromen-3-one) | Quinoline | Isoquinoline



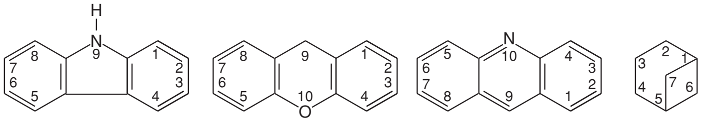
Cinnoline | Quinazoline | 1,8-Naphtyridine | 1,7-Naphtyridine | 1,5-Naphtyridine | 1,6-Naphtyridine | 2*H*-1,3-Benzoxazine



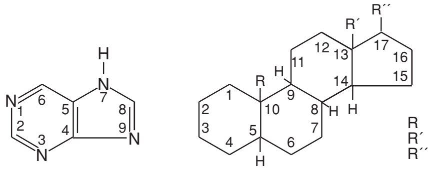
2*H*-1,4-Benzoxazine | 1*H*-2,3-Benzoxazine | 4*H*-3,1-Benzoxazine | 2*H*-1,2-Benzoxazine | 4*H*-1,4-Benzoxazine



Anthracene | Phenanthrene | Phenalene | Fluorene



Carbazole | Xanthene | Acridine | Norpinane (Bicyclo[3.1.1]heptane)



R = Nearly always methyl
R′ = Usually methyl
R′′ = Various groups

7*H*-Purine | Steroid ring system

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SCIENTIFIC ABBREVIATIONS AND SYMBOLS

This table lists some symbols, abbreviations, and acronyms encountered in the physical sciences. Most entries in italic type are symbols for physical quantities; for more details on these, see the table "Symbols and Terminology for Physical and Chemical Quantities" in this section. Additional information on units may be found in the table "International System of Units" in Section 1. Many of the terms to which these abbreviations refer are included in the tables "Definitions of Scientific Terms" in Section 2 and "Techniques for Materials Characterization" in Section 12.

Publication practices vary with regard to the use of capital or lower case letters for many abbreviations. An effort has been made to follow the most common practices in this table, but much variation is found in the literature. Likewise, policies on the use of periods in an abbreviation vary considerably. Periods are generally omitted in this table unless they are necessary for clarity. Periods should never appear in SI units. The SI prefixes (m, k ,M, etc.) are not listed here, since they should never be used alone, but selected combinations with SI units (e.g., mg, kV, MW) are included.

Abbreviations are listed in alphabetical order without regard to case. Entries beginning with Greek letters fall at the end of the table.

a	absorption coefficient, acceleration, activity
a_0	Bohr radius
A	ampere, adenine (in genetic code)
Å	ångstrom
A	absorbance, area, Helmholtz energy, mass number
A_H	Hall coefficient
A_r	atomic weight (relative atomic mass)
AAS	atomic absorption spectroscopy
Abe	abequose
abs	absolute
ac	alternating current
Ac	acetyl
AcOH	acetic acid
ACT	activated complex theory
ACTH	adrenocorticotropic hormone
Ade	adenine
ADP	adenosine diphosphate
ads	adsorption
ae	eon (10^9 years)
AES	atomic emission spectroscopy, Auger electron spectroscopy
AF	audio frequency
AFM	atomic force microscopy
AI	artificial intelligence
AIM	atoms in molecules
Al	Alfen number
Ala	alanine
alc	alcohol
aliph.	aliphatic
alk.	alkaline
All	allose
Alt	altrose
am	amorphous solid
Am	amyl
AM	amplitude modulation
AMP	adenosine 5'-monophosphate
amu	atomic mass unit (recommended symbol is u)
anh, anhyd	anhydrous
antilog	antilogarithm
AO	atomic orbital
AOM	angular overlap model
Api	apiose
APS	appearance potential spectroscopy
APW	augmented plane wave
aq	aqueous
Ar	aryl
Ara	arabinose
Ara-ol	arabinitol
Arg	arginine
as, asym	asymmetrical (as chemical descriptor)
ASCII	American National Standard Code for Information Interchange
ASE	aromatic stabilization energy
Asn	asparagine
Asp	aspartic acid
at	atomization
atm	standard atmosphere
ATP	adenosine 5'-triphosphate
ATR	attenuated total internal reflection
at.wt.	atomic weight
AU	astronomical unit
av	average
avdp	avoirdupois
b	barn
B	magnetic flux density, second virial coefficient, susceptance
bar	bar (pressure unit)
bbl	barrel
bcc	body centered cubic
BCS	Bardeen-Cooper-Schrieffer (theory)
BDE	bond dissociation energy
Bé	Baumé
BET	Brunauer-Emmett-Teller (method)
BeV	billion electronvolt
Bhn	Brinell hardness number
Bi	biot
BN	bond number
BNS	nuclear backscattering spectroscopy
BO	bond order, Born-Oppenheimer (approximation)
BOD	biochemical oxygen demand
bp	boiling point
bpy	2,2'-bipyridine
Bq	becquerel
BRE	bond resonance energy
BSSE	basis set superposition error
Btu	British thermal unit
bu	bushel
Bu	butyl
Bz	benzoyl
Bzl	benzyl
c	combustion reaction
c	amount concentration, specific heat, velocity
c_0	speed of light in vacuum
C	coulomb, cytosine (in genetic code)
°C	degree Celsius
C	capacitance, heat capacity, number concentration
ca.	approximately
cal	calorie

calc	calculated
CARS	coherent anti-Stokes Raman spectroscopy
CAS RN	Chemical Abstracts Service Registry Number
CAT	clear-air turbulence, computerized axial tomography
CBS	complete basis set
cc	cubic centimeter
CCD	charge-coupled device
cd	candela, condensed phase
c.d.	current density
CD	circular dichroism
CDP	cytidine 5'-diphosphate
CEPA	couplet electron pair approximation
cf.	compare
cfm	cubic feet per minute
cgs	centimeter-gram-second system
CHF	coupled Hartree-Fock (method)
Ci	curie
CI	configuration interaction, chemical ionization
CIDEP	chemically induced dynamic electron polarization
CIDNP	chemically induced dynamic nuclear polarization
cir	circular
CKFF	Cotton-Kraihanzel force field
CL	cathode luminescence
cm	centimeter
c.m.	center of mass
c.m.c.	critical micelle concentration
CMO	canonical molecular orbital
CMP	cytidine 5'-monophosphate
CN	coordination number
CNDO	complete neglect of differential overlap
Co	Cowling number
COD	chemical oxygen demand
conc	concentrated, concentration
const	constant
cos	cosine
cosh	hyperbolic cosine
COSY	correlation spectroscopy (in NMR)
cot	cotangent
coth	hyperbolic cotangent
cp	candle power
cP	centipoise
Cp	cyclopentadienyl
CP	chemically pure
CPA	coherent potential approximation
cpd	contact potential difference
cps	cycles per second
CPT	charge conjugation-space inversion-time reversal (theorem)
CPU	central processing unit
cr, cryst	crystalline (phase)
CRU	constitutional repeating unit
csc	cosecant
ct	carat
CT	charge transfer
CTEM	conventional transmission electron microscopy
CTP	cytidine 5'-triphosphate
CTR	controlled thermonuclear reaction
cu	cubic
CV	cyclic voltammetry
CVD	chemical vapor deposition
cw	continuous wave
cwt	hundredweight (112 pounds)
Cy	cyclohexyl
cyl	cylinder
Cys	cysteine
d	day, deuteron
d	distance, density, dextrorotatory
D	debye unit
D	diffusion coefficient, dissociation energy, electric displacement
Da	dalton
DA	donor-acceptor (complex)
dB	decibel
dc	direct current
DE	delocalization energy
dec	decomposes
deg	degree
den	density
det	determinant
dev	deviation
DFT	density functional theory
diam	diameter
dil	dilute, dilution
DIM	diatomics in molecules
dm	decimeter
dmf, DMF	*N,N*-dimethylformamide
dmso, DMSO	dimethylsulfoxide
DNA	deoxyribonucleic acid
DNase	deoxyribonuclease
DNMR	dynamic nuclear magnetic resonance
DOS	density of states
doz	dozen
d.p.	degree of polymerization
dpl	displacement
dpm	disintegrations per minute
dps	disintegrations per second
dr	dram
dRib	2-deoxyribose
DRIFT	diffuse reflectance infrared Fourier transform
DRS	diffuse reflectance spectroscopy
DSC	differential scanning calorimetry
DTA	differential thermal analysis
dyn	dyne
e	electron, base of natural logarithms
e	elementary charge, linear strain
E	electric field strength, electromotive force, energy, modulus of elasticity, entgegen (*trans* configuration)
E_h	Hartree energy
EA	electron affinity
EAN	effective atomic number
ECP	effective core potential
ECR	electron cyclotron resonance
ED	electron diffraction, effective dose
EDS	energy dispersive X-ray spectroscopy
EDTA	ethylenediaminetetraacetic acid
EELS	electron energy loss spectroscopy
EFFF	energy factored force field
EHMO	extended Hückel molecular orbital
EHT	extended Hückel theory
emf	electromotive force
emu	electromagnetic unit system
en	ethylenediamine

ENDOR	electron-nuclear double resonance
EOS	equation of state
EPMA	electron probe microanalysis
EPR	electron paramagnetic (spin) resonance
eq, eqn	equation
eqQ	quadrupole coupling constant
erf	error function
erg	erg
ESCA	electron spectroscopy for chemical analysis
e.s.d.	estimated standard deviation
ESD	electron stimulated desorption
ESR	electron spin resonance
est	estimate, estimated
esu	electrostatic unit system
Et	ethyl
ET	electron transfer, ephemeris time
Et_2O	diethyl ether
e.u.	entropy unit
Eu	Euler number
eV	electronvolt
EWG	electron withdrawing group
EXAFS	extended x-ray absorption fine structure
EXELFS	extended energy loss fine structure
exp	exponential function
expt	experimental
ext	external
f	formation reaction
f	activity coefficient, aperture ratio, focal length, force constant, frequency, fugacity
F	farad
°F	degree Fahrenheit
F	Faraday constant, force, angular momentum
FAD	flavin adenine dinucleotide
fcc	face centered cubic
FEL	free electron laser
FEM	field emission microscopy
FEMO	free electron molecular orbital
FET	field effect transistor
fid	free induction decay
FIM	field ion microscopy
FIR	far infrared
fl	fluid (phase)
FM	frequency modulation
Fo	Fourier number
fp	freezing point
fpm	feet per minute
fps	feet per second, foot-pound-second system
Fr	franklin
Fr	Froude number
Fru	fructose
FSGO	floating spherical Gaussian orbitaì
ft	foot
ft-lb	foot pound
FT	Fourier transform
FTIR	Fourier transform infrared spectroscopy
Fuc	fucose
Fuc-ol	fucitol
fus	fusion (melting)
g	gram, gas
g	acceleration due to gravity, degeneracy, statistical weight, Landé g-factor
G	gauss, guanine (in genetic code)
G	electrical conductance, Gibbs energy, gravitational constant, sheer modulus
gal	gallon
Gal	gal, galileo, galactose
GalN	galactosamine
GC	gas chromatography
GC-MS	gas chromatography-mass spectrometry
GDMS	glow discharge mass spectroscopy
gem	geminal (on the same carbon atom)
GeV	gigaelectronvolt
GIAO	gauge invariant atomic orbital
gl	glacial
GLC	gas-liquid chromatography
Glc	glucose
GlcN	glucosamine
Glc-ol	glucitol
Gln	glutamine
Glu	glutamic acid
Gly	glycine
GMP	guanosine 5'-triphosphate
GMT	Greenwich mean time
gpm	gallons per minute
gps	gallons per second
gr	grain
Gr	Grashof number
GTO	gaussian type atomic orbital
Gua	guanine
Gul	gulose
GUT	grand unified theory
GVB	generalized valence bond
GWS	Glashow-Weinberg-Salam (theory)
Gy	gray, gigayear
h	helion, hour
h	Planck constant
H	henry
H	enthalpy, Hamiltonian function, magnetic field
H_0	Hubble constant
ha	hectare
Ha	Hartmann number
Hacac	acetylacetone
HAM	hydrogenic atoms in molecules
hav	haversine
Hb	hemoglobin
hcp	hexagonal closed packed
Hea	ethanolamine
HEIS	high energy ion scattering
HEP	high energy physics
HF	high frequency
hfs	hyperfine structure
Him	imidazole
His	histidine
HMO	Hückel molecular orbital
HOMO	highest occupied molecular orbital
hp	horsepower
HPLC	high-performance liquid chromatography
Hpz	pyrazole
hr	hour
HREELS	high resolution electron energy loss spectroscopy
HREM	high resolution electron microscopy
HSAB	hard-soft acid-base (theory)

SCIENTIFIC ABBREVIATIONS AND SYMBOLS (continued)

HSE	homodesmotic stabilization energy
Hz	hertz
i	square root of minus one
I	electric current, ionic strength, moment of inertia, nuclear spin angular momentum, radiant intensity
IAT	international atomic time
i-Bu	isobutyl
IC	integrated circuit
ICP	inductively coupled plasma
ICR	ion cyclotron resonance
id	ideal (solution)
ID	inside diameter
Ido	idose
IDP	inosine 5'-diphosphate
IE	ionization energy
i.e.p.	isoelectric point
IEPA	independent electron pair approximation
IF	intermediate frequency
IGLO	individual gauge for localized orbitals
Ile	isoleucine
Im	imaginary part
imm	immersion
IMPATT	impact ionization avalanche transit time
in.	inch
INDO	intermediate neglect of differential overlap
INS	inelastic neutron scattering, ion neutralization spectroscopy
int	internal
I/O	input/output
IP	ionization potential
IPN	interpenetrating polymer network
i-Pr	isopropyl
IPR	isotopic perturbation of resonance
IPTS	International Practical Temperature Scale
IR	infrared
IRAS	reflection-absorption infrared spectroscopy
IRC	intrinsic reaction coordinate
isc	intersystem crossing
ISE	isodesmic stabilization energy
ISS	ion scattering spectroscopy
ITP	inosine 5'-triphosphate
ITS	International Temperature Scale (1990)
IU	international unit
j	angular momentum, electric current density
J	joule
J	angular momentum, electric current density, flux, Massieu function
k	absorption index, Boltzmann constant, rate constant, thermal conductivity, wave vector
K	kelvin
K	absorption coefficient, bulk modulus, equilibrium constant, kinetic energy
kb	kilobar, kilobase (DNA or RNA)
kcal	kilocalorie
KE	kinetic energy
keV	kiloelectronvolt
kg	kilogram
kgf	kilogram force
kJ	kilojoule
km	kilometer
Kn	Knudsen number
kPa	kilopascal
kt	karat
kV	kilovolt
kva	kilovolt ampere
kW	kilowatt
kwh	kilowatt hour
l	liquid, liter
l	angular momentum, length, levorotatory
L	liter, lambert
L	Avogadro constant, inductance, Lagrange function
lat.	latitude
lb	pound
lbf	pound force
lc	liquid crystal
LC	liquid chromatography
LCAO	linear combination of atomic orbitals
LD	lethal dose
Le	Lewis function
LED	light emitting diode
LEED	low-energy electron diffraction
LEIS	low energy ion scattering
Leu	leucine
LFER	linear free energy relationship
lim	limit
LIMS	laser ionization mass spectroscopy, laboratory information management system
liq	liquid
lm	lumen
ln	logarithm (natural)
LNDO	local neglect of differential overlap
log	logarithm (common)
long.	longitude
LST	local sidereal time
LT	local time
LTE	local thermodynamic equilibrium
LUMO	lowest unoccupied molecular orbital
lut	lutidine
lx	lux
ly	langley
l.y.	light year
Lys	lysine
Lyx	lyxose
m	meter, molal (as in 0.1 m solution), metastable (isotope)
m	magnetic dipole moment, mass, molality, angular momentum component, *meta* (as chemical descriptor)
M	molar (as in 0.1 M solution), metal (in chemical formulas)
M	magnetization, molar mass, mutual inductance, torque, angular momentum component
M_r	molecular weight (relative molar mass)
Ma	Mach number
Man	mannose
MASNMR	magic angle spinning nuclear magnetic resonance
max	maximum
MBE	molecular beam epitaxy
MBPT	many body perturbation theory
MC	Monte Carlo (method)
MCD	magnetic circular dichroism
MCPF	modified couple pair functional
MCSCF	multi-configurational self-consistent field

SCIENTIFIC ABBREVIATIONS AND SYMBOLS (continued)

MD	molecular dynamics
Me	methyl
MEP	molecular electrostatic potential
MERP	minimum energy reaction path
Mes	mesityl
MESFET	metal-semiconductor field-effect transistor
Met	methionine
meV	millielectronvolt
MeV	megaelectronvolt
MF	molecular formula
mg	milligram
MHD	magnetohydrodynamics
mi	mile
MIM	molecules-in-molecules
min	minimum, minute
MINDO	modified intermediate neglect of differential overlap
MIR	mid-infrared
misc	miscible
MKS	meter-kilogram-second system
MKSA	meter-kilogram-second-ampere system
mL, ml	milliliter
mm	millimeter
MM	molecular mechanics
mmf	magnetomotive force
mmHg	millimeter of mercury
MO	molecular orbital
mol	mole
mol.wt.	molecular weight
mon	monomeric form
MOS	metal-oxide semiconductor
MOSFET	metal-oxide semiconductor field-effect transistor
mp	melting point
MPa	megapascal
MPA	Mulliken population analysis
Mpc	megaparsec
MRI	magnetic resonance imaging
mRNA	messenger RNA
ms	millisecond
MS	mass spectroscopy
MSL	mean sea level
Mur	muramic acid
mV	millivolt
mW	milliwatt
MW	megawatt, microwave, molecular weight
Mx	maxwell
n	neutron
n	amount of substance, number density, principal quantum number, refractive index, normal (in chemical formulas)
N	newton
N	angular momentum, neutron number
N_A	Avogadro constant
N_E	density of states
NAA	neutron activation analysis
NAD	nicotinamide adenine dinucleotide
NADH	reduced NAD
NADP	nicotinamide adenine dinucleotide phosphate
NAO	natural atomic orbital
NBO	natural bond order
nbp	normal boiling point
Neu	neuraminic acid

NEXAFS	near-edge x-ray absorption fine structure
ng	nanogram
NIR	near infrared
nm	nanometer
NMR	nuclear magnetic resonance
NNDO	neglect of nonbonded differential overlap
NO	natural orbital
NOE	nuclear Overhauser effect
NPA	natural population analysis
NQR	nuclear quadrupole resonance
NRA	prompt nuclear reaction analysis
ns	nanosecond
NTP	normal temperature and pressure
Nu	nucleophile
Nu	Nusselt number
o	*ortho* (as chemical descriptor)
obs, obsd	observed
OD	optical density, outside diameter
Oe	oersted
ORD	optical rotatory dispersion
oz	ounce
p	proton
p	dielectric polarization, electric dipole moment, momentum, pressure, *para* (as chemical descriptor)
P	poise
P	power, pressure, probability, sound energy flux
Pa	pascal
PA	proton affinity
PAS	photoacoustic spectroscopy
pc	parsec
PCR	polymerase chain reaction
PD	potential difference
pdl	poundal
pe	probable error
Pe	Péclet number
PES	photoelectron spectroscopy
PET	positron emission tomography
peth	petroleum ether
pf	power factor
pg	picogram
pH	negative log of hydrogen ion concentration
Ph	phenyl
Phe	phenylalanine
pI	isoelectric point
pip	piperidine
p*K*	negative log of ionization constant
pm	picometer
PMO	perturbational molecular orbital
PNDO	partial neglect of differential overlap
PNRA	prompt nuclear reaction analysis
pol	polymeric form
ppb	parts per billion
ppm	parts per million
PPP	Pariser-Parr-Pople (method)
ppt	parts per thousand, precipitate
Pr	propyl
Pr	Prandtl number
PRDDO	partial retention of diatomic differential overlap
Pro	proline
ps	picosecond
PS	photoelectron spectroscopy

SCIENTIFIC ABBREVIATIONS AND SYMBOLS (continued)

PSD	photon stimulated desorption
Psi	psicose
psi	pounds per square inch
psia	pounds per square inch absolute
psig	pounds per square inch gage
pt	pint
PVT	pressure-volume-temperature
py	pyridine
q	electric field gradient, flow rate, heat, wave vector (phonons)
Q	electric charge, heat, partition function, quadrupole moment, radiant energy, vibrational normal coordinate
QCD	quantum chromodynamics
QED	quantum electrodynamics
Q.E.D.	quod erat demonstrandum (which was to be proved)
QSAR	quantitative structure-activity relationship
QSO	quasi-stellar object (quasar)
qt	quart
quad	quadrillion Btu (= 1.05510^{18} J)
Qui	quinovose
q.v.	quod vide (which you should see)
r	reaction
r	position vector, radius
R	roentgen, alkyl radical (in chemical formulas)
°R	degree Rankine
R	electrical resistance, gas constant, molar refraction, Rydberg constant
RA	right ascension
rad	radian
RAIRS	reflection-absorption infrared spectroscopy
RAM	random access memory
RBS	Rutherford backscattering spectroscopy
RE	resonance energy
Re	real part
RED	radial electron distribution
REM	reflection electron microscopy
rem	roentgen equivalent man
RF	radiofrequency
Rha	rhamnose
RHEED	reflection high-energy electron diffraction
RHF	restricted Hartree-Fock (theory)
RIA	radioimmunoassay
Rib	ribose
Ribulo	ribulose
rms	root mean square
RNA	ribonucleic acid
RNase	ribonuclease
rRNA	ribosomal RNA
ROHF	restricted open shell Hartree-Fock
ROM	read only memory
RPA	random phase approximation
rpm	revolutions per minute
rps	revolutions per second
RRK	Rice-Ramsperger-Kassel (theory)
RRKM	Rice-Ramsperger-Kassel-Marcus (theory)
RRS	resonance Raman spectroscopy
RS	Raman spectroscopy
Ry	rydberg
s	second, solid
s	path length, solubility, spin angular momentum, symmetry number, symmetrical (as stereochemical descriptor)

S	siemens
S	area, entropy, probability current density, Poynting vector, symmetry coordinate, spin angular momentum
SALC	symmetry adapted linear combinations
SALI	surface analysis by laser ionization
SAM	scanning Auger microscopy
SANS	small angle neutron scattering
Sar	sarcosine
sat, satd	saturated
SAXS	small angle x-ray scattering
s-Bu	*sec*-butyl
Sc	Schmidt number
SCE	saturated calomel electrode
SCF	self-consistent field
SCR	silicon-controlled rectifier
sd	standard deviation
sec	secant, second
sec	secondary (in chemical name)
SEELFS	surface sensitive energy loss fine structure
SEM	scanning electron microscope
sepn	separation
Ser	serine
SERS	surface-enhanced Raman spectroscopy
SET	single electron transfer
SEXAFS	surface extended x-ray absorption fine structure
Sh	Sherwood number
SI	International System of Units
SIMS	secondary ion mass spectroscopy
sin	sine
SINDO	symmetrically orthogonalized INDO method
sinh	hyperbolic sine
SIPN	semi-interpenetrating polymer network
SLAM	scanning laser acoustic microscopy
sln	solution
SMO	semiempirical molecular orbital
SMOW	Standard Mean Ocean Water
SNMS	sputtered neutral mass spectroscopy
SNU	solar neutrino unit
SO	spin orbital
sol	soluble, solution
soln	solution
SOMO	singly occupied molecular orbital
Sor	sorbose
sp gr	specific gravity
SPM	scanned probe microscopy
sq	square
sr	steradian
Sr	Strouhal number
SSMS	spark source mass spectroscopy
St	stoke
St	Stanton number
std, stnd	standard (state)
STEM	scanning transmission electron microscope
STM	scanning tunneling microscopy
STO	Slater type orbital
STP	standard temperature and pressure
sub	sublimation, sublimes
Sv	sievert
t	metric tonne, triton
t	Celsius temperature, thickness, time, transport number
T	tesla

T	kinetic energy, period, term value, temperature (thermodynamic), torque, transmittance
Tag	tagatose
Tal	talose
tan	tangent
tanh	hyperbolic tangent
t-Bu	*tert*-butyl
TCA	trichloroacetic acid
TCE	trichloroethylene
tcne	tetracyanoethylene
TCSCF	two configuration self-consistent field
TE	transverse electric
TED	transmission electron diffraction, transferred electron device
TEM	transmission electron microscopy, transverse electromagnetic
temp	temperature
tert	tertiary (in chemical name)
TFD	Thomas-Fermi-Dirac (method)
TGA	thermo-gravimetric analysis
theor	theoretical
thf, THF	tetrahydrofuran
Thr	threonine
Thy	thymine
TL	thermoluminescence
TLC	thin-layer chromatography
TM	transverse magnetic
Tol	tolyl
Torr	torr
tRNA	transfer RNA
Trp	tryptophan
trs	transition
TS	transition state
tsp	teaspoon
Tyr	tyrosine
u	unified atomic mass unit
u	Bloch function, electric mobility, velocity
U	uracil (in genetic code)
U	electric potential difference, internal energy
UDP	uridine 5'-diphosphate
UHF	ultrahigh frequency, unrestricted Hartree-Fock (theory)
UMP	uridine 5'-monophosphate
uns, unsym	unsymmetrical (as chemical descriptor)
UPES	ultraviolet photoelectron spectroscopy
UPS	ultraviolet photoelectron spectroscopy
ur	urea
Ura	uracil
USP	United States Pharmacopeia
UT	universal time
UTP	uridine 5'-triphosphate
UV	ultraviolet
v	reaction rate, specific volume, velocity, vibrational quantum number, vicinal (as chemical descriptor)
V	volt
V	electric potential, potential energy, volume
Val	valine
vap	vaporization
VB	valence band, valence bond
VCD	vibrational circular dichroism
VHF	very high frequency
vic	vicinal (on adjacent carbon atoms)
VIS	visible region of the spectrum
vit	vitreous
VSEPR	valence shell electron pair repulsion
VSLI	very large scale integrated (circuit)
VUV	vacuum ultraviolet
v/v	volume per volume (volume of solute divided by volume of solution, expressed as percent)
w	energy density, mass fraction, velocity, work
W	watt
W	radiant energy, statistical weight, work
WAXS	wide angle x-ray scattering
Wb	weber
We	Weber number
WKB	Wentzel-Kramers-Brillouin (method)
wt	weight
w/v	weight per volume (mass of solute divided by volume of solution, generally expressed as g/100 mL)
w/w	weight per weight (mass of solute divided by mass of solution, expressed as percent)
x	mole fraction
X	X unit, halogen (in chemical formula)
X	reactance
XAFS	x-ray absorption fine structure
XANES	x-ray absorption near-edge structure
XPES	x-ray photoelectron spectroscopy
XPS	x-ray photoelectron spectroscopy
XRD	x-ray diffraction
XRF	x-ray fluorescence
XRS	x-ray spectroscopy
Xyl	xylose
y, yr	year
Y	admittance, Planck function, Young's modulus
yd	yard
z	charge number (of an ion), collision frequency factor
Z	atomic number, compression factor, collision number, impedance, partition function, zusammen (*cis* configuration)
ZDO	zero differential overlap
ZPE, ZPVE	zero point vibrational energy
ZULU	Greenwich mean time
α	alpha particle
α	absorption coefficient, degree of dissociation, electric polarizability, expansion coefficient, fine structure constant
β	beta particle
γ	photon
γ	activity coefficient, conductivity, magnetogyric ratio, mass concentration, ratio of heat capacities, surface tension
Γ	Gruneisin parameter, level width, surface concentration
δ	chemical shift, Dirac delta function, Kronecker delta, loss angle
Δ	inertia defect, mass defect
ε	emittance, Levi-Civita symbol, linear strain, molar absorption coefficient, permittivity
η	overpotential, viscosity
θ	Bragg angle, temperature, scattering angle, surface coverage
Θ	quadrupole moment

SCIENTIFIC ABBREVIATIONS AND SYMBOLS (continued)

κ	compressibility, conductivity, magnetic susceptibility, molar absorption coefficient, transmission coefficient
λ	absolute activity, radioactive decay constant, thermal conductivity, wavelength
Λ	angular momentum, ionic conductivity
μ	muon
μ	chemical potential, electric dipole moment, electric mobility, friction coefficient, Joule-Thompson coefficient, magnetic dipole moment, mobility, permeability
μF	microfarad
μg	microgram
μm	micrometer
μs	microsecond
ν	frequency, kinematic velocity, stoichiometric number, wavenumber
ν_e	neutrino
π	pion
Π	osmotic pressure, Peltier coefficient
ρ	density, reflectance, resistivity
σ	electrical conductivity, cross section, normal stress, shielding constant (NMR), Stefan-Boltzmann constant, surface tension
τ	transmittance, chemical shift, shear stress, relaxation time
ϕ	electrical potential, fugacity coefficient, osmotic coefficient, quantum yield, volume fraction, wavefunction
Φ	magnetic flux, potential energy, radiant power, work function
χ	magnetic susceptibility, electronegativity
χ_e	electric susceptibility
ψ	wavefunction
ω	circular frequency, angular velocity, harmonic vibration wavenumber, statistical weight
Ω	ohm
Ω	axial angular momentum, solid angle

GREEK, RUSSIAN, AND HEBREW ALPHABETS

The following table presents the Hebrew, Greek, and Russian alphabets, their letters, the names of the letters, and the English equivalents.

HEBREW[1,3]

Letter	Name	English
א	aleph	ʼ [2]
ב	beth	b, bh
ג	gimel	g, gh
ד	daleth	d, dh
ה	he	h
ו	waw	w
ז	zayin	z
ח	heth	ḥ
ט	teth	ṭ
י	yodh	y
כ ך	kaph	k, kh
ל	lamedh	l
מ ם	mem	m
נ ן	nun	n
ס	samekh	s
ע	ayin	ʻ
פ ף	pe	p, ph
צ ץ	sadhe	ṣ
ק	qoph	q
ר	resh	r
שׂ	sin	ś
שׁ	shin	sh
ת	taw	t, th

GREEK[4]

Letter	Name	English
Α α	alpha	a
Β β	beta	b
Γ γ	gamma	g, n
Δ δ	delta	d
Ε ε	epsilon	e
Ζ ζ	zeta	z
Η η	eta	ē
Θ θ	theta	th
Ι ι	iota	i
Κ κ	kappa	k
Λ λ	lambda	l
Μ μ	mu	m
Ν ν	nu	n
Ξ ξ	xi	x
Ο ο	omicron	o
Π π	pi	p
Ρ ρ	rho	r, rh
Σ σ ς	sigma	s
Τ τ	tau	t
Υ υ	upsilon	y, u
Φ φ	phi	ph
Χ χ	chi	ch
Ψ ψ	psi	ps
Ω ω	omega	ō

RUSSIAN

Letter	English
А а	a
Б б	b
В в	v
Г г	g
Д д	d
Е е	e
Ж ж	zh
З з	z
И и Й й	i, ĭ
К к	k
Л л	l
М м	m
Н н	n
О о	o
П п	p
Р р	r
С с	s
Т т	t
У у	u
Ф ф	f
Х х	kh
Ц ц	ts
Ч ч	ch
Ш ш	sh
Щ щ	shch
Ъ ъ [5]	"
Ы ы	y
Ь ь [6]	'
Э э	e
Ю ю	yu
Я я	ya

1 Where two forms of a letter are given, the second one is the form used at the end of a word.
2 Not represented in transliteration when initial.
3 The Hebrew letters are primarily consonants; a few of them are also used secondarily to represent certain vowels, when provided at all, is by means of a system of dots or strokes adjacent to the consonated characters.
4 The letter gamma is transliterated "n" only before velars; the letter upsilon is transliterated "u" only as the final element in diphthongs.
5 This sign indicates that the immediately preceding consonant is not palatized even though immediately followed by a palatized vowel.
6 This sign indicates that the immediately preceding consonant is palatized even though not immediately followed by a palatized vowel.

DEFINITIONS OF SCIENTIFIC TERMS

Brief definitions of selected terms of importance in chemistry, physics, and related fields of science are given in this section. The selection process emphasizes the following types of terms:

- Physical quantities
- Units of measure
- Classes of chemical compounds and materials
- Important theories, laws, and basic concepts.

Individual chemical compounds are not included.

Definitions have taken wherever possible from the recommendations of international or national bodies, especially the International Union of Pure and Applied Chemistry (IUPAC) and International Organization for Standardization (ISO). For physical quantities and units, the recommended symbol is also given. The source of such definitions is indicated by the reference number in brackets following the definition. In many cases these official definitions have been edited in the interest of stylistic consistency and economy of space. The user is referred to the original source for further details.

* An asterisk following a term indicates that further information can be found by consulting the index of this handbook under the entry for that term.

REFERENCES

1. *ISO Standards Handbook 2, Units of Measurement,* International Organization for Standardization, Geneva, 1992.
2. *Quantities, Units, and Symbols in Physical Chemistry, Second Edition*, International Union of Pure and Applied Chemistry, Blackwell Scientific Publications, Oxford, 1993.
3. *Compendium of Chemical Terminology,* International Union of Pure and Applied Chemistry, Blackwell Scientific Publications, Oxford, 1987.
4. *A Guide to IUPAC Nomenclature of Organic Compounds*, International Union of Pure and Applied Chemistry, Blackwell Scientific Publications, Oxford, 1993.
5. *Glossary of Class Names of Organic Compounds and Reactive Intermediates Based on Structure, Pure and Applied Chemistry*, 67, 1307, 1995.
6. *Compendium of Analytical Nomenclature*, International Union of Pure and Applied Chemistry, Blackwell Scientific Publications, Oxford, 1987.
7. *Nomenclature of Inorganic Chemistry*, International Union of Pure and Applied Chemistry, Blackwell Scientific Publications, Oxford, 1990.
8. *Glossary of Basic Terms in Polymer Science, Pure and Applied Chemistry*, 68, 2287, 1996.
9. *The International Temperature Scale of 1990, Metrologia*, 27, 107, 1990.
10. *Compilation of ASTM Standard Definitions*, American Society of Testing and Materials, Philadelphia, 1990.
11. *ASM Metals Reference Book,* American Society for Metals, Metals Park, OH, 1983.

***Ab initio* method -** An approach to quantum-mechanical calculations on molecules which starts with the Schrödinger equation and carries out a complete integration, without introducing empirical factors derived from experimental measurement.

Absorbance (*A*) - Defined as $-\log(1-\alpha) = \log(1/\tau)$, where α is the absorptance and τ the transmittance of a medium through which a light beam passes. [2]

Absorbed dose (*D*) - For any ionizing radiation, the mean energy imparted to an element of irradiated matter divided by the mass of that element. [1]

Absorptance (α) - Ratio of the radiant or luminous flux in a given spectral interval absorbed in a medium to that of the incident radiation. Also called absorption factor. [1]

Absorption coefficient (*a*) - The relative decrease in the intensity of a collimated beam of electromagnetic radiation, as a result of absorption by a medium, during traversal of an infinitesimal layer of the medium, divided by the length traversed. [1]

Absorption coefficient, molar (ε) - Absorption coefficient divided by amount-of-substance concentration of the absorbing material in the sample solution ($\varepsilon = a/c$). The SI unit is m^2/mol. Also called extinction coefficient, but usually in units of $mol^{-1}dm^3cm^{-1}$. [2]

Acceleration - Rate of change of velocity with respect to time.

Acceleration due to gravity (*g*)* - The standard value ($9.80665\ m/s^2$) of the acceleration experienced by a body in the earth's gravitational field. [1]

Acenes - Polycyclic aromatic hydrocarbons consisting of fused benzene rings in a rectilinear arrangement. [5]

Acid - Historically, a substance that yields an H^+ ion when it dissociates in solution, resulting in a pH<7. In the Brönsted definition, an acid is a substance that donates a proton in any type of reaction. The most general definition, due to G.N. Lewis, classifies any chemical species capable of accepting an electron pair as an acid.

Acid dissociation constant (*K*$_a$)* - The equilibrium constant for the dissociation of an acid HA through the reaction $HA + H_2O$ 1 $A^- + H_3O^+$. The quantity $pK_a = -\log K_a$ is often used to express the acid dissociation constant.

Actinides - The elements of atomic number 89 through 103, e.g., Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr. [7]

Activation energy* - In general, the energy that must be added to a system in order for a process to occur, even though the process may already be thermodynamically possible. In chemical kinetics, the activation energy is the height of the potential barrier separating the products and reactants. It determines the temperature dependence of the reaction rate.

Activity - For a mixture of substances, the absolute activity λ of substance B is defined as $\lambda_B = \exp(\mu_B/RT)$, where μ_B is the chemical potential of substance B, R the gas constant, and T the thermodynamic temperature. The relative activity a is defined as $a_B = \exp[(\mu_B-\mu_B{}^\circ)/RT]$, where $\mu_B{}^\circ$ designates the chemical potential in the standard state. [2]

Activity coefficient (γ)* - Ratio of the activity a_B of component B of a mixture to the concentration of that component. The value of γ depends on the method of stating the composition. For mole fraction x_B, the relation is $a_B = \gamma_B\, x_B$; for molarity c_B, it is $a_B = \gamma_B\, c_B/c^\circ$, where c° is the standard state composition (typically chosen as 1 mol/L); for molality

m_B, it is $a_B = \gamma_B m_B/m°$, where $m°$ is the standard state molality (typically 1 mol/kg). [2]

Activity, of radioactive substance (*A*) - The average number of spontaneous nuclear transitions from a particular energy state occurring in an amount of a radionuclide in a small time interval divided by that interval. [1]

Acyl groups - Groups formed by removing the hydroxy groups from oxoacids that have the general structure RC(=O)(OH) and replacement analogues of such acyl groups. [5]

Adiabatic process - A thermodynamic process in which no heat enters or leaves the system.

Admittance (*Y*) - Reciprocal of impedance. $Y = G + iB$, where G is conductance and B is susceptance. [1]

Adsorption - A process in which molecules of gas, of dissolved substances in liquids, or of liquids adhere in an extremely thin layer to surfaces of solid bodies with which they are in contact. [10]

Albedo* - The ratio of the light reflected or scattered from a surface to the intensity of incident light. The term is often used in reference to specific types of terrain or to entire planets.

Alcohols - Compounds in which a hydroxy group, -OH, is attached to a saturated carbon atom. [5]

Aldehydes - Compounds RC(=O)H, in which a carbonyl group is bonded to one hydrogen atom and to one R group. [5]

Aldoses - Aldehydic parent sugars (polyhydroxyaldehydes $H[CH(OH)]_nC(=O)H$, n>1) and their intramolecular hemiacetals. [5]

Aldoximes - Oximes of aldehydes: RCH=NOH. [5]

Alfvén number (*Al*) - A dimensionless quantity used in plasma physics, defined by $Al = v(\rho\mu)^{1/2}/B$, where ρ is density, v is velocity, μ is permeability, and B is magnetic flux density. [2]

Alfven waves - Very low frequency waves which can exist in a plasma in the presence of a uniform magnetic field. Also called magnetohydrodynamic waves.

Alicyclic compounds - Aliphatic compounds having a carbocyclic ring structure which may be saturated or unsaturated, but may not be a benzenoid or other aromatic system. [5]

Aliphatic compounds - Acyclic or cyclic, saturated or unsaturated carbon compounds, excluding aromatic compounds. [5]

Alkali metals - The elements lithium, sodium, potassium, rubidium, cesium, and francium.

Alkaline earth metals - The elements calcium, strontium, barium, and radium. [7]

Alkaloids - Basic nitrogen compounds (mostly heterocyclic) occurring mostly in the plant kingdom (but not excluding those of animal origin). Amino acids, peptides, proteins, nucleotides, nucleic acids, and amino sugars are not normally regarded as alkaloids. [5]

Alkanes - Acyclic branched or unbranched hydrocarbons having the general formula C_nH_{2n+2}, and therefore consisting entirely of hydrogen atoms and saturated carbon atoms. [5]

Alkenes - Acyclic branched or unbranched hydrocarbons having one carbon-carbon double bond and the general formula C_nH_{2n}. Acyclic branched or unbranched hydrocarbons having more than one double bond are alkadienes, alkatrienes, etc. [5]

Alkoxides - Compounds, ROM, derivatives of alcohols, ROH, in which R is saturated at the site of its attachment to oxygen and M is a metal or other cationic species. [5]

Alkyl groups - Univalent groups derived from alkanes by removal of a hydrogen atom from any carbon atom: C_nH_{2n+1}-. The groups derived by removal of a hydrogen atom from a terminal carbon atom of unbranched alkanes form a subclass of normal alkyl (*n*-alkyl) groups. The groups RCH_2-, R_2CH-, and R_3C- (R not equal to H) are primary, secondary, and tertiary alkyl groups, respectively. [5]

Alkynes - Acyclic branched or unbranched hydrocarbons having a carbon-carbon triple bond and the general formula C_nH_{2n-2}, RC≡CR′. Acyclic branched or unbranched hydrocarbons having more than one triple bond are known as alkadiynes, alkatriynes, etc. [5]

Allotropy - The occurrence of an element in two or more crystalline forms.

Allylic groups - The group CH_2=$CHCH_2$- (allyl) and derivatives formed by substitution. The term 'allylic position' or 'allylic site' refers to the saturated carbon atom. A group, such as -OH, attached at an allylic site is sometimes described as "allylic". [5]

Amagat volume unit - A non-SI unit previously used in high pressure science. It is defined as the molar volume of a real gas at one atmosphere pressure and 273.15 K. The approximate value is 22.4 L/mol.

Amides - Derivatives of oxoacids R(C=O)(OH) in which the hydroxy group has been replaced by an amino or substituted amino group. [5]

Amine oxides - Compounds derived from tertiary amines by the attachment of one oxygen atom to the nitrogen atom: R_3N^+-O^-. By extension the term includes the analogous derivatives of primary and secondary amines. [5]

Amines - Compounds formally derived from ammonia by replacing one, two, or three hydrogen atoms by hydrocarbyl groups, and having the general structures RNH_2 (primary amines), R_2NH (secondary amines), R_3N (tertiary amines). [5]

Amino acids* - Compounds containing both a carboxylic acid group (-COOH) and an amino group (-NH_2). The most important are the α-amino acids, in which the -NH_2 group in attached to the C atom adjacent to the -COOH group. In the ß-amino acids, there is an intervening carbon atom. [4]

Ampere (A)* - The SI base unit of electric current. [1]

Ampere's law - The defining equation for the magnetic induction $\boldsymbol{B}$, viz., $d\boldsymbol{F} = I d\boldsymbol{l} \times \boldsymbol{B}$, where $d\boldsymbol{F}$ is the force produced by a current I flowing in an element of the conductor $d\boldsymbol{l}$ pointing in the direction of the current.

Ångström (Å) - A unit of length used in spectroscopy, crystallography, and molecular structure, equal to 10^{-10} m.

Angular momentum (*L*) - The angular momentum of a particle about a point is the vector product of the radius vector from this point to the particle and the momentum of the particle; i.e., $\boldsymbol{L} = \boldsymbol{r} \times \boldsymbol{p}$. [1]

Angular velocity (ω) - The angle through which a body rotates per unit time.

Anilides - Compounds derived from oxoacids R(C=O)(OH) by replacing the -OH group by the -NHPh group or derivative formed by ring substitution. Also used for salts formed by replacement of a nitrogen-bound hydrogen of aniline by a metal. [5]

Anion - A negatively charged atomic or molecular particle.

Antiferroelectricity* - An effect analogous to antiferromagnetism in which electric dipoles in a crystal are ordered in two sublattices that are polarized in opposite directions, leading to zero net polarization. The effect vanishes above a critical temperature.

Antiferromagnetism* - A type of magnetism in which the magnetic moments of atoms in a solid are ordered into two antiparallel aligned sublattices. Antiferromagnets are characterized by a zero or small positive magnetic susceptibility. The susceptibility increases with temperature up to a critical value, the Néel temperature, above which the material becomes paramagnetic.

Antiparticle - A particle having the same mass as a given elementary particle and a charge equal in magnitude but opposite in sign.

Appearance potential* - The lowest energy which must be imparted to the parent molecule to cause it to produce a particular specified parent ion. This energy, usually stated in eV, may be imparted by electron impact, photon impact, or in other ways. More properly called appearance energy. [3]

Appearance potential spectroscopy (APS) - See Techniques for Materials Characterization, page **12**-1.

Are (a) - A unit of area equal to 100 m^2. [1]

Arenes - Monocyclic and polycyclic aromatic hydrocarbons. See aromatic compounds. [5]

Aromatic compounds - Compounds whose structure includes a cyclic delocalized π-electron system. Historical use of the term implies a ring containing only carbon (e.g., benzene, naphthalene), but it is often generalized to include heterocyclic structures such as pyridine and thiophene. [5]

Arrhenius equation - A key equation in chemical kinetics which expresses the rate constant k as $k = A\exp(-E_a/RT)$, where E_a is the activation energy, R the molar gas constant, and T the temperature. A is called the preexponential factor and, for simple gas phase reactions, may be identified with the collision frequency.

Arsines - AsH_3 and compounds derived from it by substituting one, two or three hydrogen atoms by hydrocarbyl groups. $RAsH_2$, R_2AsH, R_3As (R not equal to H) are called primary, secondary and tertiary arsines, respectively. [5]

Aryl groups - Groups derived from arenes by removal of a hydrogen atom from a ring carbon atom. Groups similarly derived from heteroarenes are sometimes subsumed in this definition. [5]

Astronomical unit (AU)* - The mean distance of the earth from the sun, equal to $1.49597870 \times 10^{11}$ m.

Atomic absorption spectroscopy (AAS) - See Techniques for Materials Characterization, page **12**-1.

Atomic emission spectroscopy (AES) - See Techniques for Materials Characterization, page **12**-1.

Atomic force microscopy (AFM) - See Techniques for Materials Characterization, page **12**-1.

Atomic mass* - The mass of a nuclide, normally expressed in unified atomic mass units (u).

Atomic mass unit (u)* - A unit of mass used in atomic, molecular, and nuclear science, defined as the mass of one atom of ^{12}C divided by 12. Its approximate value is 1.66054×10^{-27} kg. Also called the unified atomic mass unit. [1]

Atomic number (Z) - A characteristic property of an element, equal to the number of protons in the nucleus.

Atomic weight (A_r)* - The ratio of the average mass per atom of an element to 1/12 of the mass of nuclide ^{12}C. An atomic weight can be defined for a sample of any given isotopic composition. The standard atomic weight refers to a sample of normal terrestrial isotopic composition. The term relative atomic mass is synonymous with atomic weight. [2]

Attenuated total reflection (ATR) - See Techniques for Materials Characterization, page **12**-1.

Auger effect - An atomic process in which an electron from a higher energy level fills a vacancy in an inner shell, transferring the released energy to another electron which is ejected.

Aurora - An atmospheric phenomenon in which streamers of light are produced when electrons from the sun are guided into the thermosphere by the earth's magnetic field. It occurs in the polar regions at altitudes of 95—300 km.

Avogadro constant (N_A)* - The number of elementary entities in one mole of a substance.

Azeotrope - A liquid mixture in a state where the variation of vapor pressure with composition at constant temperature (or, alternatively, the variation of normal boiling point with composition) shows either a maximum or a minimum. Thus when an azeotrope boils the vapor has the same composition as the liquid.

Azides - Compounds bearing the group $-N_3$, viz. $-N{=}N^+{=}N^-$; usually attached to carbon, e.g. PhN_3, phenyl azide or azidobenzene. Also used for salts of hydrazoic acid, HN_3, e.g. NaN_3, sodium azide. [5]

Azines - Condensation products, $R_2C{=}NN{=}CR_2$, of two moles of a carbonyl compound with one mole of hydrazine. [5]

Azo compounds - Derivatives of diazene (diimide), HN=NH, wherein both hydrogens are substituted by hydrocarbyl groups, e.g., PhN=NPh, azobenzene or diphenyldiazene. [5]

Balmer series - The series of lines in the spectrum of the hydrogen atom which corresponds to transitions between the state with principal quantum number $n = 2$ and successive higher states. The wavelengths are given by $1/\lambda = R_H(1/4 - 1/n^2)$, where $n = 3,4,...$ and R_H is the Rydberg constant for hydrogen. The first member of the series ($n = 2$ 1 3), which is often called the H_α line, falls at a wavelength of 6563 Å.

Bar (bar) - A unit of pressure equal to 10^5 Pa.´

Bardeen-Cooper-Schrieffer (BCS) theory - A theory of superconductivity which is based upon the formation of electron pairs as a result of an electron-lattice interaction. The theory relates the superconducting transition temperature to the density of states and the Debye temperature.

Barn (b) - A unit used for expressing cross sections of nuclear processes, equal to 10^{-28} m^2.

Barrel - A unit of volume equal to 158.9873 L.

Baryon - Any elementary particle built up from three quarks. Examples are the proton, neutron, and various short-lived hyperons. Baryons have odd half-integer spins.

Base - Historically, a substance that yields an OH^- ion when it dissociates in solution, resulting in a pH>7. In the Brönsted definition, a base is a substance capable of accepting a proton in any type of reaction. The more general definition, due to G.N. Lewis, classifies any chemical species capable of donating an electron pair as a base.

Becquerel (Bq)* - The SI unit of radioactivity (disintegrations per unit time), equal to s^{-1}. [1]

Beer's law - An approximate expression for the change in intensity of a light beam that passes through an absorbing medium, viz., $\log(I/I_0) = -\varepsilon cl$, where I_0 is the incident intensity, I is the final intensity, ε is the molar (decadic) absorption coefficient, c is the molar concentration of the absorbing substance, and l is the path length. Also called the Beer-Lambert law

Binding energy* - A generic term for the energy required to decompose a system into two or more of its constituent parts. In nuclear physics, the binding energy is the energy difference between a nucleus and the separated nucleons of which it is composed (the energy equivalent of the mass defect). In atomic physics, it is the energy required to remove an electron from an atom.

Biot (Bi) - A name sometimes used for the unit of current in the emu system.

Birefringence - A property of certain crystals in which two refracted rays result from a single incident light ray. One, the ordinary ray, follows the normal laws of refraction, while the other, the extraordinary ray, exhibits a variable refractive index which depends on the direction in the crystal.

Black body radiation* - The radiation emitted by a perfect black body, i.e., a body which absorbs all radiation incident on it and reflects none. The wavelength dependence of the radiated energy density ρ (energy per unit volume per unit wavelength range) is given by the Planck formula

$$\rho = \frac{8\pi hc}{\lambda^5\left(e^{hc/\lambda kT} - 1\right)}$$

where λ is the wavelength, h is Planck's constant, c is the speed of light, k is the Boltzmann constant, and T is the temperature.

Black hole - A very dense object, formed in a supernova explosion, whose gravitational field is so large that no matter or radiation can escape from the object.

Bloch wave function - A solution of the Schrödinger equation for an electron moving in a spatially periodic potential; used in the band theory of solids.

Bohr magneton (μ_B)* - The atomic unit of magnetic moment, defined as

$eh/4\pi m_e$, where h is Planck's constant, m_e the electron mass, and e the elementary charge. It is the moment associated with a single electron spin.

Bohr, bohr radius (a_0)* - The radius of the lowest orbit in the Bohr model of the hydrogen atom, defined as $\varepsilon_o h^2/\pi m_e e^2$, where ε_o is the permittivity of a vacuum, h is Planck's constant, m_e the electron mass, and e the elementary charge. It is customarily taken as the unit of length when using atomic units.

Boiling point - The temperature at which the liquid and gas phases of a substance are in equilibrium at a specified pressure. The normal boiling point is the boiling point at normal atmospheric pressure (101.325 kPa).

Boltzmann constant (*k*)* - The molar gas constant R divided by Avogadro's constant.

Boltzmann distribution - An expression for the equilibrium distribution of molecules as a function of their energy, in which the number of molecules in a state of energy E is proportional to $\exp(-E/kT)$, where k is the Boltzmann constant and T is the temperature.

Bond strength - See Dissociation energy.

Born-Haber cycle* - A thermodynamic cycle in which a crystalline solid is converted to gaseous ions and then reconverted to the solid. The cycle permits calculation of the lattice energy of the crystal.

Bose-Einstein distribution - A modification of the Boltzmann distribution which applies to a system of particles that are bosons. The number of particles of energy E is proportional to $[e^{(E-\mu)/kT}-1]^{-1}$, where μ is a normalization constant, k is the Boltzmann constant, and T is the temperature.

Boson - A particle that obeys Bose-Einstein Statistics; specifically, any particle with spin equal to zero or an integer. This includes the photon, pion, deuteron, and all nuclei of even mass number.

Boyle's law - The empirical law, exact only for an ideal gas, which states that the volume of a gas is inversely proportional to its pressure at constant temperature.

Bragg angle (θ) - Defined by the equation $n\lambda = 2d\sin\theta$, which relates the angle θ between a crystal plane and the diffracted x-ray beam, the wavelength λ of the x-rays, the crystal plane spacing d, and the diffraction order n (any integer).

Bravais lattices* - The 14 distinct crystal lattices that can exist in three dimensions. They include three in the cubic crystal system, two in the tetragonal, four in the orthorhombic, two in the monoclinic, and one each in the triclinic, hexagonal, and trigonal systems.

Breakdown voltage - The potential difference at which an insulating substance undergoes a physical or chemical change that causes it to become a conductor, thus allowing current to flow through the sample.

Bremsstrahlung - Electromagnetic radiation generated when the velocity of a charged particle is reduced (literally, "braking radiation"). An example is the x-ray continuum resulting from collisions of electrons with the target in an x-ray tube.

Brewster angle - The angle of incidence for which the maximum degree of plane polarization occurs when a beam of unpolarized light is incident on the surface of a medium of refractive index n. At this angle, the angle between the reflected and refracted beams is 90°. The value of the Brewster angle is $\tan^{-1}n$.

Brillouin scattering - The scattering of light by acoustic phonons in a solid or liquid.

Brillouin zone - A region of allowed wave vectors and energy levels in a crystalline solid, which plays a part in the propagation of waves through the lattice.

British thermal unit (Btu) - A non-SI unit of energy, equal to approximately 1055 J. Several values of the Btu, defined in slightly different ways, have been used.

Brownian motion - The random movements of small particles suspended in a fluid, which arise from collisions with the fluid molecules.

Brunauer-Emmett-Teller method (BET) - See Techniques for Materials Characterization, page **12**-1.

Buffer* - A solution designed to maintain a constant pH when small amounts of a strong acid or base are added. Buffers usually consist of a fairly weak acid and its salt with a strong base. Suitable concentrations are chosen so that the pH of the solution remains close to the pK_a of the weak acid.

Calorie (cal) - A non-SI unit of energy, originally defined as the heat required to raise the temperature of 1 g of water by 1°C. Several calories of slightly different values have been used. The thermochemical calorie is now defined as 4.184 J.

Candela (cd)* - The SI base unit of luminous intensity. [1]

Capacitance (C) - Ratio of the charge acquired by a body to the change in potential. [1]

Carbamates - Salts or esters of carbamic acid, $H_2NC(=O)OH$, or of N-substituted carbamic acids: $R_2NC(=O)OR'$, (R′ = hydrocarbyl or a cation). The esters are often called urethanes or urethans, a usage that is strictly correct only for the ethyl esters. [5]

Carbenes - The electrically neutral species H_2C: and its derivatives, in which the carbon is covalently bonded to two univalent groups of any kind or a divalent group and bears two nonbonding electrons, which may be spin-paired (singlet state) or spin-non-paired (triplet state). [5]

Carbinols - An obsolete term for substituted methanols, in which the name carbinol is synonymous with methanol. [5]

Carbohydrates - Originally, compounds such as aldoses and ketoses, having the stoichiometric formula $C_n(H_2O)_n$ (hence "hydrates of carbon"). The generic term carbohydrate now includes mono-, oligo-, and polysaccharides, as well as their reaction products and derivatives. [5]

Carboranes - A contraction of carbaboranes. Compounds in which a boron atom in a polyboron hydride is replaced by a carbon atom with maintenance of the skeletal structure. [5]

Carboxylic acids - Oxoacids having the structure RC(=O)OH. The term is used as a suffix in systematic name formation to denote the -C(=O)OH group including its carbon atom. [5]

Carnot cycle - A sequence of reversible changes in a heat engine using a perfect gas as the working substance, which is used to demonstrate that entropy is a state function. The Carnot cycle also provides a means to calculate the efficiency of a heat engine.

Catalyst - A substance that participates in a particular chemical reaction and thereby increases its rate but without a net change in the amount of that substance in the system. [3]

Catenanes, catena compounds - Hydrocarbons having two or more rings connected in the manner of links of a chain, without a covalent bond. More generally, the class catena compounds embraces functional derivatives and hetero analogues. [5]

Cation - A positively charged atomic or molecular particle.

Centipoise (cP) - A common non-SI unit of viscosity, equal to mPa s.

Centrifugal distortion - An effect in molecular spectroscopy in which rotational levels are lowered in energy, relative to the values of a rigid rotor, as the rotational angular momentum increases. The effect may be understood classically as a stretching of the bonds in the molecule as it rotates faster, thus increasing the moment of inertia.

Ceramic - A nonmetallic material of very high melting point.

Cerenkov radiation - Light emitted when a beam of charged particles travels through a medium at a speed greater than the speed of light in the medium. It is typically blue in color.

Cgs system of units - A system of units based upon the centimeter, gram, and second. The cgs system has been supplanted by the International System (SI).

Chalcogens - The Group VIA elements (oxygen, sulfur, selenium, tellurium, and polonium). Compounds of these elements are called chalcogenides. [7]

Chaotic system - A complex system whose behavior is governed by deterministic laws but whose evolution can vary drastically when small changes are made in the initial conditions.

Charge - See Electric charge.

Charles' law - The empirical law, exact only for an ideal gas, which states that the volume of a gas is directly proportional to its temperature at constant pressure.

Charm - A quantum number introduced in particle physics to account for certain properties of elementary particles and their reactions.

Chelate - A compound characterized by the presence of bonds from two or more bonding sites within the same ligand to a central metal atom. [3]

Chemical potential - For a mixture of substances, the chemical potential of constituent B is defined as the partial derivative of the Gibbs energy *G* with respect to the amount (number of moles) of B, with temperature, pressure, and amounts of all other constituents held constant. Also called partial molar Gibbs energy. [2]

Chemical shift* - A small change in the energy levels (and hence in the spectra associated with these levels) resulting from the effects of chemical binding in a molecule. The term is used in fields such as NMR, Mössbauer, and photoelectron spectroscopy, where the energy levels are determined primarily by nuclear or atomic effects.

Chiral molecule - A molecule which cannot be superimposed on its mirror image. A common example is an organic molecule containing a carbon atom to which four different atoms or groups are attached. Such molecules exhibit optical activity, i.e., they rotate the plane of a polarized light beam.

Chlorocarbons - Compounds consisting solely of chlorine and carbon. [5]

Chromatography* - A method for separation of the components of a sample in which the components are distributed between two phases, one of which is stationary while the other moves. In gas chromatography the gas moves over a liquid or solid stationary phase. In liquid chromatography the liquid mixture moves through another liquid, a solid, or a gel. The mechanism of separation of components may be adsorption, differential solubility, ion-exchange, permeation, or other mechanisms. [6]

Clapeyron equation - A relation between pressure and temperature of two phases of a pure substance that are in equilibrium, viz., $dp/dT = \Delta_{trs}S/\Delta_{trs}V$, where $\Delta_{trs}S$ is the difference in entropy between the phases and $\Delta_{trs}V$ the corresponding difference in volume.

Clathrates - Inclusion compounds in which the guest molecule is in a cage formed by the host molecule or by a lattice of host molecules. [5]

Clausius (Cl) - A non-SI unit of entropy or heat capacity defined as cal/K = 4.184 J/K. [2]

Clausius-Clapeyron equation - An approximation to the Clapeyron equation applicable to liquid-gas and solid-gas equilibrium, in which one assumes an ideal gas with volume much greater than the condensed phase volume. For the liquid-gas case, it takes the form $d(\ln p)/dT = \Delta_{vap}H/RT^2$, where *R* is the molar gas constant and $\Delta_{vap}H$ is the molar enthalpy of vaporization. For the solid-gas case, $\Delta_{vap}H$ is replaced by the molar enthalpy of sublimation, $\Delta_{sub}H$.

Clausius-Mosotti equation - A relation between the dielectric constant ε_r at optical frequencies and the polarizability α:

$$\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{\rho N_A \alpha}{3M\varepsilon_0}$$

where ρ is density, N_A is Avogadro's number, *M* is molar mass, and ε_0 is the permittivity of a vacuum.

Clebsch-Gordon coefficients - A set of coefficients used to describe the vector coupling of angular momenta in atomic and nuclear physics.

Codon - A set of three bases, chosen from the four primary bases found in the DNA molecule (uracil, cytosine, adenine, and guanine), which specifies the production of a particular amino acid or carries some other genetic instruction. For example, the codon UCA specifies the amino acid serine, CAG specifies glutamine, etc. There are a total of 64 codons.

Coercive force - The magnetizing force at which the magnetic flux density is equal to zero. [10]

Coercivity* - The maximum value of coercive force that can be attained when a magnetic material is symmetrically magnetized to saturation induction. [10]

Coherent anti-Stokes Raman spectroscopy (CARS) - See Techniques for Materials Characterization, page **12**-1.

Colloid - Molecules or polymolecular particles dispersed in a medium that have, at least in one direction, a dimension roughly between 1 nm and 1 µm. [3]

Color center - A defect in a crystal that gives rise to optical absorption, thus changing the color of the material. A common type is the F-center, which results when an electron occupies the site of a negative ion.

Compressibility (κ)* - The fractional change of volume as pressure is increased, viz., $\kappa = -(1/V)(dV/dp)$. [1]

Compton wavelength (λ_C)* - In the scattering of electromagnetic radiation by a free particle (e.g., electron, proton), $\lambda_C = h/mc$ is the increase in wavelength, at a 90° scattering angle, corresponding to the transfer of energy from radiation to particle. Here *h* is Planck's constant, *c* the speed of light, and *m* the mass of the particle.

Conductance (*G*)* - For direct current, the reciprocal of resistance. More generally, the real part of admittance. [1]

Conductivity, electrical (σ)* - The reciprocal of the resistivity. [1]

Conductivity, thermal - See Thermal conductivity.

Congruent transformation - A phase transition (melting, vaporization, etc.) in which the substance preserves its exact chemical composition.

Constitutional repeating unit (CRU) - In polymer science, the smallest constitutional unit, the repetition of which constitutes a regular macromolecule, i.e., a macromolecule with all units connected identically with respect to directional sense. [8]

Copolymer - A polymer derived from more than one species of monomer. [8]

Coriolis effect - The deviation from simple trajectories when a mechanical system is described in a rotating coordinate system. It affects the motion of projectiles on the earth and in molecular spectroscopy leads to an important interaction between the rotational and vibrational motions. The effect may be described by an additional term in the equations of motion, called the Coriolis force.

Cosmic rays* - High energy nuclear particles, electrons, and photons, originating mostly outside the solar system, which continually bombard the earth's atmosphere.

Coulomb (C)* - The SI unit of electric charge, equal to A s. [1]

Coulomb's law - The statement that the force *F* between two electrical charges q_1 and q_2 separated by a distance *r* is $F = (4\pi\varepsilon_0)^{-1}q_1q_2/r^2$, where ε_0 is the permittivity of a vacuum.

Covalent bond - A chemical bond between two atoms whose stability results from the sharing of two electrons, one from each atom.

Cowling number (*Co*) - A dimensionless quantity used in plasma physics, defined by $Co = B^2/\mu\rho v^2$, where ρ is density, *v* is velocity, μ is permeability, and *B* is magnetic flux density. [2]

CPT theorem - A theorem in particle physics which states that any local Lagrangian theory that is invariant under proper Lorentz transformations is also invariant under the combined operations of charge conjugation, C, space inversion, P, and time reversal, T, taken in any order.

Critical point* - In general, the point on the phase diagram of a two-phase system at which the two coexisting phases have identical properties

and therefore represent a single phase. At the liquid-gas critical point of a pure substance, the distinction between liquid and gas vanishes, and the vapor pressure curve ends. The coordinates of this point are called the critical temperature and critical pressure. Above the critical temperature, it is not possible to liquefy the substance.

Cross section (σ)* - A measure of the probability of collision (or other interaction) between a beam of particles and a target which it encounters. In rough terms it is the effective area the target particles present to the incident ones; however, the precise definition depends on the nature of the interaction. A general definition of σ is the number of encounters per unit time divided by *nv*, where *n* is the concentration of incident particles and *v* their velocity.

Crosslink - In polymer science, a small region in a macromolecule from which at least four chains emanate, and formed by reactions involving sites or groups on existing macromolecules or by interactions between existing macromolecules. [8]

Crown compounds - Macrocyclic polydentate compounds, usually uncharged, in which three or more coordinating ring atoms (usually oxygen or nitrogen) are or may become suitably close for easy formation of chelate complexes with metal ions or other cationic species. [5]

Crust* - The outer layer of the solid earth, above the Mohorovicic discontinuity. Its thickness averages about 35 km on the continents and about 7 km below the ocean floor.

Cryoscopic constant (E_f)* - The constant that expresses the amount by which the freezing point T_f of a solvent is lowered by a non-dissociating solute, through the relation $\Delta T_f = E_f\, m$, where *m* is the molality of the solute.

Curie (Ci) - A non-SI unit of radioactivity (disintegrations per unit time), equal to 3.7×10^{10} s^{-1}.

Curie temperature (T_C)* - For a ferromagnetic material, the critical temperature above which the material becomes paramagnetic. Also applied to the temperature at which the spontaneous polarization disappears in a ferroelectric solid. [1]

Cyanohydrins - Alcohols substituted by a cyano group, most commonly, but not limited to, examples having a CN and an OH group attached to the same carbon atom. They are formally derived from aldehydes or ketones by the addition of hydrogen cyanide. [5]

Cycloalkanes - Saturated monocyclic hydrocarbons (with or without side chains). See alicyclic compounds. Unsaturated monocyclic hydrocarbons having one endocyclic double or one triple bond are called cycloalkenes and cycloalkynes, respectively. [5]

Cyclotron resonance - The resonant absorption of energy from a system in which electrons or ions that are orbiting in a uniform magnetic field are subjected to radiofrequency or microwave radiation. The resonance frequency is given by $\nu = eH/2\pi m^*c$, where *e* is the elementary charge, *H* is the magnetic field strength, *m** is the effective mass of the charged particle, and *c* is the speed of light. The effect occurs in both solids (involving electrons or holes) and in low pressure gasses (involving ions)

Dalton (Da) - A name sometimes used in biochemistry for the unified atomic mass unit (u).

De Broglie wavelength - The wavelength associated with the wave representation of a moving particle, given by *h*/*mv*, where *h* is Planck's constant, *m* the particle mass, and *v* the velocity.

De Haas-Van Alphen effect - An effect observed in certain metals and semiconductors at low temperatures and high magnetic fields, characterized by a periodic variation of magnetic susceptibility with field strength.

Debye equation* - The relation between the relative permittivity (dielectric constant) ε_r, polarizability α, and permanent dipole moment μ in a dielectric material whose molecules are free to rotate. It takes the form

$$\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{\rho N_A}{3M\varepsilon_0}\left(\alpha + \frac{\mu^2}{3kT}\right)$$

where ρ is density, N_A is Avogadro's number, *M* is molar mass, and ε_0 is the permittivity of a vacuum.

Debye length - In the Debye-Hückel theory of ionic solutions, the effective thickness of the cloud of ions of opposite charge which surrounds each given ion and shields the Coulomb potential produced by that ion.

Debye temperature (θ_D)* - In the Debye model of the heat capacity of a crystalline solid, $\theta_D = h\nu_D/k$, where *h* is Planck's constant, *k* is the Boltzmann constant, and ν_D is the maximum vibrational frequency the crystal can support. For $T \ll \theta_D$, the heat capacity is proportional to T^3.

Debye unit (D) - A non-SI unit of electric dipole moment used in molecular physics, equal to 3.335641×10^{-30} C m.

Debye-Waller factor (*D*) - The factor by which the intensity of a diffraction line is reduced because of lattice vibrations. [1]

Defect - Any departure from the regular structure of a crystal lattice. A Frenkel defect results when an atom or ion moves to an interstitial position and leaves behind a vacancy. A Schottky defect involves either a vacancy where the atom has moved to the surface or a structure where a surface atom has moved to an interstitial position.

Degree of polymerization - The number of monomeric units in a macromolecule or an oligomer molecule. [8]

Dendrite - A tree-like crystalline pattern often observed, for example, in ice crystals and alloys in which the crystal growth branches repeatedly.

Density (ρ)* - In the most common usage, mass density or mass per unit volume. More generally, the amount of some quantity (mass, charge, energy, etc.) divided by a length, area, or volume.

Density of states (N_E, ρ) - The number of one-electron states in an infinitesimal interval of energy, divided by the range of that interval and by volume. [1]

Dew point* - The temperature at which liquid begins to condense as the temperature of a gas mixture is lowered. In meteorology, it is the temperature at which moisture begins to condense on a surface in contact with the air.

Diamagnetism - A type of magnetism characterized by a negative magnetic susceptibility, so that the material, when placed in an external magnetic field, becomes weakly magnetized in the direction opposite to the field. This magnetization is independent of temperature.

Diazo compounds - Compounds having the divalent diazo group, $=N^+=N^-$, attached to a carbon atom, e.g., $CH_2=N_2$ diazomethane. [5]

Dielectric constant (ε)* - Ratio of the electric displacement in a medium to the electric field strength. Also called permittivity. [1]

Dienes - Compounds that contain two fixed double bonds (usually assumed to be between carbon atoms). Dienes in which the two double-bond units are linked by one single bond are termed conjugated. [5]

Differential scanning calorimetry (DSC) - See Techniques for Materials Characterization, page **12**-1.

Differential thermal analysis (DTA) - See Techniques for Materials Characterization, page **12**-1.

Diffusion* - The migration of atoms, molecules, ions, or other particles as a result of some type of gradient (concentration, temperature, etc.).

Diopter - A unit used in optics, formally equal to m^{-1}. It is used in expressing dioptic power, which is the reciprocal of the focal length of a lens.

Dipole moment, electric (*p*,μ)* - For a distribution of equal positive and

negative charge, the magnitude of the dipole moment vector is the positive charge multiplied by the distance between the centers of positive and negative charge distribution. The direction is given by the line from the center of negative charge to the center of positive charge.

Dipole moment, magnetic (m,μ) - Formally defined in electromagnetic theory as a vector quantity whose vector product with the magnetic flux density equals the torque. The magnetic dipole generated by a current I flowing in a small loop of area A has a magnetic moment of magnitude IA. In atomic and nuclear physics, a magnetic moment is associated with the angular momentum of a particle; e.g., an electron with orbital angular momentum $\boldsymbol{l}$ exhibits a magnetic moment of $-e\boldsymbol{l}/2m_e$ where e is the elementary charge and m_e the mass of the electron. [1]

Disaccharides - Compounds in which two monosaccharides are joined by a glycosidic bond. [5]

Dislocation - An extended displacement of a crystal from a regular lattice. An edge dislocation results when one portion of the crystal has partially slipped with respect to the other, resulting in an extra plane of atoms extending through part of the crystal. A screw dislocation transforms successive atomic planes into the surface of a helix.

Dispersion - Splitting of a beam of light (or other electromagnetic radiation) of mixed wavelengths into the constituent wavelengths as a result of the variation of refractive index of the medium with wavelength.

Dissociation constant* - The equilibrium constant for a chemical reaction in which a compound dissociates into its constituent parts.

Dissociation energy (D_e)* - For a diatomic molecule, the difference between the energies of the free atoms at rest and the minimum in the potential energy curve. The term bond dissociation energy (D_0), which can be applied to polyatomic molecules as well, is used for the difference between the energies of the fragments resulting when a bond is broken and the energy of the original molecule in its lowest energy state. The term bond strength implies differences in enthalpy rather than energy.

Domain - A small region of a solid in which the magnetic or electric moments of the individual units (atoms, molecules, or ions) are aligned in the same direction.

Domain wall - The transition region between adjacent ferromagnetic domains, generally a layer with a thickness of a few hundred ångström units. Also called Bloch wall.

Doppler effect - The change in the apparent frequency of a wave (sound, light, or other) when the source of the wave is moving relative to the observer.

Dose equivalent (H) - The product of the absorbed dose of radiation at a point of interest in tissue and various modifying factors which depend on the type of tissue and radiation. [1]

Drift velocity - The velocity of charge carriers (electrons, ions, etc.) moving under the influence of an electric field in a medium which subjects the carriers to some frictional force.

Dyne (dyn) - A non-SI (cgs) unit of force, equal to 10^{-5} N.

Ebullioscopic constant (E_b)* - The constant that expresses the amount by which the boiling point T_b of a solvent is raised by a non-dissociating solute, through the relation $\Delta T_b = E_b\, m$, where m is the molality of the solute.

Eddy currents - Circulating currents set up in conducting bulk materials or sheets by varying magnetic fields.

Effinghausen effect - The appearance of a temperature gradient in a current carrying conductor that is placed in a transverse magnetic field. The direction of the gradient is perpendicular to the current and the field.

Eigenvalue - An allowed value of the constant a in the equation $Au = au$, where A is an operator acting on a function u (which is called an eigenfunction). In quantum mechanics, the outcome of any observation is an eigenvalue of the corresponding operator. Also called characteristic value.

Einstein - A non-SI unit used in photochemistry, equal to one mole of photons.

Einstein temperature (θ_V) - In the Einstein theory of the heat capacity of a crystalline solid, $\theta_V = h\nu/k$, where h is Planck's constant, k is the Boltzmann constant, and ν is the vibrational frequency of the crystal.

Einstein transition probability - A constant in the Einstein relation $A_{ij} + B_{ij}\rho$ for the probability of a transition between two energy levels i and j in a radiation field of energy density ρ. The A_{ij} coefficient describes the probability of spontaneous emission, while B_{ij} and B_{ji} govern the probability of stimulated emission and absorption, respectively ($B_{ij} = B_{ji}$).

Elastic limit - The greatest stress which a material is capable of sustaining without any permanent strain remaining after complete release of the stress. [10]

Elastic modulus - See Young's modulus.

Electric charge (Q) - The quantity of electricity; i.e., the property that controls interactions between bodies through electrical forces.

Electric current (I) - The charge passing through a circuit per unit time. [1]

Electric displacement (D) - A vector quantity whose magnitude equals the electric field strength multiplied by the permittivity of the medium and whose direction is the same as that of the field strength.

Electric field strength (E) - The force exerted by an electric field on a point charge divided by the electric charge. [1]

Electric potential (V) - A scalar quantity whose gradient is equal to the negative of the electric field strength.

Electrical conductance - See Conductance

Electrical resistance - See Resistance

Electrical resistivity - See Resistivity.

Electrochemical series* - An arrangement of reactions which produce or consume electrons in an order based on standard electrode potentials. A common arrangement places metals in decreasing order of their tendency to give up electrons.

Electrode potential* - The electromotive force of a cell in which the electrode on the left is the standard hydrogen electrode and that on the right is the electrode in question. [2]

Electrolysis - The decomposition of a substance as a result of passing an electric current between two electrodes immersed in the sample.

Electromotive force (emf) - The energy supplied by a source divided by the charge transported through the source. [1]

Electron* - An elementary particle in the family of leptons, with negative charge and spin of 1/2.

Electron affinity* - The energy difference between the ground state of a gas-phase atom or molecule and the lowest state of the corresponding negative ion.

Electron cyclotron resonance (ECR) - See Techniques for Materials Characterization, page **12**-1.

Electron energy loss spectroscopy (EELS) - See Techniques for Materials Characterization, page **12**-1.

Electron nuclear double resonance (ENDOR) - See Techniques for Materials Characterization, page **12**-1.

Electron paramagnetic resonance (EPR) - See Techniques for Materials Characterization, page **12**-1.

Electron probe microanalysis (EPMA) - See Techniques for Materials Characterization, page **12**-1.

Electron spectroscopy for chemical analysis (ESCA) - See Techniques for Materials Characterization, page **12**-1.

Electron spin (s) - The quantum number, equal to 1/2, that specifies the intrinsic angular momentum of the electron.

Electron stimulated desorption (ESD) - See Techniques for Materials Characterization, page **12**-1.

Electron volt (eV)* - A non-SI unit of energy used in atomic and nuclear physics, equal to approximately 1.602177×10^{-19} J. The electron volt is defined as the kinetic energy acquired by an electron upon acceleration through a potential difference of 1 V. [1]

Electronegativity* - A parameter originally introduced by Pauling which describes, on a relative basis, the power of an atom or group of atoms to attract electrons from the same molecular entity. [3]

Electrophoresis - The motion of macromolecules or colloidal particles in an electric field. [3]

Emissivity (ε)* - Ratio of the radiant flux emitted per unit area to that of an ideal black body at the same temperature. Also called emittance. [1]

Emu - The electromagnetic system of units, based upon the cm, g, and s plus the emu of current (sometimes called the abampere).

Enantiomers - A chiral molecule and its non-superposable mirror image. The two forms rotate the plane of polarized light by equal amounts in opposite directions. Also called optical isomers.

Energy (*E*,*U*)* - The characteristic of a system that enables it to do work.

Energy gap* - In the theory of solids, the region between two energy bands, in which no bound states can occur.

Enols, alkenols - The term refers specifically to vinylic alcohols, which have the structure $HOCR'=CR_2$. Enols are tautomeric with aldehydes (R′ = H) or ketones (R′ not equal to H). [5]

Enthalpy (*H*)* - A thermodynamic function, especially useful when dealing with constant-pressure processes, defined by $H = E + PV$, where E is energy, P pressure, and V volume. [1]

Enthalpy of combustion* - The enthalpy change in a combustion reaction. Its negative is the heat released in combustion.

Enthalpy of formation, standard* - The enthalpy change for the reaction in which a substance is formed from its constituent elements, each in its standard reference state (normally refers to 1 mol, sometimes to 1 g, of the substance).

Enthalpy of fusion* - The enthalpy change in the transition from solid to liquid state.

Enthalpy of sublimation - The enthalpy change in the transition from solid to gas state.

Enthalpy of vaporization* - The enthalpy change in the transition from liquid to gas state.

Entropy (*S*)* - A thermodynamic function defined such that when a small quantity of heat dQ is received by a system at temperature T, the entropy of the system is increased by dQ/T, provided that no irreversible change takes place in the system. [1]

Entropy unit (e.u.) - A non-SI unit of entropy, equal to 4.184 J/K mol.

Ephemeris time - Time measured in tropical years from January 1, 1900.

Epoxy compounds - Compounds in which an oxygen atom is directly attached to two adjacent or non-adjacent carbon atoms of a carbon chain or ring system; thus cyclic ethers. [5]

Equation of continuity - Any of a class of equations that express the fact that some quantity (mass, charge, energy, etc.) cannot be created or destroyed. Such equations typically specify that the rate of increase of the quantity in a given region of space equals the net current of the quantity flowing into the region.

Equation of state* - An equation relating the pressure, volume, and temperature of a substance or system.

Equilibrium constant (*K*)* - For a chemical reaction aA + bB 1 cC + dD, the equilibrium constant is defined by:

$$K = \frac{a_C{}^c \cdot a_D{}^d}{a_A{}^a \cdot a_B{}^b}$$

where a_i is the activity of component i. To a certain approximation, the activities can be replaced by concentrations. The equilibrium constant is related to $\Delta_r G°$, the standard Gibbs energy change in the reaction, by $RT \ln K = -\Delta_r G°$.

Equivalent conductance - See Conductivity, electrical

Erg (erg) - A non-SI (cgs) unit of energy, equal to 10^{-7} J.

Esters - Compounds formally derived from an oxoacid RC(=O)(OH) and an alcohol, phenol, heteroarenol, or enol by linking, with formal loss of water from an acidic hydroxy group of the former and a hydroxy group of the latter. [5]

Esu - The electrostatic system of units, based upon the cm, g, and s plus the esu of charge (sometimes called the statcoulomb or franklin).

Ethers - Compounds with formula ROR, where R is not equal to H. [5]

Euler number (*Eu*) - A dimensionless quantity used in fluid mechanics, defined by $Eu = \Delta p/\rho v^2$, where p is pressure, ρ is density, and v is velocity. [2]

Eutectic - The point on a two-component solid-liquid phase diagram which represents the lowest melting point of any possible mixture. A liquid having the eutectic composition will freeze at a single temperature without change of composition.

Excitance (*M*) - Radiant energy flux leaving an element of a surface divided by the area of that element. [1]

Exciton - A localized excited state consisting of a bound electron-hole pair in a molecular or ionic crystal. The exciton can propagate through the crystal.

Exosphere - The outermost part of the earth's atmosphere, beginning at about 500 to 1000 km above the surface. It is characterized by densities so low that air molecules can escape into outer space.

Expansion coefficient - See thermal expansion coefficient.

Extended electron energy loss fine structure (EXELFS) - See Techniques for Materials Characterization, page **12**-1.

Extended x-ray absorption fine structure (EXAFS) - See Techniques for Materials Characterization, page **12**-1.

Extinction coefficient - See Absorption coefficient, molar

F-Center - See Color center

Fahrenheit temperature (°F) - The temperature scale based on the assignment of 32°F = 0°C and a temperature interval of °F =(5/9)°C; i.e., t/°F = (9/5)t/°C + 32.

Farad (F)* - The SI unit of electric capacitance, equal to C/V. [1]

Faraday constant (*F*)* - The electric charge of 1 mol of singly charged positive ions; i.e., $F = N_A e$, where N_A is Avogadro's constant and e is the elementary charge. [1]

Faraday effect* - The rotation of the plane of plane-polarized light by a medium placed in a magnetic field parallel to the direction of the light beam. The effect can be observed in solids, liquids, and gasses.

Fatty acids - Aliphatic monocarboxylic acids derived from or contained in esterified form in an animal or vegetable fat, oil, or wax. Natural fatty acids commonly have a chain of 4 to 28 carbons (usually unbranched and even-numbered), which may be saturated or unsaturated. By extension, the term is sometimes used to embrace all acyclic aliphatic carboxylic acids. [5]

Fermat's principle - The law that a ray of light traversing one or more media will follow a path which minimizes the time required to pass between two given points.

Fermi (f) - Name sometimes used in nuclear physics for the femtometer.

Fermi level - The highest energy of occupied states in a solid at zero temperature. Sometimes called Fermi energy. The Fermi surface is the surface in momentum space formed by electrons occupying the Fermi level.

Fermi resonance - An effect observed in vibrational spectroscopy when an overtone of one fundamental vibration closely coincides in energy with another fundamental of the same symmetry species. It leads to a splitting of vibrational bands.

Fermi-Dirac distribution - A modification of the Boltzmann distribu-

tion which takes into account the Pauli exclusion principle. The number of particles of energy E is proportional to $[e^{(E-\mu)/kT}+1]^{-1}$, where μ is a normalization constant, k the Boltzmann constant, and T the temperature. The distribution is applicable to a system of fermions.

Fermion - A particle that obeys Fermi-Dirac statistics. Specifically, any particle with spin equal to an odd multiple of 1/2. Examples are the electron, proton, neutron, muon, etc.

Ferrimagnetism* - A type of magnetism in which the magnetic moments of atoms in a solid are ordered into two nonequivalent sublattices with unequal magnetic moments, leading to a nonzero magnetic susceptibility.

Ferrite - A ferrimagnetic material of nominal formula MFe_2O_4, where M is a divalent metal; widely used in microwave switches and other solid state devices.

Ferroelectricity* - The retention of electric polarization by certain materials after the external field that produced the polarization has been removed.

Ferromagnetism* - A type of magnetism in which the magnetic moments of atoms in a solid are aligned within domains which can in turn be aligned with each other by a weak magnetic field. Some ferromagnetic materials can retain their magnetization when the external field is removed, as long as the temperature is below a critical value, the Curie temperature. They are characterized by a large positive magnetic susceptibility.

Fick's law - The statement that the flux J of a diffusing substance is proportional to the concentration gradient, i.e., $J = -D(\mathrm{d}c/\mathrm{d}x)$, where D is called the diffusion coefficient.

Field - A mathematical construct which describes the interaction between particles resulting from gravity, electromagnetism, or other physical phenomena. In classical physics a field is described by equations. Quantum field theory introduces operators to represent the physical observables.

Field emission microscopy (FEM) - See Techniques for Materials Characterization, page **12**-1.

Field ion microscopy (FIM) - See Techniques for Materials Characterization, page **12**-1.

Fine structure - The splitting in spectral lines that results from interactions of the electron spin with the orbital angular momentum.

Fine structure constant (α)* - Defined as $e^2/2hc\varepsilon_0$, where e is the elementary charge, h Planck's constant, c the speed of light, and ε_0 the permittivity of a vacuum. It is a measure of the strength of the electromagnetic interaction between particles.

First radiation constant (c_1)* - Constant ($= 2\pi hc^2$) in the equation for the radiant excitance M_λ of a black body:

$$M_\lambda = \frac{c_1\lambda^{-5}\Delta\lambda}{e^{c_2/\lambda T} - 1}$$

where λ is the wavelength, T is the temperature, and $c_2 = hc/k$ is the second radiation constant.

Flash point - The lowest temperature at which vapors above a volatile combustible substance will ignite in air when exposed to a flame. [10]

Fluence (*F*) - Term used in photochemistry to specify the energy per unit area delivered in a given time interval, for example by a laser pulse. [2]

Fluorocarbons - Compounds consisting solely of fluorine and carbon. [5]

Fluxoid - The quantum of magnetic flux in superconductivity theory, equal to $hc/2e$, where h is Planck's constant, c the velocity of light, and e the elementary charge.

Force (*F*) - The rate of change of momentum with time. [1]

Force constants (*f, k*)* - In molecular vibrations, the coefficients in the expression of the potential energy in terms of atom displacements from their equilibrium positions. In a diatomic molecule, $f = \mathrm{d}^2V/\mathrm{d}r^2$, where $V(r)$ is the potential energy and r is the interatomic distance. [2]

Fourier number (*Fo*) - A dimensionless quantity used in fluid mechanics, defined by $Fo = at/l^2$, where a is thermal diffusivity, t is time, and l is length. [2]

Fourier transform infrared spectroscopy (FTIR) - A technique for obtaining an infrared spectrum by use of an interferometer in which the path length of one of the beams is varied. A Fourier transformation of the resulting interferogram yields the actual spectrum. The technique is also used for NMR and other types of spectroscopy.

Fractals - Geometrical objects that are self-similar under a change of scale; i.e., they appear similar at all levels of magnification. They can be considered to have fractional dimensionality. Examples occur in diverse fields such as geography (rivers and shorelines), biology (trees), and solid state physics (amorphous materials).

Franck-Condon principle - An important principle in molecular spectroscopy which states that the nuclei in a molecule remain essentially stationary while an electronic transition is taking place. The physical interpretation rests on the fact that the electrons move much more rapidly than the nuclei because of their much smaller mass.

Franklin (Fr) - Name sometimes given to the unit of charge in the esu system.

Fraunhofer diffraction - Diffraction of light in situations where the source and observation point are so far removed that the wave surfaces may be considered planar.

Fraunhofer lines - Sharp absorption lines in the spectrum of sunlight, caused by absorption of the solar blackbody radiation by atoms near the sun's surface.

Free radical - See Radicals. The term "free radical" is often used more broadly for molecules that have a paramagnetic ground state (e.g., O_2) and sometimes for any transient or highly reactive molecular species.

Freezing point - See Melting point

Frequency (ν)* - Number of cycles of a periodic phenomenon divided by time. [1]

Fresnel diffraction - Diffraction of light in a situation where the source and observation point are sufficiently close together that the curvature of the wave surfaces must be taken into account.

Froude number (*Fr*) - A dimensionless quantity used in fluid mechanics, defined by $Fr = v/(lg)^{1/2}$, where v is velocity, l is length, and g is acceleration due to gravity. [2]

Fugacity (f_B) - For a gas mixture, the fugacity of component B is defined as the absolute activity λ_B times the limit, as the pressure p approaches zero at constant temperature, of p_B/λ_B. [2]

Fullerenes - Compounds composed solely of an even number of carbon atoms, which form a cage-like fused-ring polycyclic system with twelve five-membered rings and the rest six-membered rings. The archetypal example is [60]fullerene, where the atoms and bonds delineate a truncated icosahedron. The term has been broadened to include any closed cage structure consisting entirely of three-coordinate carbon atoms. [5]

Fulvalenes - The hydrocarbon fulvalene and its derivatives formed by substitution (and by extension, analogues formed by replacement of one or more carbon atoms of the fulvalene skeleton by a heteroatom). [5]

Fulvenes - The hydrocarbon fulvene and its derivatives formed by substitution (and by extension, analogues formed by replacement of one or more carbon atoms of the fulvene skeleton by a heteroatom). [5]

Fundamental vibrational frequencies* - In molecular spectroscopy, the characteristic vibrational frequencies obtained when the vibrational energy is expressed in normal coordinates. They determine the primary features of the infrared and Raman spectra of the molecule.

γ - Name sometimes used for microgram.

γ-rays* - Electromagnetic radiation (photons) with energy greater than about 0.1 MeV (wavelength less than about 1 pm).

***g*-Factor of the electron* -** The proportionality factor in the equation

relating the magnetic moment μ of an electron to its total angular momentum quantum number J, i.e., $\mu = -g\mu_B J$, where μ_B is the Bohr magneton. Also called Landé factor.

Gal - A non-SI unit of acceleration, equal to 0.01 m/s. Also called galileo.

Gallon (US) - A unit of volume equal to 3.785412 L.

Gallon (UK, Imperial) - A unit of volume equal to 4.546090 L.

Gauss (G) - A non-SI unit of magnetic flux density (B) equal to 10^{-4} T.

Gaussian system of units - A hybrid system used in electromagnetic theory, which combines features of both the esu and emu systems.

Gel - A colloidal system with a finite, but usually rather small, yield stress (the sheer stress at which yielding starts abruptly). [3]

Genetic code* - The set of relations between each of the 64 codons of DNA and a specific amino acid (or other genetic instruction).

Gibbs energy (*G*)* - An important function in chemical thermodynamics, defined by $G = H-TS$, where H is the enthalpy, S the entropy, and T the thermodynamic temperature. Sometimes called Gibbs free energy and, in older literature, simply "free energy". [2]

Gibbs phase rule - The relation $F = C - P + 2$, where C is the number of components in a mixture, P is the number of phases, and F is the degrees of freedom, i.e., the number of intensive variables that can be changed independently without affecting the number of phases.

Glass transition temperature* - The temperature at which an amorphous polymer is transformed, in a reversible way, from a viscous or rubbery condition to a hard and relatively brittle one. [10]

Glow discharge mass spectroscopy (GDMS) - See Techniques for Materials Characterization, page **12**-1.

Gluon - A hypothetical particle postulated to take part in the binding of quarks, in analogy to the role of the photon in electromagnetic interactions.

Glycerides - Esters of glycerol (propane-1,2,3-triol) with fatty acids, widely distributed in nature. They are by long-established custom subdivided into triglycerides, 1,2- or 1,3-diglycerides, and 1- or 2-monoglycerides, according to the number and positions of acyl groups. [5]

Glycols - Dihydric alcohols in which two hydroxy groups are on different carbon atoms, usually but not necessarily adjacent. Also called diols. [5]

Grain (gr) - A non-SI unit of mass, equal to 64.79891 mg.

Grain boundary - The interface between two regions of different crystal orientation.

Grashof number (*Gr*) - A dimensionless quantity used in fluid mechanics, defined by $Gr = l^3 g\alpha\Delta T\rho^2/\eta^2$, where T is temperature, ρ is density, l is length, η is viscosity, α is cubic expansion coefficient, and g is acceleration of gravity. [2]

Gravitational constant (*G*)* - The universal constant in the equation for the gravitational force between two particles, $F = Gm_1m_2/r^2$, where r is the distance between the particles and m_1 and m_2 are their masses. [1]

Gray (Gy)* - The SI unit of absorbed dose of radiation, equal to J/kg. [1]

Gregorian calendar - The modification of the Julian calendar introduced in 1582 by Pope Gregory XII which specified that a year divisible by 100 is a leap year only if divisible by 400.

Grignard reagents - Organomagnesium halides, RMgX, having a carbon-magnesium bond (or their equilibrium mixtures in solution with $R_2Mg + MgX_2$). [5]

Gruneisen parameter (γ) - Defined by $\gamma = \alpha_V/\kappa\, c_V\, \rho$, where α_V is the cubic thermal expansion coefficient, κ is the isothermal compressibility, c_V is the specific heat capacity at constant volume, and ρ is the mass density. γ is independent of temperature for most crystalline solids. [1]

Gyromagnetic ratio (γ) - Ratio of the magnetic moment of a particle to its angular momentum. Also called magnetogyric ratio.

Hadron - Any elementary particle that can take part in the strong interaction. Hadrons are subdivided into baryons, with odd half integer spins, and mesons, which have zero or integral spin.

Hall effect* - The development of a transverse potential difference V in a conducting material when subjected to a magnetic field H perpendicular to the direction of the current. The potential difference is given by $V = R_H BJt$, where B is the magnetic induction, J the current density, t the thickness of the specimen in the direction of the potential difference, and R_H is called the Hall coefficient.

Halocarbon - A compound containing no elements other than carbon, hydrogen, and one or more halogens. In common practice, the term is used mainly for compounds of no more than four or five carbon atoms.

Halogens - The elements F, Cl, Br, I, and At. Compounds of these elements are called halogenides or halides. [7]

Hamiltonian (*H*) - An expression for the total energy of a mechanical system in terms of the momenta and positions of constituent particles. In quantum mechanics, the Hamiltonian operator appears in the eigenvalue equation $H\psi = E\psi$, where E is an energy eigenvalue and ψ the corresponding eigenfunction.

Hardness* - The resistance of a material to deformation, indentation, or scratching. Hardness is measured on various scales, such as Mohs, Brinell, Knoop, Rockwell, and Vickers. [10]

Hartmann number (*Ha*) - A dimensionless quantity used in plasma physics, defined by $Ha = Bl(\kappa/\eta)^{1/2}$, where B is magnetic flux density, l is length, κ is electric conductivity, and η is viscosity. [2]

Hartree (E_h)* - An energy unit used in atomic and molecular science, equal to approximately $4.3597482 \times 10^{-18}$ J.

Hartree-Fock method - A iterative procedure for solving the Schrödinger equation for an atom or molecule in which the equation is solved for each electron in an initial assumed potential from all the other electrons. The new potential that results is used to repeat the calculation and the procedure continued until convergence is reached. Also called self-consistent field (SCF) method.

Heat capacity* - Defined in general as dQ/dT, where dQ is the amount of heat that must be added to a system to increase its temperature by a small amount dT. The heat capacity at constant pressure is $C_p = (\partial H/\partial T)_p$; that at constant volume is $C_V = (\partial E/\partial T)_V$, where H is enthalpy, E is internal energy, p is pressure, V is volume, and T is temperature. An upper case C normally indicates the molar heat capacity, while a lower case c is used for the specific (per unit mass) heat capacity. [1]

Heat of formation, vaporization, etc. - See corresponding terms under Enthalpy.

Hectare (ha) - A unit of area equal to 10^4 m^2. [1]

Heisenberg uncertainty principle - The statement that two observable properties of a system that are complementary, in the sense that their quantum-mechanical operators do not commute, cannot be specified simultaneously with absolute precision. An example is the position and momentum of a particle; according to this principle, the uncertainties in position Δq and momentum Δp must satisfy the relation $\Delta p\Delta q \geq h/4\pi$, where h is Planck's constant.

Heitler-London model - An early quantum-mechanical model of the hydrogen atom which introduced the concept of the exchange interaction between electrons as the primary reason for stability of the chemical bond.

Helicon - A low-frequency wave generated when a metal at low temperature is exposed to a uniform magnetic field and a circularly polarized electric field.

Helmholz energy (*A*) - A thermodynamic function defined by $A = E-TS$, where E is the energy, S the entropy, and T the thermodynamic temperature. [2]

Hemiacetals - Compounds having the general formula $R_2C(OH)OR'$ (R' not equal to H). [5]

Henry (H)* - The SI unit of inductance, equal to Wb/A. [1]

Henry's law * - An expression which applies to an ideal dilute solution in which one or more gasses are dissolved, viz., $p_i = H_i x_i$, where p_i is the partial pressure of component *i* above the solution, x_i is its mole fraction in the solution, and H_i is the Henry's law constant (a characteristic of the given gas and solvent, as well as the temperature).

Hermitian operator - An operator *A* that satisfies the relation $\int u_m{}^*Au_n\mathrm{d}x = (\int u_n{}^*Au_m\,\mathrm{d}x)^*$, where * indicates the complex conjugate. The eigenvalues of Hermitian operators are real, and eigenfunctions belonging to different eigenvalues are orthogonal.

Hertz (Hz) - The SI unit of frequency, equal to s^{-1}. [1]

Heterocyclic compounds - Cyclic compounds having as ring members atoms of at least two different elements, e.g., quinoline, 1,2-thiazole, bicyclo[3.3.1]tetrasiloxane. [5]

Heusler alloys - Alloys of manganese, copper, aluminum, nickel, and sometimes other metals which find important uses as permanent magnets.

Holography - A technique for creating a three-dimensional image of a object by recording the interference pattern between a light beam diffracted from the object and a reference beam. The image can be reconstructed from this pattern by a suitable optical system.

Homopolymer - A polymer derived from one species of (real, implicit, or hypothetical) monomer. [8]

Hooke's law - The statement that the ratio of stress to strain is a constant in a totally elastic medium.

Horse power - A non-SI unit of energy, equal to approximately 746 W.

Hubble constant - The ratio of the recessional velocity of an extragalactic object to the distance of that object. Its value is about 2×10^{-18} s^{-1}.

Huckel theory - A simple approximation for calculating the energy of conjugated molecules in which only the resonance integrals between neighboring bonds are considered. Also called CNDO method (complete neglect of differential overlap).

Hume-Rothery rules - A set of empirical rules for predicting the occurrence of solid solutions in metallic systems. The rules involve size, crystal structure, and electronegativity.

Hund's rules - A series of rules for predicting the sequence of energy states in atoms and molecules. One of the important results is that when two electrons exist in different orbitals, the state with their spins parallel (triplet state) lies at lower energy than the state with antiparallel spins (singlet).

Hydrazines - Hydrazine (diazane), H_2NNH_2, and its hydrocarbyl derivatives. When one or more substituents are acyl groups, the compound is a hydrazide. [5]

Hydrocarbon - A compound containing only carbon and hydrogen. [5]

Hydrolysis - A reaction occurring in water in which a chemical bond is cleaved and a new bond formed with the oxygen atom of water.

Hyperfine structure - Splitting of energy levels and spectral lines into several closely spaced components as a result of interaction of nuclear spin angular momentum with other angular momenta in the atom or molecule.

Hysteresis* - An irreversible response of a system (parameter *A*) as a function of an external force (parameter *F*), usually symmetric with respect to the origin of the *A* vs. *F* graph after the initial application of the force. A common example is magnetic induction vs. magnetic field strength in a ferromagnet.

Ideal gas law - The equation of state $pV = RT$, which defines an ideal gas, where *p* is pressure, *V* molar volume, *T* temperature, and *R* the molar gas constant.

Ideal solution - A solution in which solvent-solvent and solvent-solute interactions are identical, so that properties such as volume and enthalpy are exactly additive. Ideal solutions follow Raoult's law, which states that the vapor pressure p_i of component *i* is $p_i = x_i p_i{}^*$, where x_i is the mole fraction of component *i* and $p_i{}^*$ the vapor pressure of the pure substance *i*.

Ignition temperature* - The lowest temperature at which combustion of a material will occur spontaneously under specified conditions. Sometimes called autoignition temperature, kindling point. [10]

Imides - Diacyl derivatives of ammonia or primary amines, especially those cyclic compounds derived from diacids. Also used for salts having the anion RN_2^-. [5]

Impedence (*Z*) - The complex representation of potential difference divided by the complex representation of current. In terms of reactance *X* and resistance *R*, the impedance is given by $Z = R + \mathrm{i}X$. [1]

Index of refraction (*n*)* - For a non-absorbing medium, the ratio of the velocity of electromagnetic radiation *in vacuo* to the phase velocity of radiation of a specified frequency in the medium. [1]

Inductance - The ratio of the electromagnetic force induced in a coil by a current to the rate of change of the current.

Inductive coupled plasma mass spectroscopy (ICPMS) - See Techniques for Materials Characterization, page **12**-1.

Inertial defect - In molecular spectroscopy, the quantity I_c-I_a-I_b for a molecule whose equilibrium configuration is planar, where I_a, I_b, and I_c are the effective principal moments of inertia. The inertial defect for a rigid planar molecule would be zero, but vibration-rotation interactions in a real molecule lead to a positive inertial defect.

Insulator - A material in which the highest occupied energy band (valence band) is completely filled with electrons, while the next higher band (conduction band) is empty. Solids with an energy gap of 5 eV or more are generally considered as insulators at room temperature. Their conductivity is less than 10^{-6} S/m and increases with temperature.

Intercalation compounds - Compounds resulting from reversible inclusion, without covalent bonding, of one kind of molecule in a solid matrix of another compound, which has a laminar structure. The host compound, a solid, may be macromolecular, crystalline, or amorphous. [5]

International System of Units (SI)* - The unit system adopted by the General Conference on Weights and Measures in 1960. It consists of seven base units (meter, kilogram, second, ampere, kelvin, mole, candela), plus derived units and prefixes. [1]

International Temperature Scale (ITS-90)* - The official international temperature scale adopted in 1990. It consists of a set of fixed points and equations which enable the thermodynamic temperature to be determined from operational measurements. [9]

Ion - An atomic or molecular particle having a net electric charge. [3]

Ion exchange - A process involving the adsorption of one or several ionic species accompanied by the simultaneous desorption (displacement) of one or more other ionic species. [3]

Ion neutralization spectroscopy (INS) - See Techniques for Materials Characterization, page **12**-1.

Ionic strength (*I*) - A measure of the total concentration of ions in a solution, defined by $I = 1/2\Sigma_i\, z_i^2 m_i$, where z_i is the charge of ionic species *i* and m_i is its molality. For a 1-1 electrolyte at molality *m*, $I = m$.

Ionization constant* - The equilibrium constant for a reaction in which a substance in solution dissociates into ions.

Ionization potential* - The minimum energy required to remove an electron from an isolated atom or molecule (in its vibrational ground state) in the gaseous phase. More properly called ionization energy. [3]

Irradiance (*E*) - The radiant energy flux incident on an element of a surface, divided by the area of that element. [1]

Isentropic process - A thermodynamic process in which the entropy of the system does not change.

Ising model - A model describing the coupling between two atoms in a ferromagnetic lattice, in which the interaction energy is proportional to the negative of the product of the spin components along a specified axis.

Isobar - A line connecting points of equal pressure on a graphical representation of a physical system.

Isochore - A line or surface of constant volume on a graphical representation of a physical system.

Isoelectric point* - The pH of a solution or dispersion at which the net charge on the macromolecules or colloidal particles is zero. In electrophoresis there is no motion of the particles in an electric field at the isoelectric point.

Isomers - In chemistry, compounds that have identical molecular formulas but differ in the nature or sequence of bonding of their atoms or in the arrangement of their atoms in space. In physics, nuclei of the same atomic number Z and mass number A but in different energy states. [3]

Isomorphs - Substances of different chemical nature but having the same crystal structure.

Isotactic macromolecule - A tactic macromolecule, essentially comprising only one species of repeating unit which has chiral or prochiral atoms in the main chain in a unique arrangement with respect to its adjacent constitutional units. [8]

Isotherm - A line connecting points of equal temperature on a graphical representation of a physical system.

Isothermal process - A thermodynamic process in which the temperature of the system does not change.

Isotones - Nuclides having the same neutron number N but different atomic number Z. [3]

Isotopes - Two or more nuclides with the same atomic number Z but different mass number A. The term is sometimes used synonymously with nuclide, but it is preferable to reserve the word nuclide for a species of specific Z and A. [3]

Jahn-Teller effect - An interaction of vibrational and electronic motions in a nonlinear molecule which removes the degeneracy of certain electronic energy levels. It can influence the spectrum, crystal structure, and magnetic properties of the substance.

Johnson noise - Electrical noise generated by random thermal motion of electrons in a conductor or semiconductor. Also called thermal noise.

Josephson effect - The tunneling of electron pairs through a thin insulating layer which separates two superconductors. When a potential difference is applied to the superconductors, an alternating current is generated whose frequency is precisely proportional to the potential difference. This effect has important applications in metrology and determination of fundamental physical constants.

Joule (J)* - The SI unit of energy, equal to N m. [1]

Joule-Thomson coefficient (μ) - A parameter which describes the temperature change when a gas expands adiabatically through a nozzle from a high pressure to a low pressure region. It is defined by $\mu = (\partial T/\partial p)_H$, where H is enthalpy.

Julian calendar - The calendar introduced by Julius Caeser in 46 B.C. which divided the year into 365 days with a leap year of 366 days every fourth year.

Julian date (JD) - The number of days elapsed since noon Greenwich Mean Time on January 1, 4713 B.C. Thus January 1, 2000, 0h (midnight) will be JD 2,451,543.5. This dating system was introduced by Joseph Scaliger in 1582.

Kaon - One of the elementary particles in the family of mesons. Kaons have a spin of zero and may be neutral or charged.

Kelvin (K)* - The SI base unit of thermodynamic temperature. [1]

Kepler's laws - The three laws of planetary motion, which established the elliptical shape of planetary orbits and the relation between orbital dimensions and the period of rotation.

Kerr effect* - An electrooptical effect in which birefringence is induced in a liquid or gas when a strong electric field is applied perpendicular to the direction of an incident light beam. The Kerr constant k is given by $n_1-n_2 = k\lambda E^2$, where λ is the wavelength, E is the electric field strength, and n_1 and n_2 are the indices of refraction of the ordinary and extraordinary rays, respectively.

Ketenes - Compounds in which a carbonyl group is connected by a double bond to an alkylidene group: $R_2C{=}C{=}O$. [5]

Ketones - Compounds in which a carbonyl group is bonded to two carbon atoms: $R_1R_2C{=}O$ (neither R may be H). [5]

Kilogram (kg)* - The SI base unit of mass. [1]

Kinetic energy (E_k, T) - The energy associated with the motion of a system of particles in a specified reference frame. For a single particle of mass m moving at velocity v, $E_k = 1/2mv^2$.

Kirchhoff's laws - Basic rules for electric circuits, which state (a) the algebraic sum of the currents at a network node is zero and (b) the algebraic sum of the voltage drops around a closed path is zero.

Klein-Gordon equation - A relativistic extension of the Schrödinger equation.

Klein-Nishima formula - An expression for the scattering cross section of a photon by an unbound electron, based upon the Dirac electron theory.

Knight shift - The change in magnetic resonance frequency of a nucleus in a metal relative to the same nucleus in a diamagnetic solid. The effect is due to the polarization of the conduction electrons in the metal.

Knudsen number (*Kn*) - A dimensionless quantity used in fluid mechanics, defined by $Kn = \lambda/l$, where λ is mean free path and l is length. [2]

Kondo effect - A large increase in electrical resistance observed at low temperatures in certain dilute alloys of a magnetic metal in a nonmagnetic material.

Kramers-Kronig relation - A set of equations relating the real and imaginary parts of the index of refraction of a medium

Lactams - Cyclic amides of amino carboxylic acids, having a 1-azacycloalkan-2-one structure, or analogues having unsaturation or heteroatoms replacing one or more carbon atoms of the ring. [5]

Lactones - Cyclic esters of hydroxy carboxylic acids, containing a 1-oxacycloalkan-2-one structure, or analogues having unsaturation or heteroatoms replacing one or more carbon atoms of the ring. [5]

Lagrangian function (*L*) - A function used in classical mechanics, defined as the kinetic energy minus the potential energy for a system of particles.

Lamb shift - The small energy difference between the $^2S_{1/2}$ and $^2P_{1/2}$ levels in the hydrogen atom, which results from interactions between the electron and the radiation field.

Laminar flow - Smooth, uniform, non-turbulent flow of a gas or liquid in parallel layers, with little mixing between layers. It is characterized by small values of the Reynolds number.

Landé *g*-factor - See *g*-Factor of the electron

Langevin function - The mathematical function $L(x) = (e^x+e^{-x})/(e^x-e^{-x})-1/x$, which occurs in the expression for the average dipole moment of a group of rotating polar molecules in an electric field: $\mu_{av} = \mu L(\mu E/kT)$, where μ is the electric dipole moment of a single molecule, E is the electric field strength, k is the Boltzmann constant, and T is the temperature.

Lanthanides - The elements of atomic number 57 through 71, which share common chemical properties: La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu. [7]

Larmor frequency (ν_L) - The precession frequency of a magnetic dipole in an applied magnetic field. In particular, a nucleus in a magnetic field of strength B has a Larmor frequency of $\gamma B/2\pi$, where γ is the magnetogyric ratio of the nucleus.

Laser* - A device in which an optical cavity is filled with a medium where a population inversion can be produced by some means. When the resonant frequency of the cavity bears the proper relation to the separation of the inverted energy levels, stimulated emission occurs, producing a highly monochromatic, coherent beam of light.

Laser ionization mass spectroscopy (LIMS) - See Techniques for Materials Characterization, page **12**-1.

Lattice constants* - Parameters specifying the dimensions of a unit cell in a crystal lattice, specifically the lengths of the cell edges and the angles between them.

Lattice energy* - The energy per ion pair required to separate completely the ions in a crystal lattice at a temperature of absolute zero.

Laue diagram - A diffraction pattern produced when an x-ray beam passes through a thin slice of a crystal and impinges on a detector behind the crystal.

Lenz's law - The statement that the current induced in a circuit by a change in magnetic flux is so directed as to oppose the change in flux

Leonard-Jones potential - A simple but useful function for approximating the interaction between two neutral atoms or molecules separated by a distance r by writing the potential energy as $U(r) = 4\varepsilon\{(r_0/r)^{12} - (r_0/r)^6\}$, where ε and r_0 are adjustable parameters. In this form the depth of the potential well is ε and the minimum occurs at $2^{1/6}r_0$. The $(1/r)^{12}$ term is often replaced by other powers of $1/r$.

Lepton - One of the class of elementary particles that do not take part in the strong interaction. Included are the electron, muon, and neutrino. All leptons have a spin of 1/2.

Lewis number (*Le*) - A dimensionless quantity used in fluid mechanics, defined by $Le = a/D$, where a is thermal diffusivity and D is diffusion coefficient. [2]

Ligand field theory - A description of the structure of crystals containing a transition metal ion surrounded by nonmetallic ions (ligands). It is based on construction of molecular orbitals involving the *d*-orbitals of the central metal ion and combinations of atomic orbitals of the ligands.

Light year (l.y.) - A unit of distance used in astronomy, defined as the distance light travels in one year in a vacuum. Its approximate value is 9.46073×10^{15} m.

Lignins - Macromolecular constituents of wood related to lignans, composed of phenolic propylbenzene skeletal units, linked at various sites and apparently randomly. [5]

Ligroin - The petroleum fraction consisting mostly of C_7 and C_8 hydrocarbons and boiling in the range 90-140°C; commonly used as a laboratory solvent.

Lipids - A loosely defined term for substances of biological origin that are soluble in nonpolar solvents. They consist of saponifiable lipids, such as glycerides (fats and oils) and phospholipids, as well as nonsaponifiable lipids, principally steroids. [5]

Lipoproteins - Clathrate complexes consisting of a lipid enwrapped in a protein host without covalent binding, in such a way that the complex has a hydrophilic outer surface consisting of all the protein and the polar ends of any phospholipids. [5]

Liter (L)* - A synonym for cubic decimeter. [1]

Lithosphere* - The outer layer of the solid earth, extending from the base of the mantle to the surface of the crust.

Lorentz contraction - The reduction in length of a moving body in the direction of motion, given by the factor $(1-v^2/c^2)^{1/2}$, where v is the velocity of the body and c the velocity of light. Also known as the FitzGerald-Lorentz contraction.

Lorentz force - The force exerted on a point charge Q moving at velocity $\boldsymbol{v}$ in the presence of external fields $\boldsymbol{E}$ and $\boldsymbol{B}$. It is given (in SI units) by $\boldsymbol{F} = Q(\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B})$.

Loss angle (δ) - For a dielectric material in an alternating electromagnetic field, δ is the phase difference between the current and the potential difference. The function $\tan \delta$ is a measure of the ratio of the power dissipated in the dielectric to the power stored.

Low energy electron diffraction (LEED) - See Techniques for Materials Characterization, page **12**-1.

Lumen (lm)* - The SI unit of luminous flux, equal to cd sr. [1]

Luminous flux (Φ) - The intensity of light from a source multiplied by the solid angle. The SI unit is lumen. [1]

Lux (lx)* - The SI unit of illuminance, equal to cd sr m^{-2}. [1]

Lyddane-Sachs-Teller relation - A relation between the phonon frequencies and dielectric constants of an ionic crystal which states that $(\omega_T/\omega_L)^2 = \varepsilon(\infty)/\varepsilon(0)$, where ω_T is the angular frequency of transverse optical phonons, ω_L that of longitudinal optical phonons, $\varepsilon(0)$ is the static dielectric constant, and $\varepsilon(\infty)$ the dielectric constant at optical frequencies.

Lyman series - The series of lines in the spectrum of the hydrogen atom which corresponds to transitions between the ground state (principal quantum number $n = 1$) and successive excited states. The wavelengths are given by $1/\lambda = R_H(1-1/n^2)$, where $n = 2,3,4,\ldots$ and R_H is the Rydberg constant for hydrogen. The first member of the series ($n = 1 \leftrightarrow 2$), which is often called the Lyman-α line, falls at a wavelength of 1216 Å, and the series converges at 912 Å, the ionization limit of hydrogen.

Mach number (*Ma*) - A dimensionless quantity used in fluid mechanics, defined by $Ma = v/c$, where v is velocity and c is the speed of sound. [2]

Macromolecule - A molecule of high relative molecular mass (molecular weight), the structure of which essentially comprises the multiple repetition of units derived, actually or conceptually, from molecules of low relative molecular mass [8]

Madelung constant* - A constant characteristic of a particular crystalline material which gives a measure of the electrostatic energy binding the ions in the crystal.

Magnetic field strength (*H*) - An axial vector quantity, the curl of which is equal to the current density, including the displacement current. [1]

Magnetic induction (*B*) - An axial vector quantity such that the force exerted on an element of current is equal to the vector product of this element and the magnetic induction. [1]

Magnetic moment - See Dipole moment, magnetic.

Magnetic susceptibility (χ_m, κ)* - Defined by $\chi_m = (\mu-\mu_0)/\mu_0$, where μ is the permeability of the medium and μ_0 the permeability of a vacuum. [1]

Magnetization (*M*) - Defined by $M = (B/\mu_0)-H$, where B is magnetic induction, H magnetic field strength, and μ_0 the permeability of a vacuum. [1]

Magnetogyric ratio (γ) - Ratio of the magnetic moment of a particle to its angular momentum. Also called gyromagnetic ratio.

Magneton - See Bohr magneton, Nuclear magneton.

Magnetostriction* - The change in dimensions of a solid sample when it is placed in a magnetic field.

Magnon - A quantum of magnetic energy associated with a spin wave in a ferromagnetic or antiferromagnetic crystal.

Mantle - The layer of the earth between the crust and the liquid outer core, which begins about 2900 km below the earth's surface.

Maser - A device in which a microwave cavity is filled with a medium where a population inversion can be produced by some means. When the resonant frequency of the cavity bears the proper relation to the separation of the inverted energy levels, the device can serve as an amplifier or oscillator at that frequency.

Mass (*m*)* - Quantity of matter. Mass can also be defined as "resistance to acceleration".

Mass defect (*B*) - Defined by $B = Zm(^1H) + Nm_n - m_a$, where Z is the atomic number, $m(^1H)$ is the mass of the hydrogen atom, N is the neutron number, m_n is the rest mass of the neutron, and m_a is the mass of the atom in question. Thus Bc^2 can be equated to the binding energy of the nucleus if the binding energy of atomic electrons is neglected. [1]

Mass excess (Δ) - Defined by $\Delta = m_a - Am_u$, where m_a is the mass of the

atom, A the number of nucleons, and m_u the unified atomic mass constant (m_u = 1 u). [1]

Mass fraction (w_B) - The ratio of the mass of substance B to the total mass of a mixture. [1]

Mass number (A) - A characteristic property of a specific isotope of an element, equal to the sum of the number of protons and neutrons in the nucleus.

Mass spectrometry - An analytical technique in which ions are separated according to the mass/charge ratio and detected by a suitable detector. The ions may be produced by electron impact on a gas, a chemical reaction, energetic vaporization of a solid, etc. [6]

Massieu function - A thermodynamic function defined by $J = -A/T$, where A is the Helmholz energy and T the thermodynamic temperature. [2]

Matthiessen's rule - The statement that the electrical resistivity ρ of a metal can be written as $\rho = \rho_L + \rho_i$, where ρ_L is due to scattering of conduction electrons by lattice vibrations and ρ_i to scattering by impurities and imperfections. If the impurity concentration is small, ρ_i is temperature independent.

Maxwell (Mx)* - A non-SI unit of magnetic field strength (H) equal to 10^{-8} Wb. [1]

Maxwell's equations - The fundamental equations of electromagnetism. In a form appropriate to SI units, they are:

$\text{curl } \boldsymbol{H} = \partial\boldsymbol{D}/\partial t + \boldsymbol{j}$

$\text{div } \boldsymbol{B} = 0$

$\text{curl } \boldsymbol{E} = -\partial\boldsymbol{B}/\partial t$

$\text{div } \boldsymbol{D} = \rho$

where $\boldsymbol{H}$ is the magnetic field strength, $\boldsymbol{B}$ the magnetic induction, $\boldsymbol{E}$ the electric field strength, $\boldsymbol{D}$ the electric displacement, $\boldsymbol{j}$ the current density, ρ the charge density, and t is time.

Maxwell-Boltzmann distribution - An expression for the fraction of molecules $f(v)$ in a gas that have velocity v within a specified interval. It takes the form

$$f(v) = 4\pi(M/2\pi RT)^{3/2} v^2 e^{-Mv^2/2RT}$$

where M is the molar mass, R the molar gas constant, and T the temperature.

Mean free path* - The average distance a gas molecule travels between collisions.

Meissner effect - The complete exclusion of magnetic induction from the interior of a superconductor.

Melting point* - The temperature at which the solid and liquid phases of a substance are in equilibrium at a specified pressure (normally taken to be atmospheric unless stated otherwise).

Mercaptans - A traditional term abandoned by IUPAC, synonymous with thiols. This term is still widely used. [5]

Meson - Any elementary particle that has zero or integral spin. Mesons are responsible for the forces between protons and neutrons in the nucleus.

Mesosphere - The part of the earth's atmosphere extending from the top of the stratosphere (about 50 km above the surface) to 80-90 km. It is characterized by a decrease in temperature with increasing altitude.

Metal - A material in which the highest occupied energy band (conduction band) is only partially filled with electrons. The electrical conductivity of metals generally decreases with temperature.

Metallocenes - Organometallic coordination compounds in which one atom of a transition metal such as iron, ruthenium or osmium is bonded to and only to the face of two cyclopentadienyl ligands which lie in parallel planes. [5]

Meter (m)* - The SI base unit of length. [1]

Methine group - In organic compounds, the -C= group. [5]

Mho - An archaic name for the SI unit siemens (reciprocal ohm).

Micelle - A particle formed by the aggregation of surfactant molecules (typically, 10 to 100 molecules) in solution. For aqueous solutions, the hydrophilic end of the molecule is on the surface of the micelle, while the hydrophobic end (often a hydrocarbon chain) points toward the center. At the critical micelle concentration (cmc) the previously dissolved molecules aggregate into a micelle.

Micron (μ) - An obsolete name for micrometer.

Mie scattering - The scattering of light by spherical dielectric particles whose diameter is comparable to the wavelength of the light.

Milky way - The band of light in the night sky resulting from the stars in the galactic plane. The term is also used to denote the galaxy in which the sun is located.

Miller indices (*hkl*) - A set of indices used to label planes in a crystal lattice. [2]

Millimeter of mercury (mmHg) - A non-SI unit of pressure, equal to 133.322 Pa. The name is generally considered interchangeable with torr.

Mobility (μ)* - In solid state physics, the drift velocity of electrons or holes in a solid divided by the applied electric field strength. The term is used in a similar sense in other fields.

Molality (m) - A measure of concentration of a solution in which one states the amount of substance (i.e., number of moles) of solute per kilogram of solvent. Thus a 0.1 molal solution (often written as 0.1 m) has m = 0.1 mol/kg.

Molar mass - The mass of one mole of a substance. It is normally expressed in units of g/mol, in which case its numerical value is identical with the molecular weight (relative molecular mass). [1]

Molar quantity - It is often convenient to express an extensive quantity (e.g., volume, enthalpy, heat capacity, etc.) as the actual value divided by amount of substance (number of moles). The resulting quantity is called molar volume, molar enthalpy, etc

Molar refraction (R) - A property of a dielectric defined by the equation $R = V_m[(n^2-1)/(n^2+2)]$, where n is the index of refraction of the medium (at optical wavelengths) and V_m the molar volume. It is related to the polarizability α of the molecules that make up the medium by the Lorenz-Lorentz equation, $R = N_A\alpha/3\varepsilon_0$, where N_A is Avogadro's constant and ε_0 is the permittivity of a vacuum.

Molarity (c) - A measure of concentration of a solution in which one states the amount of substance (i.e., number of moles) of solute per liter of solution. Thus a 0.1 molar solution (often referred to as 0.1 M) has a concentration c = 0.1 mol/L.

Mole (mol)* - The SI base unit of amount of substance. [1]

Mole fraction (x_B) - The ratio of the amount of substance (number of moles) of substance B to the total amount of substance in a mixture. [1]

Molecular orbital - See Orbital.

Molecular weight (M_r)* - The ratio of the average mass per molecule or specified entity of a substance to 1/12 of the mass of nuclide ^{12}C. Also called relative molar (or molecular) mass. [1]

Moment of inertia (I) - The moment of inertia of a body about an axis is the sum (or integral) of the products of its elements of mass and the squares of their distances from the axis. [1]

Momentum (p) - The product of mass and velocity. [1]

Monomer - A substance consisting of molecules which can undergo polymerization, thereby contributing constitutional units to the essential structure of a macromolecule. [8]

Monosaccharides - A term which includes aldoses, ketoses, and a wide variety of derivatives. [5]

Mössbauer effect - The recoilless emission of γ-rays from nuclei bound in a crystal under conditions where the recoil energy associated with the γ emission is taken up by the crystal as a whole. This results in a very narrow line width, which can be exploited in various types of precise measurements.

Muon* - An unstable elementary particle of spin 1/2 and mass about 200 times that of the electron.

Naphtha - The petroleum fraction consisting mostly of C_6 to C_8 hydrocarbons and boiling in the range 80-120°C. Solvents derived from this fraction include ligroin and petroleum ether.

Nautical mile - A non-SI unit of length, equal to exactly 1852 m.

Navier-Stokes equations - A set of complex equations for the motion of a viscous fluid subject to external forces.

Néel temperature (T_N)* - The critical temperature above which an antiferromagnetic substance becomes paramagnetic. [1]

Nernst effect - The production of an electric field in a conductor subject to an applied magnetic field and containing a transverse temperature gradient. The electric field is perpendicular to the magnetic field and the temperature gradient.

Network - In polymer science, a highly ramified macromolecule in which essentially each constitutional unit is connected to each other constitutional unit and to the macroscopic phase boundary by many permanent paths through the macromolecule, the number of such paths increasing with the number of intervening bonds. The paths must on the average be coextensive with the macromolecule. [8]

Neutrino - A stable elementary particle in the lepton family. Neutrinos have zero (or at least near-zero) rest mass and spin 1/2.

Neutron* - An elementary particle on spin 1/2 and zero charge. The free neutron has a mean lifetime of 887 seconds. Neutrons and protons, which are collectively called nucleons, are the constituents of the nucleus.

Neutron activation analysis (NAA) - See Techniques for Materials Characterization, page **12**-1.

Neutron number (*N*) - A characteristic property of a specific isotope of an element, equal to the number of neutrons in the nucleus.

Newton (N)* - The SI unit of force, equal to m kg s^{-2}. [1]

Nitriles - Compounds having the structure RC≡N; thus C-substituted derivatives of hydrocyanic acid, HC≡N. [5]

Nitrosamines - N-Nitroso amines: compounds of the structure R_2NNO. Compounds RNHNO are not ordinarily isolatable, but they, too, are nitrosamines. The name is a contraction of N-nitrosoamine and, as such, does not require the N locant. [5]

Nuclear magnetic resonance (NMR)* - A widely used technique in which the resonant absorption of radiofrequency radiation by magnetic nuclei in a magnetic field is measured. The results give important information on the local environment of each nucleus.

Nuclear magneton (μ_N)* - The unit of nuclear magnetic moment, defined as $eh/4\pi m_p$, where *h* is Planck's constant, m_p the proton mass, and *e* the elementary charge.

Nuclear quadrupole resonance (NQR) - See Techniques for Materials Characterization, page **12**-1.

Nuclear reaction analysis (NRA) - See Techniques for Materials Characterization, page **12**-1.

Nuclear spin (*I*) - The quantum number that specifies the intrinsic angular momentum of a particular nucleus. The magnitude of the angular momentum is given by $[I(I+1)]^{1/2}\, h/2\pi$, where *h* is Planck's constant.

Nucleic acids* - Macromolecules, the major organic matter of the nuclei of biological cells, made up of nucleotide units, and hydrolyzable into certain pyrimidine or purine bases (usually adenine, cytosine, guanine, thymine, uracil), D-ribose or 2-deoxy-D-ribose. [5]

Nucleon - A collective term for the proton and neutron.

Nucleosides - Ribosyl or deoxyribosyl derivatives (rarely, other glycosyl derivatives) of certain pyrimidine or purine bases. They are thus glycosylamines or N-glycosides related to nucleotides by the lack of phosphorylation. [5]

Nucleotides - Compounds formally obtained by esterification of the 3′ or 5′ hydroxy group of nucleosides with phosphoric acid. They are the monomers of nucleic acids and are formed from them by hydrolytic cleavage. [5]

Nuclide - A species of atoms in which each atom has identical atomic number *Z* and identical mass number *A*. [3]

Nusselt number (*Nu*) - A dimensionless quantity used in fluid mechanics, defined by $Nu = hl/k$, where *h* is coefficient of heat transfer, *l* is length, and *k* is thermal conductivity. [2]

Nyquist theorem - An expression for the mean square thermal noise voltage across a resistor, given by $4RkT\Delta f$ where *R* is the resistance, *k* the Boltzmann constant, *T* the temperature, and Δf the frequency band within which the voltage is measured.

Octanol-water partition coefficient (*P*)* - A measure of the way in which a compound will partition itself between the octanol and water phases in the two-phase octanol-water system, and thus an indicator of certain types of biological activity. Specifically, *P* is the ratio of the concentration (in moles per liter) of the compound in the octanol phase to that in the water phase at infinite dilution. The quantity normally reported is log *P*.

Oersted (Oe) - A non-SI unit of magnetic field (*H*), equal to 79.57747 A/m.

Ohm (Ω)* - The SI unit of electric resistance, equal to V/A. [1]

Ohm's law - A relation among electric current *I*, potential difference *V*, and resistance *R*, viz., $I = V/R$. The resistance is constant at constant temperature to high precision for many materials.

Olefins - Acyclic and cyclic hydrocarbons having one or more carbon-carbon double bonds, apart from the formal ones in aromatic compounds. The class olefins subsumes alkenes and cycloalkenes and the corresponding polyenes. [5]

Oligomer - A substance consisting of molecules of intermediate relative molecular mass (molecular weight), the structure of which essentially comprises the multiple repetition of units derived, actually or conceptually, from molecules of low relative molecular mass. In contrast to a polymer, the properties of an oligomer can vary significantly with the removal of one or a few of its units. [8]

Oligopeptides - Peptides containing from three to nine amino groups. [5]

Onsager relations - An important set of equations in the thermodynamics of irreversible processes. They express the symmetry between the transport coefficients describing reciprocal processes in systems with a linear dependence of flux on driving forces.

Optical rotary power - Angle by which the plane of polarization of a light beam is rotated by an optically active medium, divided by path length and by concentration of the active constituent. Depending on whether mass or molar concentration is used, the modifier "specific" or "molar" is attached. [2]

Orbital - A one-electron wavefunction. Atomic orbitals are classified as *s*-, *p*-, *d*,- or *f*-orbitals according to whether the angular momentum quantum number *l* = 0, 1, 2, or 3. Molecular orbitals, which are usually constructed as linear combinations of atomic orbitals, describe the distribution of electrons over the entire molecule.

Oscillator strength (*f*) - A measure of the intensity of a spectroscopic transition, defined by

$$f = \frac{8\pi^2 Me\nu}{3he^2}\left|\mu_{ij}\right|^2$$

where ν is the frequency, μ_{ij} the transition dipole moment, m_e the mass of the electron, *e* the elementary charge, and *h* Planck's constant.

Osmosis - The flow of a solvent in a system in which two solutions of different concentration are separated by a semipermeable membrane which cannot pass solute molecules. The solvent will flow from the side of lower concentration to that of higher concentration, thus tending to equalize the concentrations. The pressure that must be

applied to the more concentrated side to stop the flow is called the osmotic pressure.

Osmotic coefficient (ϕ) - Defined by $\phi = \ln a_A/(M_A \Sigma m_B)$, where M_A is the molar mass of substance A (normally the solvent), a_A is its activity, and the m_B are molalities of the solutes. [1]

Osmotic pressure (Π) - The excess pressure necessary to maintain osmotic equilibrium between a solution and the pure solvent separated by a membrane permeable only to the solvent. In an ideal dilute solution $\Pi = c_B RT$, where c_B is the amount-of-substance concentration of the solute, R is the molar gas constant, and T the temperature. [1,2]

Ostwald dilution law - A relation for the concentration dependence of the molar conductivity Λ of an electrolyte solution, viz.,

$$\frac{1}{\Lambda} = \frac{1}{\Lambda^\circ} + \frac{\Lambda c}{K\left(\Lambda^\circ\right)^2}$$

where c is the solute concentration, K is the equilibrium constant for dissociation of the solute, and Λ° is the conductivity at $c\Lambda = 0$.

Ounce (oz) - A non-SI unit of mass. The avoirdupois once equals 28.34952 g, while the troy ounce equals 31.10348 g.

Overpotential (η) - In an electrochemical cell, the difference between the potential of an electrode and its zero-current value.

Oximes - Compounds of structure R_2C=NOH derived from condensation of aldehydes or ketones with hydroxylamine. Oximes from aldehydes may be called aldoximes; those from ketones may be called ketoximes. [5]

Oxo compounds - Compounds containing an oxygen atom, =O, doubly bonded to carbon or another element. The term thus embraces aldehydes, carboxylic acids, ketones, sulfonic acids, amides and esters. [5]

Ozonides - The 1,2,4-trioxolanes formed by the reaction of ozone at a carbon-carbon double bond, or the analogous compounds derived from acetylenic compounds. [5]

Pair production - A process in which a photon is converted into a particle and its antiparticle (e.g., an electron and positron) in the electromagnetic field of a nucleus.

Paraffins - Obsolescent term for saturated hydrocarbons, commonly but not necessarily acyclic. Still widely used in the petrochemical industry, where the term designates acyclic saturated hydrocarbons, and stands in contradistinction to naphthenes. [5]

Paramagnetism* - A type of magnetism characterized by a positive magnetic susceptibility, so that the material becomes weakly magnetized in the direction of an external field. The magnetization disappears when the field in removed. In the simplest approximation (Curie's law) the susceptibility is inversely proportional to temperature.

Parity - The property of a quantum-mechanical wave function that describes its behavior under the symmetry operation of coordinate inversion. A parity of +1 (or even) is assigned if the wave function does not change sign when the signs of all the coordinates are changed; the parity is -1 (or odd) if the wave function changes sign under this operation.

Parsec (pc) - A unit of distance defined as the distance at which 1 astronomical unit (AU) subtends an angle of 1 second of arc. It is equal to 206264.806 AU or 3.085678×10^{16} m.

Particle induced x-ray emission (PIXE) - See Techniques for Materials Characterization, page **12**-1.

Partition function (*q*, *z*) - For a single molecule, $q = \Sigma_i g_i \exp(\varepsilon_i/kT)$, where ε_i is an energy level of degeneracy g_i, k the Boltzmann constant, and T the absolute temperature; the summation extends over all energy states. For a system of N non-interacting molecules which are indistinguishable, as in an ideal gas, the canonical partition function $Q = qN/N!$.

Pascal (Pa)* - The SI unit of pressure, equal to N/m^2. [1]

Paschen series - The series of lines in the spectrum of the hydrogen atom which corresponds to transitions between the state with principal quantum number $n = 3$ and successive higher states. The wavelengths are given by $1/\lambda = R_H(1/9-1/n^2)$, where n = 4,5,6,… and R_H is the Rydberg constant. The first member of the series ($n = 3 \leftrightarrow 4$), which is often called the P_α line, falls in the infrared at a wavelength of 1.875 μm.

Paschen-Back effect - In atomic spectroscopy, the decoupling of electron spin from orbital angular momentum as the strength of an external magnetic field is increased.

Pauli exclusion principle - The statement that two electrons in an atom cannot have identical quantum numbers; thus if there are two electrons in the same orbital, their spin quantum numbers must be of opposite sign.

Pearson symbol - A code for designating crystallographic information, including the crystal system, the lattice type, and the number of atoms per unit cell.

Péclet number (*Pe*) - A dimensionless quantity used in fluid mechanics, defined by $Pe = vl/a$, where v is velocity, l is length, and a is thermal diffussivity. [2]

Peltier effect - The absorption or generation of heat (depending on the current direction) which occurs when an electric current is passed through a junction between two materials.

Peptides - Amides derived from two or more amino carboxylic acid molecules (the same or different) by formation of a covalent bond from the carbonyl carbon of one to the nitrogen atom of another with formal loss of water. [5]

Permeability (μ) - Magnetic induction divided by magnetic field strength; i.e. $\mu = B/H$. The relative permeability $\mu_r = \mu/\mu_0$, where μ_0 is the permeability of a vacuum. [1]

Permittivity (ε) - Ratio of the electric displacement in a medium to the electric field strength. Also called dielectric constant. [1]

Peroxides - Compounds of structure ROOR in which R may be any organic group. In inorganic chemistry, salts of the anion O_2^{-2} [5]

Peroxy acids - Acids in which an acidic -OH group has been replaced by an -OOH group; e.g. CH_3C(=O)OOH peroxyacetic acid, PhS$(=O)_2$OOH benzeneperoxysulfonic acid. [5]

Petroleum ether - The petroleum fraction consisting of C_5 and C_6 hydrocarbons and boiling in the range 35-60°C; commonly used as a laboratory solvent.

pH* - A convenient measure of the acid-base character of a solution, usually defined by pH = -log [$c(H^+)$/mol L^{-1})], where $c(H^+)$ is the concentration of hydrogen ions.The more precise definition is in terms af activity rather than concentration. [2]

Phenols - Compounds having one or more hydroxy groups attached to a benzene or other arene ring. [5]

Phonon - A quantum of energy associated with a vibrational mode of a crystal lattice.

Phosphines - PH_3 and compounds derived from it by substituting one, two or three hydrogen atoms by hydrocarbyl groups. RPH_2, R_2PH and R_3P (R not equal to H) are called primary, secondary and tertiary phosphines, respectively. [5]

Phosphonium compounds - Salts (and hydroxides) $[R_4P]^+X^-$ containing tetracoordinate phosphonium ion and the associated anion. [5]

Phosphonium ylides - Compounds having the structure R_3P^+-C^-R_2 1 R_3P=CR $_2$. Also known as Wittig reagents. [5]

Phosphoresence - The process by which a molecule is excited by light to a higher electronic state and then undergoes a radiationless transition to a state of different multiplicity from which it decays, after some delay, to the ground state. The emitted light is normally of longer wavelength than the exciting light because vibrational energy has been dissipated.

Photoelectric effect - The complete absorption of a photon by a solid with the emission of an electron.

Photon - An elementary particle of zero mass and spin 1/2. The photon is involved in electromagnetic interactions and is the quantum of electromagnetic radiation.

Photon stimulated desorption (PSD) - See Techniques for Materials Characterization, page **12**-1.

Pinacols - Tetra(hydrocarbyl)ethane-1,2-diols, $R_2C(OH)C(OH)R_2$, of which the tetramethyl example is the simplest one and is itself commonly known as pinacol. [5]

Pion - An elementary particle in the family of mesons. Pions have zero spin and may be neutral or charged. They participate in the strong interaction which holds the nucleus together.

p*K** - The negative logarithm (base 10) of an equilibrium constant *K*. For pK_a, see Acid dissociation constant.

Planck constant (*h*)* - The elementary quantum of action, which relates energy to frequency through the equation $E = h\nu$.

Planck distribution - See Black body radiation

Planck function - A thermodynamic function defined by $Y = -G/T$, where *G* is Gibbs energy and *T* thermodynamic temperature. [2]

Plasma - A highly ionized gas in which the charge of the electrons is balanced by the charge of the positive ions, so that the system as a whole is electrically neutral.

Plasmon - A quantum associated with a plasma oscillation in the electron gas of a solid.

Point group* - A group of symmetry operations (rotations, reflections, etc.) that leave a molecule invariant. Every molecular conformation can be assigned to a specific point group, which plays a major role in determining the spectrum of the molecule.

Poise (P) - A non-SI unit of viscosity, equal to 0.1 Pa s.

Poiseuille's equation - A formula for the rate of flow of a viscous fluid through a tube:

$$\frac{dV}{dt} = \frac{\left(p_1^2 - p_2^2\right)\pi r^4}{16 l \eta p_0}$$

where *V* is the volume as measured at pressure p_0; p_1 and p_2 are the pressures at each end of the tube; *r* is the radius and *l* the length of the tube; and η is the viscosity.

Poisson ratio (μ) - The absolute value of the ratio of the transverse strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit (i.e., where Hooke's law is valid). [10]

Polariton - A quantum associated with the coupled modes of photons and optical phonons in an ionic crystal.

Polarizability (α)* - The change in dipole moment of a molecule produced by an external electric field; specifically, $\alpha_{ab} = \partial p_a/\partial E_b$, where p_a is the dipole moment component on the *a* axis and E_b is the component of the electric field strength along the *b* axis. [2]

Polymer - A substance composed of molecules of high relative molecular mass (molecular weight), the structure of which essentially comprises the multiple repetition of units derived, actually or conceptually, from molecules of low relative molecular mass. A single molecule of a polymer is called a macromolecule. [8]

Polypeptides - Peptides containing 10 or more amino acid residues. See also Peptides. [5]

Polysaccharides - Compounds consisting of a large number of monosaccharides linked glycosidically. This term is commonly used only for those containing more than ten monosaccharide residues. Also called glycans. [5]

Porphyrins - Natural pigments containing a fundamental skeleton of four pyrrole nuclei united through the α-positions by four methine groups to form a macrocyclic structure (porphyrin is designated porphine in Chemical Abstracts indexes). [5]

Positron - The antiparticle of the electron. It has the same mass and spin as an electron, and an equal but opposite charge.

Positronium - The hydrogen-like "atom" formed from a positron nucleus and an electron. Its lifetime is very short because of annihilation of the positron and electron.

Potential - See Electric potential

Potential energy (E_p, *V*, *U*) - The portion of the energy of a system that is associated with its position in a force field.

Pound (lb) - A non-SI unit of mass, equal to 0.4535924 kg.

Power (*P*) - Rate of energy transfer. For electrical circuits, this is equal to the product of current and potential difference, $P = IV$. [1]

Poynting vector (*S*) - For electromagnetic radiation, the vector product of the electric field strength and the magnetic field strength. [1]

Prandtl number (*Pr*) - A dimensionless quantity used in fluid mechanics, defined by $Pr = \eta/\rho a$, where η is viscosity, ρ is density, and *a* is thermal diffusivity. [2]

Pressure* - Force divided by area. [1]

Proteins - Naturally occurring and synthetic polypeptides having molecular weights greater than about 10,000 (the limit is not precise). See also Peptides. [5]

Proton* - A stable elementary particle of unit positive charge and spin 1/2. Protons and neutrons, which are collectively called nucleons, are the constituents of the nucleus.

Pulsar - A neutron star which rotates rapidly and emits electromagnetic radiation in regular pulses at a frequency related to the rotation period.

Purine bases* - Purine and its substitution derivatives, especially naturally occurring examples. [5]

Pyrimidine bases* - Pyrimidine and its substitution derivatives, especially naturally occurring examples. [5]

Q-switching - A technique for obtaining very high power from a laser by keeping the *Q* factor of the laser cavity low while the population inversion builds up, then suddenly increasing the *Q* to initiate the stimulated emission.

Quad - A unit of energy defined as 10^{15} Btu, equal to approximately 1.055056×10^{18} J.

Quadrupole moment - A coefficient of the third term (after monopole and dipole) in the power series expansion of the electric potential of an array of charges. A nucleus of spin greater than 1/2 has a non-vanishing nuclear quadrupole moment which can interact with the electric field gradient of the surrounding electrons. Molecular quadrupole moments have an influence on intermolecular forces.

Quality factor (*Q*) - The ratio of the absolute value of the reactance of an electrical system to the resistance; thus a measure of the energy stored per cycle relative to the energy dissipated.

Quantum yield - In photochemistry, the number of moles transformed in a specific process, either physically (e.g., by emission of photons) or chemically, per mole of photons absorbed by the system. [3]

Quark - An elementary entity which has not been directly observed but is considered a constituent of protons, neutrons, and other hadrons.

Quasar - An extragalactic object emitting electromagnetic radiation at a very high power level and showing a very large red shift, thus indicating that the object is receding at a speed approaching the speed of light.

Quasicrystal - A solid having conventional crystalline properties but whose lattice does not display translational periodicity.

Quaternary ammonium compounds - Derivatives of ammonium compounds, $NH_4^+Y^-$, in which all four of the hydrogens bonded to nitrogen have been replaced with hydrocarbyl groups. Compounds having a carbon-nitrogen double bond (i.e. $R_2C{=}N^+R_2Y^-$) are more accurately called iminium compounds. [5]

Quinones - Compounds having a fully conjugated cyclic dione structure, such as that of benzoquinones, derived from aromatic compounds by conversion of an even number of -CH= groups into -C(=O)- groups with any necessary rearrangement of double bonds. [5]

Racemic mixture - A mixture of equal amounts of a pair of enantiomers (optical isomers); such a mixture is not optically active.

Rad - A non-SI unit of absorbed dose of radiation, equal to 0.01 Gy.

Radiance (*L*) - The radiant intensity in a given direction from an element of a surface, divided by the area of the orthogonal projection of this element on a plane perpendicular to the given direction. [1]

Radiant intensity (*I*) - The radiant energy flux leaving an element of a source within an element of solid angle, divided by that element of solid angle. [1]

Radicals - Molecular entities possessing an unpaired electron, such as $\cdot CH_3$, $\cdot SnH_3$, ·Cl. (In these formulas the dot, symbolizing the unpaired electron, should be placed so as to indicate the atom of highest spin density, if this is possible). [5]

Raman effect - The inelastic scattering of light by a molecule, in which the incident photon either gives up to, or receives energy from, one of the internal vibrational modes of the molecule. The scattered light thus has either a lower frequency (Stokes radiation) or higher frequency (anti-Stokes radiation) than the incident light. These shifts provide a measure of the normal vibrational frequencies of the molecule.

Rankine cycle - A thermodynamic cycle which can be used to calculate the ideal performance of a heat engine that uses a condensable vapor as the working fluid (e.g., a steam engine or a heat pump).

Rankine temperature - A thermodynamic temperature scale based on a temperature interval °R = (5/9) K ; i.e., T/°R = (9/5)T/K = t/°F + 459.67.

Raoult's law - The expression for the vapor pressure p_i of component i in an ideal solution, viz., $p_i = x_i\, p_{i0}$, where x_i is the mole fraction of component i and p_{i0} the vapor pressure of the pure substance i.

Rare earth elements - The elements Sc, Y, and the lanthanides (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu). [7]

Rayleigh number (*Ra*) - A dimensionless quantity used in fluid mechanics, defined by $Ra = l^3 g\alpha\Delta T\rho/\eta a$, where l is length, g is acceleration of gravity, α is cubic expansion coefficient, T is temperature, ρ is density, η is viscosity, and a is thermal diffusivity. [2]

Rayleigh scattering - The scattering of light by particles which are much smaller than the wavelength of the light. It is characterized by a scattered intensity which varies as the inverse fourth power of the wavelength.

Rayleigh wave - A guided elastic wave along the surface of a solid; also called surface acoustic wave.

Reactance (*X*) - The imaginary part of impedance. For an inductive reactance L and a capacitive reactance C in series, the reactance is $X = L\omega - 1/(C\omega)$, where ω is 2π times the frequency of the current. [1]

Red shift - A displacement of a spectral line toward longer wavelengths. This can occur through the Doppler effect (e.g., in the light from receding galaxies) or, in the general theory of relativity, from the effects of a star's gravitational field.

Reflectance (ρ) - Ratio of the radiant or luminous flux at a given wavelength that is reflected to that of the incident radiation. Also called reflection factor. [1]

Reflection high energy electron diffraction (RHEED) - See Techniques for Materials Characterization, page **12**-1.

Relative humidity* - The ratio of the partial pressure of water vapor in air to the saturation vapor pressure of water at the same temperature, expressed as a percentage. [10]

Relative molar mass - See Molecular weight.

Rem - A non-SI unit of dose equivalent, equal to 0.01 Sv.

Resistance (*R*) - Electric potential difference divided by current when there is no electromotive force in the conductor. This definition applies to direct current. More generally, resistance is defined as the real part of impedance. [1]

Resistivity (ρ) - Electric field strength divided by current density when there is no electromotive force in the conductor. Resistivity is an intrinsic property of a material. For a conductor of uniform cross section with area A and length L, and whose resistance is R, the resistivity is given by $\rho = RA/L$. [1]

Reynolds number (*Re*) - A dimensionless quantity used in fluid mechanics, defined by $Re = \rho v l/\eta$, where ρ is density, v is velocity, l is length, and η is viscosity. [2]

Rheology - The study of the flow of liquids and deformation of solids. Rheology addresses such phenomena as creep, stress relaxation, anelasticity, nonlinear stress deformation, and viscosity.

Ribonucleic acids (RNA) - Naturally occurring polyribonucleotides. See also nucleic acids, nucleosides, nucleotides, ribonucleotides. [5]

Ribonucleotides - Nucleotides in which the glycosyl group is a ribosyl group. See also nucleotides. [5]

Roentgen (R) - A unit used for expressing the charge (positive or negative) liberated by x-ray or γ radiation in air, divided by the mass of air. A roentgen is defined as 2.58×10^{-4} C/kg.

Rotational constants - In molecular spectroscopy, the constants appearing in the expression for the rotational energy levels as a function of the angular momentum quantum numbers. These constants are proportional to the reciprocals of the principal moments of inertia, averaged over the vibrational motion.

Rutherford back scattering (RBS) - See Techniques for Materials Characterization, page **12**-1.

Rydberg constant (R_∞)* - The fundamental constant which appears in the equation for the energy levels of hydrogen-like atoms; i.e., $E_n = hcR_\infty Z^2\mu/n^2$, where h is Planck's constant, c the speed of light, Z the atomic number, μ the reduced mass of nucleus and electron, and n the principal quantum number (n = 1, 2, …).

Rydberg series - A regular series of lines in the spectrum of an atom or molecule, with the spacing between successive lines becoming smaller as the frequency increases (wavelength decreases). The series eventually converges to a limit which usually corresponds to the complete removal of an electron from the atom or molecule.

Sackur-Tetrode equation* - An equation for the molar entropy S_m of an ideal monatomic gas: $S_m = R\ln(e^{5/2}\, V/N_A\Lambda^3)$, where R is the molar gas constant, V is the volume, and N_A is Avogadro's number. The constant Λ is given by $\Lambda = h/(2\pi mkT)^{1/2}$, where h is Planck's constant, m the atomic mass, k the Boltzmann constant, and T the temperature.

Salinity (*S*)* - A parameter used in oceanography to describe the concentration of dissolved salts in seawater. It is defined in terms of electrical conductivity relative to a standard solution of KCl. When expressed in units of parts per thousand, S may be roughly equated to the concentration of dissolved material in grams per kilogram of seawater.

Salt - An ionic compound formed by the reaction of an acid and a base.

Scanned probe microscopy (SPM) - See Techniques for Materials Characterization, page **12**-1.

Scanning electron microscopy (SEM) - See Techniques for Materials Characterization, page **12**-1.

Scanning laser acoustic microscopy (SLAM) - See Techniques for Materials Characterization, page **12**-1.

Scanning transmission electron microscopy (STEM) - See Techniques for Materials Characterization, page **12**-1.

Scanning tunneling microscopy (STM) - See Techniques for Materials Characterization, page **12**-1.

Schiff bases - Imines bearing a hydrocarbyl group on the nitrogen atom: $R_2C{=}NR'$ (R′ not equal to H). Considered by many to be synonymous with azomethines. [5]

Schmidt number (*Sc*) - A dimensionless quantity used in fluid mechanics, defined by $Sc = \eta/\rho D$, where η is viscosity, ρ is density, and *D* is diffusion coefficient. [2]

Schottky barrier - A potential barrier associated with a metal-semiconductor contact. It forms the basis for the rectifying device known as the Schottly diode.

Schrödinger equation - The basic equation of wave mechanics which, for systems not dependent on time, takes the form:

$$-(\hbar/2m)\nabla^2\psi + V\psi = E\psi$$

where ψ is the wavefunction, *V* is the potential energy expressed as a function of the spatial coordinates, *E* is an energy eigenvalue, ∇^2 is the Laplacian operator, \ is Planck's constant divided by 2π, and *m* is the mass.

Second (s)* - The SI base unit of time. [1]

Second radiation constant (c_2)* - See First radiation constant.

Secondary ion mass spectroscopy (SIMS) - See Techniques for Materials Characterization, page **12**-1.

Seebeck effect - The development of a potential difference in a circuit where two different metals or semiconductors are joined and their junctions maintained at different temperatures. It is the basis of the thermocouple.

Selenides - Compounds having the structure RSeR (R not equal to H). They are thus selenium analogues of ethers. Also used for metal salts of H_2Se. [5]

Semicarbazones - Compounds having the structure $R_2C{=}NNHC({=}O)NH_2$, formally derived by condensation of aldehydes or ketones with semicarbazide [$NH_2NHC({=}O)NH_2$]. [5]

Semiconductor - A material in which the highest occupied energy band (valence band) is completely filled with electrons at $T = 0$ K, and the energy gap to the next highest band (conduction band) ranges from 0 to 4 or 5 eV. With increasing temperature electrons are excited into the conduction band, leading to an increase in the electrical conductivity.

Semiquinones - Radical anions having the structure -O-Z-O· where Z is an ortho- or para-arylene group or analogous heteroarylene group; they are formally generated by the addition of an electron to a quinone. [5]

SI units* - The International System of Units adopted in 1960 and recommended for use in all scientific and technical fields. [1]

Siemens (S)* - The SI unit of electric conductance, equal to Ω^{-1}. [1]

Sievert (Sv)* - The SI unit of dose equivalent (of radiation), equal to J/kg. [1]

Silanes - Saturated silicon hydrides, analogues of the alkanes; i.e. compounds of the general formula Si_nH_{2n+2}. Silanes may be subdivided into silane, oligosilanes, and polysilanes. Hydrocarbyl derivatives are often referred to loosely as silanes. [5]

Silicones - Polymeric or oligomeric siloxanes, usually considered unbranched, of general formula $[\text{-OSiR}_2\text{-}]_n$ (R not equal to H). [5]

Siloxanes - Saturated silicon-oxygen hydrides with unbranched or branched chains of alternating silicon and oxygen atoms (each silicon atom is separated from its nearest silicon neighbors by single oxygen atoms). [5]

Skin effect - The concentration of high frequency alternating currents near the surface of a conductor.

Slater orbital - A particular mathematical expression for the radial part of the wave function of a single electron, which is used in quantum-mechanical calculations of the energy and other properties of atoms and molecules.

Small angle neutron scattering (SANS) - See Techniques for Materials Characterization, page **12**-1.

Snell's law - The relation between the angle of incidence *i* and the angle of refraction *r* of a light beam which passes from a medium of refractive index n_0 to a medium of index n_1, viz., $\sin i/\sin r = n_1/n_0$.

Solar constant* - The mean radiant energy flux from the sun on a unit surface normal to the direction of the rays at the mean distance of the earth from the sun. The value is approximately 1373 W/m^2.

Solar wind - The stream of high velocity hydrogen and helium ions emitted by the sun which flows through the solar system and beyond.

Soliton - A spatially localized wave in a solid or liquid that can interact strongly with other solitons but will afterwards regain its original form.

Solubility* - A quantity expressing the maximum concentration of some material (the solute) that can exist in another liquid or solid material (the solvent) at thermodynamic equilibrium at specified temperature and pressure. Common measures of solubility include the mass of solute per unit mass of solution (mass fraction), mole fraction of solute, molality, molarity, and others.

Solubility product constant (K_{sp})* - The equilibrium constant for the dissolution of a sparsely soluble salt into its constituent ions.

Space group* - A group of symmetry operations (reflections, rotations, etc.) that leave a crystal invariant. A total of 230 space groups have been identified.

Spark source mass spectroscopy (SSMS) - See Techniques for Materials Characterization, page **12**-1.

Specific gravity - Ratio of the mass density of a material to that of water. Since one must specify the temperature of both the sample and the water to have a precisely defined quantity, the use of this term is now discouraged.

Specific heat - Heat capacity divided by mass. See Heat capacity.

Specific quantity - It is often convenient to express an extensive quantity (e.g., volume, enthalpy, heat capacity, etc.) as the actual value divided by mass. The resulting quantity is called specific volume, specific enthalpy, etc.

Specific rotation $[\alpha]^{\theta}_{\lambda}$- For an optically active substance, defined by $[\alpha]^{\theta}_{\lambda} = \alpha/\gamma l$, where α is the angle through which plane polarized light is rotated by a solution of mass concentration γ and path length *l*. Here θ is the Celsius temperature and λ the wavelength of the light at which the measurement is carried out. Also called specific optical rotatory power. [2]

Spin (*s*, *I*)* - A measure of the intrinsic angular momentum of a particle, which it possesses independent of its orbital motion. The symbol *s* is used for the spin quantum number of an electron, while *I* is generally used for nuclear spin.

Spiro compounds - Compounds having one atom (usually a quaternary carbon) as the only common member of two rings. [5]

Stacking fault - An error in the normal sequence of layer growth in a crystal.

Standard mean ocean water (SMOW) - A standard sample of pure water of accurately known isotopic composition which is maintained by the International Atomic Energy Agency. It is used for precise calibration of density and isotopic composition measurements.

Standard reduction potential ($E°$) - The zero-current potential of a cell in which the specified reduction reaction occurs at the right-hand electrode and the left-hand electrode is the standard hydrogen electrode. Also called Standard electrode potential.

Standard state - A defined state (specified temperature, pressure, concentration, etc.) for tabulating thermodynamic functions and carrying out thermodynamic calculations. The standard state pressure is usually taken as 100,000 Pa (1 bar), but various standard state temperatures are used. [2]

Stanton number (*St*) - A dimensionless quantity used in fluid mechanics, defined by $St = h/\rho v c_p$, where *h* is coefficient of heat transfer, ρ is

density, v is velocity, and c_p is specific heat capacity at constant pressure. [2]

Stark effect - The splitting of an energy level of an atom or molecule, and hence a splitting of spectral lines arising from that level, as a result of the application of an external electric field.

Statistical weight (*g*) - The number of distinct states corresponding to the same energy level. Also called degeneracy.

Stefan-Boltzmann constant (σ)* - Constant in the equation for the radiant exitance M (radiant energy flux per unit area) from a black body at thermodynamic temperature T, viz. $M = \sigma T^4$. [1]

Stibines - SbH_3 and compounds derived from it by substituting one, two or three hydrogen atoms by hydrocarbyl groups: R_3Sb. $RSbH_2$, R_2SbH, and R_3Sb (R not equal to H) are called primary, secondary and tertiary stibines, respectively. [5]

Stochastic process - A process which involves random variables and whose outcome can thus be described only in terms of probabilities.

Stoichiometric number (ν) - The number appearing before the symbol for each compound in the equation for a chemical reaction. By convention, it is negative for reactants and positive for products. [2]

Stokes (St) - A non-SI unit of kinematic viscosity, equal to 10^{-4} m^2/s.

Stokes' law - The statement, valid under certain conditions, that the viscous force F experienced by a sphere of radius a moving at velocity v in a medium of viscosity η is given by $F = -6\pi\eta a v$.

Strain - The deformation of a body that results from an applied stress.

Stratosphere - The part of the earth's atmosphere extending from the top of the troposphere (typically 10 to 15 km above the surface) to about 50 km. It is characterized by an increase in temperature with increasing altitude.

Stress - Force per unit area (pressure) applied to a body. Tensile stress tends to stretch or compress the body in the direction of the applied force. Sheer stress results from a tangential force which tends to twist the body.

Strong interaction - The short range (order of 1 fm) attractive forces between protons, neutrons, and other hadrons which are responsible for the stability of the nucleus.

Strouhal number (*Sr*) - A dimensionless quantity used in fluid mechanics, defined by $Sr = lf/v$, where l is length, f is frequency, and v is velocity. [2]

Structure factor - In x-ray crystallography, the sum of the scattering factors of all the atoms in a unit cell, weighted by an appropriate phase factor. The intensity of a given reflection is proportional to the square of the structure factor.

Sublimation pressure - The pressure of a gas in equilibrium with a solid at a specified temperature.

Sulfides - Compounds having the structure RSR (R not equal to H). Such compounds were once called thioethers. In an inorganic sense, salts or other derivatives of hydrogen sulfide. [5]

Sulfones - Compounds having the structure, $RS(=O)_2R$ (R not equal to H), e.g. $C_2H_5S(=O)_2CH_3$, ethyl methyl sulfone. [5]

Sulfonic acids - $HS(=O)_2OH$, sulfonic acid, and its S-hydrocarbyl derivatives. [5]

Sulfoxides - Compounds having the structure $R_2S{=}O$ (R not equal to H), e.g. $Ph_2S{=}O$, diphenyl sulfoxide. [5]

Superconductor - A material that experiences a nearly total loss of electrical resistivity below a critical temperature T_c. The effect can occur in pure metals, alloys, semiconductors, organic compounds, and certain inorganic solids.

Superfluid - A fluid with near-zero viscosity and extremely high thermal conductivity. Liquid helium exhibits these properties below 2.186 K (the λ point).

Supernova - A star in the process of exploding because of instabilities which follow the exhaustion of its nuclear fuel.

Surface analysis by laser ionization (SALI) - See Techniques for Materials Characterization, page **12**-1.

Surface tension (γ,σ)* - The force per unit length in the plane of the interface between a liquid and a gas, which resists an increase in the area of that surface. It can also be equated to the surface Gibbs energy per unit area.

Surfactant - A substance which lowers the surface tension of the medium in which it is dissolved, and/or the interfacial tension with other phases, and accordingly is positively adsorbed at the liquid-vapor or other interfaces. [3]

Susceptance (*B*) - Imaginary part of admittance. [1]

Svedberg - A non-SI unit of time, used to express sedimentation coefficients, equal to 10^{-13} s.

Syndiotactic macromolecule - A tactic macromolecule, essentially comprising alternating enantiomeric configurational base units which have chiral or prochiral atoms in the main chain in a unique arrangement with respect to their adjacent constitutional units. In this case the repeating unit consists of two configurational base units that are enantiomeric. [8]

Tacticity - The orderliness of the succession of configurational repeating units of a macromolecule or oligomer molecule. In a tactic macromolecule essentially all the configurational repeating units are identical with respect to directional sense. See Configurational repeating unit, Isotactic, Syndiotactic. [8]

Tautomerism - Isomerism of the general form G-X-Y=Z 1 X=Y-Z-G, where the isomers (called tautomers) are readily interconvertible; the atoms connecting the groups X, Y, Z are typically any of C, H, O, or S, and G is a group which becomes an electrofuge (i.e., a group that does not carry away the bonding electron pair when it leaves its position in the molecule) or nucleofuge (a group that does carry away the bonding electrons when leaving) during isomerization. The commonest case, when the electrofuge is H^+, is also known as prototropy. A common example, written so as to illustrate the general pattern given above, is keto-enol tautomerism, such as

$H{-}O{-}C(CH_3){=}CH{-}CO_2Et$ (enol) 1 $(CH_3)C({=}O){-}CH_2{-}CO_2Et$ (keto)

In some cases the interconversion rate between tautomers is slow enough to permit isolation of the separate keto and enol forms. [5]

Tensile strength* - In tensile testing, the ratio of maximum load a body can bear before breaking to original cross-sectional area. Also called ultimate strength. [11]

Terpenes - Hydrocarbons of biological origin having carbon skeletons formally derived from isoprene $[CH_2{=}C(CH_3)CH{=}CH_2]$. [5]

Terpenoids - Natural products and related compounds formally derived from isoprene units. They contain oxygen in various functional groups. The skeleton of terpenoids may differ from strict additivity of isoprene units by the loss or shift of a methyl (or other) group. [5]

Tesla (T)* - The SI unit of magnetic flux density (B), equal to V s/m^2. [1]

Thermal conductivity* - Rate of heat flow divided by area and by temperature gradient. [1]

Thermal diffusivity - Thermal conductivity divided by density and by specific heat capacity at constant pressure. [1]

Thermal expansion coefficient (α)* - The linear expansion coefficient is defined by $\alpha_l = (1/l)(dl/dT)$; the volume expansion coefficient by $\alpha_V = (1/V)(dV/dT)$. [1]

Thermionic emission - The emission of electrons from a solid as a result of heat. The effect requires a high enough temperature to impart sufficient kinetic energy to the electrons to exceed the work function of the solid.

Thermodynamic laws - The foundation of the science of thermodynamics:

First law: The internal energy of an isolated system is constant; if energy is supplied to the system in the form of heat dq and work dw, then the change in energy dU = dq + dw.

Second law: No process is possible in which the only result is the transfer of heat from a reservoir and its complete conversion to work.

Third law: The entropy of a perfect crystal approaches zero as the thermodynamic temperature approaches zero.

Thermoelectric power - For a bar of a pure material whose ends are at different temperatures, the potential difference divided by the difference in temperature of the ends. See also Seeback effect.

Thermogravimetric analysis (TGA) - See Techniques for Materials Characterization, page **12**-1.

Thermosphere - The layer of the earth's atmosphere extending from the top of the mesosphere (typically 80-90 km above the surface) to about 500 km. It is characterized by a rapid increase in temperature with increasing altitude up to about 200 km, followed by a leveling off in the 300-500 km region.

Thiols - Compounds having the structure RSH (R not equal to H). Also known by the term mercaptans (abandoned by IUPAC); e.g. CH_3CH_2SH, ethanethiol. [5]

Thomson coefficient (μ, τ) - The heat power developed in the Thomson effect (whereby heat is evolved in a conductor when a current is flowing in the presence of a temperature gradient), divided by the current and the temperature difference. [1]

Tonne (t) - An alternative name for megagram (1000 kg). [1]

Torque (*T*) - For a force $\boldsymbol{F}$ that produces a torsional motion, $\boldsymbol{T} = \boldsymbol{r} \times \boldsymbol{F}$, where $\boldsymbol{r}$ is a vector from some reference point to the point of application of the force.

Torr - A non-SI unit of pressure, equal to 133.322 Pa. The name is generally considered interchangeable with millimeter of mercury.

Townsend coefficient - In a radiation counter, the number of ionizing collisions by an electron per unit path length in the direction of an applied electric field.

Transducer - Any device that converts a signal from acoustical, optical, or some other form of energy into an electrical signal (or vice versa) while preserving the information content of the original signal.

Transistor - A voltage amplifier using controlled electron currents inside a semiconductor.

Transition metals - Elements characterized by a partially filled *d* subshell. The First Transition Series comprises Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu. The Second and Third Transition Series include the lanthanides and actinides, respectively. [7]

Transition probability* - See Einstein transition probability.

Transmittance (τ) - Ratio of the radiant or luminous flux at a given wavelength that is transmitted to that of the incident radiation. Also called transmission factor. [1]

Tribology - The study of frictional forces between solid surfaces.

Triple point* - The point in p,T space where the solid, liquid, and gas phases of a substance are in thermodynamic equilibrium. The corresponding temperature and pressure are called the triple point temperature and triple point pressure.

Troposphere - The lowest part of the earth's atmosphere, extending to 10-15 km above the surface. It is characterized by a decrease in temperature with increasing altitude. The exact height varies with latitude and season.

Tunnel diode - A device involving a p-n junction in which both sides are so heavily doped that the Fermi level on the p-side lies in the valence band and on the n-side in the conduction band. This leads to a current-voltage curve with a maximum, so that the device exhibits a negative resistance in some regions.

Ultraviolet photoelectron spectroscopy (UPS) - See Techniques for Materials Characterization, page **12**-1.

Umklapp process - A process involving the interaction of three or more waves (lattice or electron) in a solid in which the sum of the wave vectors does not equal zero.

Unified atomic mass unit (u)* - A unit of mass used in atomic, molecular, and nuclear science, defined as the mass of one atom of ^{12}C divided by 12. Its approximate value is 1.66054×10^{-27} kg. [1]

Universal time (t_U, UT) - Mean solar time counted from midnight at the Greenwich meridian. Also called Greenwich mean time (GMT). The interval of mean solar time is based on the average, over one year, of the time between successive transits of the sun across the observer's meridian.

Vacancy - A missing atom or ion in a crystal lattice.

Van Allen belts - Two toroidal regions above the earth's atmosphere containing protons and electrons. The outer belt at about 25,000 km above the surface is probably of solar origin. The inner belt at about 3000 km contains more energetic particles from outside the solar system.

Van der Waals' equation* - An equation of state for fluids which takes the form:

$$pV_m = RT\left(\frac{1}{V_m - b} - \frac{a}{V_m{}^2}\right)$$

where p is pressure, V_m is molar volume, T is temperature, R is the molar gas constant, and a and b are characteristic parameters of the substance which describe the effect of attractive and repulsive intermolecular forces, respectively.

Van der Waals' force - The weak attractive force between two molecules which arises from electric dipole interactions. It can lead to the formation of stable but weakly bound dimer molecules or clusters.

Van't Hoff equation - The equation expressing the temperature dependence of the equilibrium constant K of a chemical reaction:

$$\frac{\mathrm{d}\ln k}{\mathrm{d}T} = \frac{\Delta_r H^\circ}{RT^2}$$

where $\Delta_r H^\circ$ is the standard enthalpy of reaction, R the molar gas constant, and T the temperature. Also called van't Hoff isochore.

Vapor pressure* - The pressure of a gas in equilibrium with a liquid (or, in some usage, a solid) at a specified temperature.

Varistor - A device that utilizes the properties of certain metal oxides with small amounts of impurities, which show abrupt nonlinearities at specific voltages where the material changes from a semiconductor to an insulator.

Velocity (*v*) - Rate of change of distance with time.

Verdet constants (*V*)* - Angle of rotation of a plane polarized light beam passing through a medium in a magnetic field, divided by the field strength and by the path length.

Virial equation of state* - An equation relating the pressure p, molar volume V_m, and temperature T of a real gas in the form of an expansion in powers of the molar volume, viz., $pV_m = RT(1+BV_m^{-1}+CV_m^{-2}+ \ldots)$, where R is the molar gas constant. B is called the second virial coefficient, C the third virial coefficient, etc. The virial coefficients are functions of temperature.

Viscosity (η)* - The proportionality factor between sheer rate and sheer stress, defined through the equation $F = \eta\, A(\mathrm{d}v/\mathrm{d}x)$, where F is the tangential force required to move a planar surface of area A at velocity v relative to a parallel surface separated from the first by a distance x. Sometimes called dynamic or absolute viscosity. The term kinematic viscosity (symbol ν) is defined as η divided by the mass density.

Volt (V)* - The SI unit of electric potential, equal to W/A. [1]

Volume fraction (ϕ_j) - Defined as $V_j/\Sigma_i V_i$, where V_j is the volume of the specified component and the V_i are the volumes of all the components of a mixture prior to mixing. [2]

Watt (W)* - The SI unit of power, equal to J/s. [1]

Wave function - A function of the coordinates of all the particles in a quantum mechanical system (and, in general, of time) which fully describes the state of the system. The product of the wave function and its complex conjugate is proportional to the probability of finding a particle at a particular point in space.

Weak interaction - The weak forces (order of 10^{-12} of the strong interaction) between elementary particles which are responsible for beta decay and other nuclear effects.

Weber (Wb)* - The SI unit of magnetic flux, equal to V s. [1]

Weber number (*We*) - A dimensionless quantity used in fluid mechanics, defined by $We = \rho v^2 l/\gamma$, where ρ is density, *v* is velocity, *l* is length, and γ is surface tension. [2]

Weight - That force which, when applied to a body, would give it an acceleration equal to the local acceleration of gravity. [1]

Wiedeman-Franz law - The law stating that the thermal conductivity *k* and electrical conductivity σ of a pure metal are related by $k = L\sigma T$, where *T* is the temperature and *L* (called the Lorenz ratio) has the approximate value 2.45×10^{-8} V^2/K^2.

Wien displacement law - The relation, which can be derived from the Planck formula for black body radiation, that $\lambda_{max}T = 0.0028978$ m K, where λ_{max} is the wavelength of maximum radiance at temperature *T*.

Wigner-Seitz method - A method of calculating electron energy levels in a solid using a model in which each electron is subject to a spherically symmetric potential.

Wittig reagents - See phosphonium ylides.

Work (*W*) - Force multiplied by the displacement in the direction of the force. [1]

Work function (Φ)* - The energy difference between an electron at rest at infinity and an electron at the Fermi level in the interior of a substance. It is thus the minimum energy required to remove an electron from the interior of a solid to a point just outside the surface. [1]

X unit (X) - A unit of length used in x-ray crystallography, equal to approximately 1.002×10^{-13} m.

X-ray photoelectron spectroscopy (XPS) - See Techniques for Materials Characterization, page **12**-1.

Yield strength - The stress at which a material exhibits a specified deviation (often chosen as 0.2% for metals) from proportionality of stress and strain. [11]

Young's modulus (*E*) - In tension or compression of a body below its elastic limit, the ratio of stress to corresponding strain. Since strain is normally expressed on a fractional basis, Young's modulus has dimensions of pressure. Also called elastic modulus. [11]

Zeeman effect - The splitting of an energy level of an atom or molecule, and hence a splitting of spectral lines arising from that level, as a result of the application of an external magnetic field.

Zener diode - A control device utilizing a p-n junction with a well defined reverse-bias avalanche breakdown voltage.

Zeotrope - A liquid mixture that shows no maximum or minimum when vapor pressure is plotted against composition at constant temperature. See Azeotrope.

Zero-point energy - The energy possessed by a quantum mechanical system as a result of the uncertainty principle even when it is in its lowest energy state; e.g., the difference between the lowest energy level of a harmonic oscillator and the minimum in the potential well.

Zeta potential (ζ) - The electric potential at the surface of a colloidal particle relative to the potential in the bulk medium at a long distance. Also called electrokinetic potential.

Zwitterions - Neutral compounds having formal unit electrical charges of opposite sign. Some chemists restrict the term to compounds with the charges on non-adjacent atoms. Sometimes referred to as inner salts, dipolar ions (a misnomer). [5]

PHYSICAL CONSTANTS OF ORGANIC COMPOUNDS

The basic physical constants for over 12,000 organic compounds are presented in this table, along with structures and references to other sources of information. An effort has been made to include the compounds most frequently encountered in the laboratory, the workplace, and the environment. The selection was based mainly on the appearance of the compounds in various specialized tables in this Handbook and in other widely used reference sources, such as the Merck Index and the DIPPR Database of Pure Compound Properties. The occurrence of a compound on regulatory lists of hazardous chemicals was also taken into consideration, as was the availability of reliable physical constant data. Clearly, criteria of this type are somewhat subjective, and compounds considered important by some users have undoubtedly been omitted. Suggestions for additional compounds or other improvements are welcomed.

The data in the table have been taken from many sources, including both compilations and the primary literature. Where conflicts were found, the value deemed most reliable was chosen. Some of the useful compilations of physical property data are listed at the end of this introduction.

In the default listing, the table is arranged alphabetically by the substance name which, in most cases, is either an IUPAC systematic name or, in the case of pesticides and pharmaceuticals, a simple trivial name. Synonyms are given in the column following the primary name. The explanation of the data columns follows:

- **Mol. Form.**: The molecular formula written in the Hill convention.
- **CAS Reg. No**.: The Chemical Abstracts Service Registry Number assigned by CAS as a unique identifier for the compound.
- **Merck 12 Ed.**: Monograph Number in *The Merck Index, Twelfth Edition*. It should be noted that this is not a unique identifier for a single compound, since several derivatives or isomers of a compound may be included in the same Monograph.
- **Beilstein Ref.**: Citation to the Beilstein Handbook of Organic Chemistry. An entry of 5-18-11-01234, for example, indicates that the compound may be found in the 5th Series, Volume 18, Subvolume 11, page 1234.
- **Mol. Wt**: Molecular weight (relative molar mass) as calculated with the 1991 IUPAC Standard Atomic Weights.
- **mp**: Normal melting point in °C. A value is sometimes followed by “dec”, indicating decomposition is observed at the stated temperature (so that it is probably not a true melting point). The notation “tp” indicates a triple point, where solid, liquid, and gas are in equilibrium.
- **nbp**: Normal boiling point in °C. This is the temperature at which the liquid phase is in equilibrium with the vapor at a pressure of 760 mmHg (101.325 kPa). When a notation such as “dec” or “exp” (explodes) follow the value, the temperature may not be a true normal boiling point. The notation “sub” indicates the solid has a significant sublimation pressure at ambient temperatures.
- **Other bp**: A boiling point at reduced pressure. The pressure in mmHg is indicated by a superscript.

- **ρ**: Density (mass per unit volume) in g/cm^3. The temperature in °C is indicated by a superscript. Values are given only for the liquid and solid phases, and all values are true densities, not specific gravities. The number of decimal places gives a rough estimate of the accuracy of the value.
- **n_D**: Refractive index, at the temperature indicated in the superscript. Unless otherwise indicated, all values refer to a wavelength of 589 nm (sodium D line). Values are given only for liquids and solids.
- **Solubility**: Qualitative indication of solubility in common solvents. Abbreviations are:
  - i insoluble
  - sl slightly soluble
  - s soluble
  - vs very soluble
  - msc miscible
  - dec decomposes

LIST OF ABBREVIATIONS

Ac	acetyl
ac	acid
Ac_2O	acetic anhydride
ace	acetone
AcOEt	ethyl acetate
alk	alkali
anh	anhydrous
aq	aqueous
Bu	butyl
BuOH	1-butanol
bz	benzene
chl	chloroform
con, conc	concentrated
ctc	carbon tetrachloride
cy, cyhex	cyclohexane
dec	decomposes
dil	dilute
diox	dioxane
DMF	dimethylformamide
DMSO	dimethylsulfoxide
Et	ethyl
EtOH	ethanol
eth	diethyl ether
exp	explodes
gl	glacial
HOAc	acetic acid
hp	heptane

hx	hexane
i	insoluble
iso	isooctane
lig	ligroin
liq	liquid
Me	methyl
MeCN	acetonitrile
MeOH	methanol
misc	miscible
mp	melting point
nbp	normal boiling point
org	organic
os	organic solvents
peth	petroleum ether
Ph	phenyl
PhCl	chlorobenzene
$PhNH_2$	aniline
$PhNO_2$	nitrobenzene
Pr	propyl
PrOH	1-propanol
py	pyridine
pyr, pyrim	pyrimidine
reac	reacts
s	soluble
sat	saturated
sl	slightly
solv	solvent
sub	sublimes
sulf	sulfuric acid
tfa	trifluoroacetic acid
thf, THF	tetrahydrofuran
tol	toluene
undil	undiluted
unst	unstable
v	very
vap	vapor
wr	warm
xyl	xylene

REFERENCES

1. Lide, D. R., and Milne, G. W. A., Editors, *Handbook of Data on Organic Compounds, Third Edition*, CRC Press, Boca Raton, FL, 1993.
2. Luckenbach, R., Editor, *Beilstein Handbook of Organic Chemistry*, Springer-Verlag, Heidelberg. Data can also be accessed through the online Beilstein Database.
3. Budavari, S., Editor, *The Merck Index, Twelfth Edition*, Merck & Co., Rahway, NJ, 1996.
4. Daubert, T. E., Danner, R. P., Sibul, H. M., and Stebbins, C. C., *Physical and Thermodynamic Properties of Pure Compounds: Data Compilation*, extant 1994 (core with 4 supplements), Taylor & Francis, Bristol, PA (also available as database).
5. *TRC Thermodynamic Tables*, Thermodynamic Research Center, Texas A & M University, College Station, TX.
6. Riddick, J. A., Bunger, W. B., and Sakano, T. K., *Organic Solvents*, Fourth Edition, John Wiley & Sons, New York, 1986.
7. *Physical Constants of Hydrocarbon and Non-Hydrocarbon Compounds*, ASTM Data Series DS 4B, ASTM, Philadelphia, 1988.
8. Stevenson, R. M., and Malanowski, S., *Handbook of the Thermodynamics of Organic Compounds*, Elsevier, New York, 1987.
9. Buckingham, J., Editor, *Dictionary of Organic Compounds*, Fifth Edition (and Supplements), Chapman and Hall, New York, 1982-1993.
10. Lide, D. R., and Kehiaian, H. V., *Handbook of Thermophysical and Thermochemical Data*, CRC Press, Boca Raton, FL, 1994.

DIAMAGNETIC SUSCEPTIBILITY OF SELECTED ORGANIC COMPOUNDS

When a material is placed in a magnetic field ***H***, a magnetization ***M*** is induced in the material which is related to ***H*** by ***M*** = κ***H***, where κ is called the volume susceptibility. Since ***H*** and ***M*** have the same dimensions, κ is dimensionless. A more useful parameter is the molar susceptibility χ_m, defined by

$$\chi_m = \kappa V_m = \kappa M/\rho$$

where V_m is the molar volume of the substance, *M* the molar mass, and ρ the mass density. When the cgs system is used, the customary unit for χ_m is $cm^3\ mol^{-1}$; the corresponding SI unit is $m^3\ mol^{-1}$. Substances with no unpaired electrons are called diamagnetic; they have negative values of χ_m.

This table gives values of the diamagnetic susceptibility for about 400 common organic compounds. All values refer to room temperature and atmospheric pressure and to the physical form that is stable under these conditions. Substances are arranged by molecular formula in Hill order. A more extensive table may be found in Reference 1.

In keeping with customary practice, the molar susceptibility is given here in units appropriate to the cgs system. These values should be multiplied by 4π to obtain values for use in SI equations (where the magnetic field strength ***H*** has units of $A\ m^{-1}$).

REFERENCES

1. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series,* II/16*, Diamagnetic Susceptibility,* Gupta, R. R., Ed., Springer-Verlag, Heidelberg*,* 1986.
2. Barter, C., Meisenheimer, R. G., and Stevenson, D. P., *J. Phys. Chem*. 64, 1312, 1960.
3. Broersma, S., *J. Chem. Phys*. 17, 873, 1949.

Molecular Formula	Compound	$-\chi_m/10^{-6}\ cm^3\ mol^{-1}$
$CBrCl_3$	Bromotrichloromethane	73.2
CBr_4	Tetrabromomethane	93.7
$CClF_3$	Chlorotrifluoromethane	45.3
$CClN$	Cyanogen chloride	32.4
CCl_2F_2	Dichlorodifluoromethane	52.2
CCl_2O	Carbonyl chloride	47.9
CCl_3F	Trichlorofluoromethane	58.7
CCl_3NO_2	Trichloronitromethane	75.3
CCl_4	Tetrachloromethane	66.8
$CHBrCl_2$	Bromodichloromethane	66.3
$CHBr_3$	Tribromomethane	82.6
$CHCl_3$	Trichloromethane	58.9
CHI_3	Triiodomethane	117.1
CH_2BrCl	Bromochloromethane	55.1
CH_2Br_2	Dibromomethane	65.1
CH_2Cl_2	Dichloromethane	46.6
CH_2I_2	Diiodomethane	93.1
CH_2N_2	Cyanamide	24.8
CH_2O	Formaldehyde	18.6
CH_2O_2	Formic acid	19.9
CH_3Br	Bromomethane	42.8
CH_3Cl	Chloromethane	32.0
CH_3F	Fluoromethane	17.8
CH_3I	Iodomethane	57.2
CH_3NO	Formamide	23.0
CH_3NO_2	Nitromethane	21.0
CH_4	Methane	17.4
CH_4N_2O	Urea	33.5
CH_4O	Methanol	21.4
CH_5N	Methylamine	27.0
CI_4	Tetraiodomethane	136
CN_4O_8	Tetranitromethane	43.0
C_2ClF_3	Chlorotrifluoroethylene	49.1
C_2Cl_4	Tetrachloroethylene	81.6
C_2Cl_6	Hexachloroethane	112.8
C_2HCl_3	Trichloroethylene	65.8
C_2HCl_3O	Trichloroacetaldehyde	73.0
C_2HCl_3O	Dichloroacetyl chloride	69.0
$C_2HCl_3O_2$	Trichloroacetic acid	73.0
C_2HCl_5	Pentachloroethane	99.1
$C_2HF_3O_2$	Trifluoroacetic acid	43.3
C_2H_2	Acetylene	20.8
$C_2H_2Br_4$	1,1,2,2-Tetrabromoethane	123.4
$C_2H_2Cl_2$	1,1-Dichloroethylene	49.2
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethylene	51.0
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethylene	48.9
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane	89.8
C_2H_3Cl	Chloroethylene	35.9
C_2H_3ClO	Acetyl chloride	39.3
C_2H_3N	Acetonitrile	27.8
C_2H_4	Ethylene	18.8
$C_2H_4Br_2$	1,2-Dibromoethane	78.9
$C_2H_4Cl_2$	1,1-Dichloroethane	57.4
$C_2H_4Cl_2$	1,2-Dichloroethane	59.6
C_2H_4O	Acetaldehyde	22.2
C_2H_4O	Ethylene oxide	30.5
$C_2H_4O_2$	Acetic acid	31.8
$C_2H_4O_2$	Methyl formate	31.1
C_2H_5Br	Bromoethane	78.8
C_2H_5Cl	Chloroethane	69.9
C_2H_5I	Iodoethane	69.1
C_2H_5NO	Acetamide	33.9
$C_2H_5NO_2$	Nitroethane	35.4
$C_2H_5NO_2$	Glycine	39.6
C_2H_6	Ethane	26.8
C_2H_6O	Ethanol	33.7
C_2H_6O	Dimethyl ether	26.3
$C_2H_6O_2$	Ethylene glycol	38.9
C_2H_6S	Ethanethiol	47.0
C_2H_6S	Dimethyl sulfide	44.9
$C_2H_8N_2$	1,2-Ethanediamine	46.5
C_2N_2	Cyanogen	21.6

DIAMAGNETIC SUSCEPTIBILITY OF SELECTED ORGANIC COMPOUNDS (continued)

Molecular Formula	Compound	$-\chi_m/10^{-6}$ cm^3 mol^{-1}
C_3H_4	Allene	25.3
$C_3H_4O_2$	Vinyl formate	34.7
C_3H_5Br	3-Bromopropene	58.6
C_3H_5Cl	2-Chloropropene	47.8
C_3H_5Cl	3-Chloropropene	47.8
C_3H_5N	Propanenitrile	38.6
C_3H_6	Propene	30.7
C_3H_6	Cyclopropane	39.2
C_3H_6O	Allyl alcohol	36.7
C_3H_6O	Propanal	34.2
C_3H_6O	Acetone	33.8
C_3H_6O	Methyloxirane	42.5
$C_3H_6O_2$	Propanoic acid	43.2
$C_3H_6O_2$	Ethyl formate	42.4
C_3H_7Br	1-Bromopropane	65.6
C_3H_7Br	2-Bromopropane	65.1
C_3H_7Cl	1-Chloropropane	56.0
C_3H_7I	1-Iodopropane	84.3
C_3H_7N	Allylamine	40.1
$C_3H_7NO_2$	1-Nitropropane	45.0
$C_3H_7NO_2$	2-Nitropropane	45.4
$C_3H_7NO_2$	Ethyl carbamate	57.0
C_3H_8	Propane	38.6
C_3H_8O	1-Propanol	44.8
C_3H_8O	2-Propanol	45.7
$C_3H_8O_2$	1,3-Propylene glycol	50.2
$C_3H_8O_2$	Dimethoxymethane	47.3
$C_3H_8O_3$	Glycerol	57.1
$C_4H_2O_3$	Maleic anhydride	35.8
$C_4H_4N_2$	Pyrazine	37.8
$C_4H_4N_2$	Pyrimidine	43.1
C_4H_4O	Furan	43.1
$C_4H_4O_3$	Succinic anhydride	47.5
$C_4H_4O_4$	Maleic acid	49.6
$C_4H_4O_4$	Fumaric acid	49.1
C_4H_4S	Thiophene	57.3
C_4H_5N	Pyrrole	48.6
C_4H_6	1,2-Butadiene	35.6
C_4H_6	1,3-Butadiene	32.1
$C_4H_6O_2$	Vinyl acetate	46.4
$C_4H_6O_3$	Acetic anhydride	52.8
$C_4H_6O_4$	Succinic acid	58.0
$C_4H_6O_4$	Dimethyl oxalate	55.7
C_4H_7N	Butanenitrile	50.4
C_4H_8	1-Butene	41.0
C_4H_8	*cis*-2-Butene	42.6
C_4H_8	*trans*-2-Butene	43.3
C_4H_8	Isobutene	40.8
C_4H_8	Cyclobutane	40.0
C_4H_8O	Ethyl vinyl ether	47.9
C_4H_8O	1,2-Epoxybutane	54.8
C_4H_8O	Butanal	45.9
C_4H_8O	2-Butanone	45.6
$C_4H_8O_2$	Butanoic acid	55.2
$C_4H_8O_2$	2-Methylpropanoic acid	56.1
$C_4H_8O_2$	Propyl formate	55.0
$C_4H_8O_2$	Ethyl acetate	54.1
$C_4H_8O_2$	Methyl propanoate	54.5
$C_4H_8O_2$	1,4-Dioxane	52.2
C_4H_9Br	1-Bromobutane	77.1
C_4H_9Br	1-Bromo-2-methylpropane	79.9
C_4H_9Cl	1-Chlorobutane	67.1
C_4H_9Cl	2-Chlorobutane	67.4
C_4H_9I	1-Iodobutane	93.6
C_4H_9N	Pyrrolidine	54.8
C_4H_9NO	Morpholine	55.0
C_4H_{10}	Butane	50.3
C_4H_{10}	Isobutane	50.5
$C_4H_{10}O$	1-Butanol	56.4
$C_4H_{10}O$	2-Butanol	57.6
$C_4H_{10}O$	2-Methyl-1-propanol	57.6
$C_4H_{10}O$	2-Methyl-2-propanol	56.6
$C_4H_{10}O$	Diethyl ether	55.5
$C_4H_{10}O_2$	1,3-Butanediol	61.8
$C_4H_{10}O_2$	1,4-Butanediol	61.8
$C_4H_{10}S$	1-Butanethiol	70.2
$C_4H_{11}N$	Butylamine	58.9
$C_4H_{11}N$	Isobutylamine	59.8
$C_4H_{11}N$	Diethylamine	56.8
$C_5H_4O_2$	Furfural	47.2
C_5H_5N	Pyridine	48.7
$C_5H_6O_2$	Furfuryl alcohol	61.0
$C_5H_7NO_2$	Ethyl cyanoacetate	67.3
C_5H_8	2-Methyl-1,3-butadiene	46.0
C_5H_8O	Cyclopentanone	51.6
$C_5H_8O_2$	Methyl methacrylate	57.3
$C_5H_8O_2$	2,4-Pentanedione	54.9
C_5H_{10}	1-Pentene	54.6
C_5H_{10}	2-Methyl-2-butene	54.7
C_5H_{10}	Cyclopentane	56.2
$C_5H_{10}O$	Cyclopentanol	64.0
$C_5H_{10}O$	Pentanal	57.5
$C_5H_{10}O$	2-Pentanone	57.5
$C_5H_{10}O$	3-Pentanone	57.7
$C_5H_{10}O_2$	Pentanoic acid	66.5
$C_5H_{10}O_2$	3-Methylbutanoic acid	67.7
$C_5H_{10}O_2$	Butyl formate	65.8
$C_5H_{10}O_2$	Isobutyl formate	66.8
$C_5H_{10}O_2$	Propyl acetate	65.9
$C_5H_{10}O_2$	Isopropyl acetate	67.0
$C_5H_{10}O_2$	Ethyl propanoate	66.3
$C_5H_{10}O_2$	Tetrahydrofurfuryl alcohol	69.4
$C_5H_{10}O_3$	Diethyl carbonate	75.4
$C_5H_{11}N$	Piperidine	64.2
C_5H_{12}	Pentane	61.5
C_5H_{12}	Isopentane	63.0
C_5H_{12}	Neopentane	63.0
$C_5H_{12}O$	1-Pentanol	67.0
$C_5H_{12}O$	2-Pentanol	69.1
$C_5H_{12}O_2$	1,5-Pentanediol	73.5
$C_5H_{13}N$	Pentylamine	69.3
C_6Cl_6	Hexachlorobenzene	147.0
$C_6H_4ClNO_2$	1-Chloro-2-nitrobenzene	75.5
$C_6H_4ClNO_2$	1-Chloro-3-nitrobenzene	77.2
$C_6H_4ClNO_2$	1-Chloro-4-nitrobenzene	74.7
$C_6H_4Cl_2$	*o*-Dichlorobenzene	84.4

DIAMAGNETIC SUSCEPTIBILITY OF SELECTED ORGANIC COMPOUNDS (continued)

Molecular Formula	Compound	$-\chi_m/10^{-6}$ cm^3 mol^{-1}
$C_6H_4Cl_2$	*m*-Dichlorobenzene	84.1
$C_6H_4Cl_2$	*p*-Dichlorobenzene	81.7
$C_6H_4O_2$	*p*-Benzoquinone	36
C_6H_5Br	Bromobenzene	78.4
C_6H_5Cl	Chlorobenzene	69.5
C_6H_5ClO	*o*-Chlorophenol	77.3
C_6H_5ClO	*m*-Chlorophenol	77.6
C_6H_5ClO	*p*-Chlorophenol	77.7
C_6H_5F	Fluorobenzene	58.4
C_6H_5I	Iodobenzene	92.0
$C_6H_5NO_2$	Nitrobenzene	61.9
$C_6H_5NO_3$	*o*-Nitrophenol	68.9
$C_6H_5NO_3$	*m*-Nitrophenol	65.9
$C_6H_5NO_3$	*p*-Nitrophenol	66.9
C_6H_6	Benzene	54.8
C_6H_6ClN	*o*-Chloroaniline	79.5
C_6H_6ClN	*m*-Chloroaniline	76.6
C_6H_6ClN	*p*-Chloroaniline	76.7
$C_6H_6N_2O_2$	*o*-Nitroaniline	67.4
$C_6H_6N_2O_2$	*m*-Nitroaniline	69.7
$C_6H_6N_2O_2$	*p*-Nitroaniline	68.0
C_6H_6O	Phenol	60.6
$C_6H_6O_2$	*p*-Hydroquinone	64.7
$C_6H_6O_2$	Pyrocatechol	68.2
$C_6H_6O_2$	Resorcinol	67.2
C_6H_7N	Aniline	62.4
C_6H_7N	4-Methylpyridine	59.8
C_6H_8	1,4-Cyclohexadiene	48.7
$C_6H_8N_2$	*o*-Phenylenediamine	72.5
$C_6H_8N_2$	*m*-Phenylenediamine	70.4
$C_6H_8N_2$	*p*-Phenylenediamine	70.7
C_6H_{10}	1,5-Hexadiene	55.1
C_6H_{10}	1-Hexyne	64.5
C_6H_{10}	Cyclohexene	58.0
$C_6H_{10}O$	Cyclohexanone	62.0
$C_6H_{10}O_3$	Ethyl acetoacetate	71.7
$C_6H_{10}O_4$	Diethyl oxalate	81.7
C_6H_{12}	1-Hexene	66.4
C_6H_{12}	2,3-Dimethyl-2-butene	65.9
C_6H_{12}	Cyclohexane	68
C_6H_{12}	Methylcyclopentane	70.2
$C_6H_{12}O$	Hexanal	69.4
$C_6H_{12}O$	2-Hexanone	69.2
$C_6H_{12}O$	3-Hexanone	69.0
$C_6H_{12}O$	4-Methyl-2-pentanone	69.7
$C_6H_{12}O$	Cyclohexanol	73.4
$C_6H_{12}O_2$	Hexanoic acid	78.1
$C_6H_{12}O_2$	Isopentyl formate	78.4
$C_6H_{12}O_2$	Isobutyl acetate	78.7
$C_6H_{12}O_2$	Propyl propanoate	77.7
$C_6H_{12}O_3$	Paraldehyde	86.1
C_6H_{14}	Hexane	74.1
C_6H_{14}	2-Methylpentane	75.3
C_6H_{14}	3-Methylpentane	75.5
C_6H_{14}	2,2-Dimethylbutane	76.2
C_6H_{14}	2,3-Dimethylbutane	76.2
$C_6H_{14}O$	1-Hexanol	79.5
$C_6H_{14}O$	4-Methyl-2-pentanol	80.4
$C_6H_{14}O$	Dipropyl ether	79.4
$C_6H_{14}O_2$	1,6-Hexanediol	84.3
$C_6H_{14}O_2$	1,1-Diethoxyethane	81.4
$C_6H_{14}O_6$	*D*-Glucitol	107.8
$C_6H_{15}N$	Triethylamine	83.3
C_7H_5N	Benzonitrile	65.2
C_7H_6O	Benzaldehyde	60.7
$C_7H_6O_2$	Salicylaldehyde	66.8
$C_7H_6O_3$	Salicylic acid	75
C_7H_7Br	*p*-Bromotoluene	88.7
C_7H_7Cl	*o*-Chlorotoluene	82.4
C_7H_7Cl	*m*-Chlorotoluene	79.7
C_7H_7Cl	*p*-Chlorotoluene	80.3
C_7H_7Cl	(Chloromethyl)benzene	81.6
C_7H_7NO	Benzamide	72.0
$C_7H_7NO_2$	*o*-Nitrotoluene	72.2
$C_7H_7NO_2$	*m*-Nitrotoluene	72.7
$C_7H_7NO_2$	*p*-Nitrotoluene	73.3
C_7H_8	Toluene	65.6
C_7H_8O	*o*-Cresol	73.3
C_7H_8O	*m*-Cresol	72.2
C_7H_8O	*p*-Cresol	72.4
C_7H_8O	Benzyl alcohol	71.8
C_7H_8O	Anisole	72.2
C_7H_9N	*o*-Methylaniline	74.9
C_7H_9N	*m*-Methylaniline	74.6
C_7H_9N	*p*-Methylaniline	72.5
C_7H_9N	*N*-Methylaniline	74.1
C_7H_9N	2,4-Dimethylpyridine	71.3
C_7H_9N	2,6-Dimethylpyridine	72.5
C_7H_9NO	*o*-Methoxyaniline [*o*-Anisidine]	79.1
$C_7H_{12}O_4$	Diethyl malonate	92.6
C_7H_{14}	1-Heptene	77.8
C_7H_{14}	Cycloheptane	73.9
C_7H_{14}	Methylcyclohexane	78.9
$C_7H_{14}O$	1-Heptanal	81.0
$C_7H_{14}O$	2-Heptanone	80.5
$C_7H_{14}O$	3-Heptanone	80.7
$C_7H_{14}O$	4-Heptanone	80.5
$C_7H_{14}O$	2,4-Dimethyl-3-pentanone	81.1
$C_7H_{14}O_2$	Heptanoic acid	89.0
$C_7H_{14}O_2$	Pentyl acetate	88.9
$C_7H_{14}O_2$	Isopentyl acetate	89.4
$C_7H_{14}O_2$	Butyl propanoate	89.1
$C_7H_{14}O_2$	Ethyl 3-methylbutanoate	91.1
C_7H_{16}	Heptane	85.2
C_7H_{16}	3-Ethylpentane	86.2
C_7H_{16}	2,2-Dimethylpentane	87.0
C_7H_{16}	2,3-Dimethylpentane	87.5
C_7H_{16}	2,4-Dimethylpentane	87.5
C_7H_{16}	3,3-Dimethylpentane	89.5
$C_7H_{16}O$	1-Heptanol	91.7
$C_7H_{16}O$	4-Heptanol	92.1
$C_8H_4O_3$	Phthalic anhydride	66.7
$C_8H_6O_4$	Phthalic acid	83.6
$C_8H_6O_4$	Isophthalic acid	84.6
$C_8H_6O_4$	Terephthalic acid	83.5
C_8H_7N	Benzeneacetonitrile	76.9

DIAMAGNETIC SUSCEPTIBILITY OF SELECTED ORGANIC COMPOUNDS (continued)

Molecular Formula	Compound	$-\chi_m/10^{-6}\ cm^3\ mol^{-1}$
C_8H_7N	Indole	85.0
C_8H_8	Styrene	68.2
C_8H_8O	Acetophenone	72.5
$C_8H_8O_2$	*o*-Toluic acid	84.3
$C_8H_8O_2$	*m*-Toluic acid	83.0
$C_8H_8O_2$	*p*-Toluic acid	82.4
$C_8H_8O_2$	Benzeneacetic acid	82.4
$C_8H_8O_2$	Methyl benzoate	81.6
$C_8H_8O_3$	Methyl salicylate	86.6
C_8H_{10}	Ethylbenzene	77.3
C_8H_{10}	*o*-Xylene	77.7
C_8H_{10}	*m*-Xylene	76.4
C_8H_{10}	*p*-Xylene	77.0
$C_8H_{10}O$	Phenetole	84.5
$C_8H_{11}N$	*N*-Ethylaniline	85.6
$C_8H_{11}N$	*N*,*N*-Dimethylaniline	85.1
$C_8H_{11}N$	2,4,6-Trimethylpyridine	83.1
$C_8H_{14}O_4$	Ethyl succinate	105.0
C_8H_{16}	1-Octene	88.8
C_8H_{16}	Cyclooctane	85.3
$C_8H_{16}O_2$	Octanoic acid	99.5
$C_8H_{16}O_2$	Hexyl acetate	100.9
$C_8H_{17}Cl$	1-Chlorooctane	114.9
C_8H_{18}	Octane	96.6
C_8H_{18}	4-Methylheptane	97.3
C_8H_{18}	3-Ethylhexane	97.8
C_8H_{18}	3,4-Dimethylhexane	99.1
C_8H_{18}	2,2,4-Trimethylpentane	99.1
C_8H_{18}	2,3,4-Trimethylpentane	99.8
$C_8H_{18}O$	1-Octanol	101.6
$C_8H_{19}N$	Dibutylamine	103.7
C_9H_7N	Quinoline	86.1
C_9H_7N	Isoquinoline	83.9
C_9H_8	Indene	83
C_9H_{10}	Isopropenylbenzene	80.0
$C_9H_{10}O_2$	Ethyl benzoate	93.8
$C_9H_{10}O_2$	Benzyl acetate	93.2
C_9H_{12}	Propylbenzene	89.1
C_9H_{12}	Isopropylbenzene [Cumene]	89.5
C_9H_{12}	1,3,5-Trimethylbenzene [Mesitylene]	92.3
C_9H_{18}	1-Nonene	100.1
$C_9H_{18}O$	2,6-Dimethyl-4-heptanone	104.3
C_9H_{20}	Nonane	108.1
$C_{10}H_7Br$	1-Bromonaphthalene	123.6
$C_{10}H_7Cl$	1-Chloronaphthalene	107.6
$C_{10}H_8$	Naphthalene	91.6
$C_{10}H_8$	Azulene	123.7
$C_{10}H_8O$	1-Naphthol	96.2
$C_{10}H_8O$	2-Naphthol	96.8
$C_{10}H_9N$	1-Naphthalenamine	92.5
$C_{10}H_9N$	2-Naphthalenamine	98.0
$C_{10}H_{10}O_2$	Safrole	97.5
$C_{10}H_{10}O_4$	Dimethyl terephthalate	101.6
$C_{10}H_{14}$	Butylbenzene	100.7
$C_{10}H_{14}$	*tert*-Butylbenzene	101.8
$C_{10}H_{14}$	Isobutylbenzene	101.7
$C_{10}H_{14}$	*p*-Cymene	102.8
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene	101.2
$C_{10}H_{14}O$	*p*-*tert*-Butylphenol	108.0
$C_{10}H_{15}N$	*N*,*N*-Diethylaniline	107.9
$C_{10}H_{16}$	*d*-Limonene	98.0
$C_{10}H_{16}$	α-Pinene	100.7
$C_{10}H_{16}$	β-Pinene	101.9
$C_{10}H_{16}O$	Camphor, (+)	103.0
$C_{10}H_{18}$	*cis*-Decahydronaphthalene	107.0
$C_{10}H_{18}$	*trans*-Decahydronaphthalene	107.6
$C_{10}H_{22}$	Decane	119.5
$C_{11}H_{10}$	1-Methylnaphthalene	102.9
$C_{11}H_{10}$	2-Methylnaphthalene	102.7
$C_{11}H_{24}$	Undecane	131.8
$C_{12}H_8$	Acenaphthylene	111.6
$C_{12}H_9N$	Carbazole	119.9
$C_{12}H_{10}$	Acenaphthene	109.9
$C_{12}H_{10}$	Biphenyl	103.3
$C_{12}H_{10}N_2$	Azobenzene	106.8
$C_{12}H_{11}N$	Diphenylamine	108.4
$C_{12}H_{14}O_4$	Diethyl phthalate	127.5
$C_{12}H_{18}$	Hexamethylbenzene	122.5
$C_{12}H_{24}O_2$	Dodecanoic acid	113.0
$C_{13}H_9N$	Acridine	118.8
$C_{13}H_{10}O$	Benzophenone	109.6
$C_{13}H_{12}$	Diphenylmethane	116.0
$C_{13}H_{28}$	Tridecane	153.7
$C_{14}H_8O_2$	9,10-Anthracenedione	113.0
$C_{14}H_{10}$	Anthracene	129.8
$C_{14}H_{10}$	Phenanthrene	127.6
$C_{14}H_{10}$	Diphenylacetylene	116
$C_{14}H_{10}O_2$	Benzil	106.8
$C_{14}H_{12}O_2$	Benzyl benzoate	132.2
$C_{14}H_{14}$	1,2-Diphenylethane	127.8
$C_{14}H_{28}O_2$	Tetradecanoic acid [Myristic acid]	176.0
$C_{14}H_{30}$	Tetradecane	166.2
$C_{16}H_{10}$	Pyrene	147
$C_{16}H_{32}O_2$	Hexadecanoic acid [Palmitic acid]	198.6
$C_{16}H_{34}$	Hexadecane	187.6
$C_{16}H_{34}O$	1-Hexadecanol	183.5
$C_{18}H_{12}$	Chrysene	148.0
$C_{18}H_{14}$	*o*-Terphenyl	150.4
$C_{18}H_{14}$	*m*-Terphenyl	155.5
$C_{18}H_{14}$	*p*-Terphenyl	156.0
$C_{18}H_{34}O_2$	*cis*-9-Octadecenoic acid [Oleic acid]	208.5
$C_{18}H_{36}O_2$	Octadecanoic acid [Steric acid]	220.8
$C_{20}H_{12}$	Perylene	167.5

THE ELEMENTS
C. R. Hammond

One of the most striking facts about the elements is their unequal distribution and occurrence in nature. Present knowledge of the chemical composition of the universe, obtained from the study of the spectra of stars and nebulae, indicates that hydrogen is by far the most abundant element and may account for more than 90% of the atoms or about 75% of the mass of the universe. Helium atoms make up most of the remainder. All of the other elements together contribute only slightly to the total mass.

The chemical composition of the universe is undergoing continuous change. Hydrogen is being converted into helium, and helium is being changed into heavier elements. As time goes on, the ratio of heavier elements increases relative to hydrogen. Presumably, the process is not reversible.

Burbidge, Burbidge, Fowler, and Hoyle, and more recently, Peebles, Penzias, and others have studied the synthesis of elements in stars. To explain all of the features of the nuclear abundance curve — obtained by studies of the composition of the earth, meteorites, stars, etc. — it is necessary to postulate that the elements were originally formed by at least eight different processes: (1) hydrogen burning, (2) helium burning, (3) χ process, (4) *e* process, (5) *s* process, (6) *r* process, (7) *p* process, and (8) the X process. The X process is thought to account for the existence of light nuclei such as D, Li, Be, and B. Common metals such as Fe, Cr, Ni, Cu, Ti, Zn, etc. were likely produced early in the history of our galaxy. It is also probable that most of the heavy elements on earth and elsewhere in the universe were originally formed in supernovae, or in the hot interior of stars.

Studies of the solar spectrum have led to the identification of 67 elements in the sun's atmosphere; however, all elements cannot be identified with the same degree of certainty. Other elements may be present in the sun, although they have not yet been detected spectroscopically. The element helium was discovered on the sun before it was found on earth. Some elements such as scandium are relatively more plentiful in the sun and stars than here on earth.

Minerals in lunar rocks brought back from the moon on the Apollo missions consist predominantly of *plagioclase* $\{(Ca,Na)(Al,Si)O_4O_8\}$ and *pyroxene* $\{(Ca,Mg,Fe)_2Si_2O_6\}$ — two minerals common in terrestrial volcanic rock. No new elements have been found on the moon that cannot be accounted for on earth; however, three minerals, *armalcolite* $\{(Fe,Mg)Ti_2O_5\}$, *pyroxferroite* $\{CaFe_6(SiO_3)_7\}$, and *tranquillityite* $\{Fe_8(Zr,Y)Ti_3Si_3O_2\}$, are new. The oldest known terrestrial rocks are about 4 billion years old. One rock, known as the "Genesis Rock," brought back from the Apollo 15 Mission, is about 4.15 billion years old. This is only about one-half billion years younger than the supposed age of the moon and solar system. Lunar rocks appear to be relatively enriched in refractory elements such as chromium, titanium, zirconium, and the rare earths, and impoverished in volatile elements such as the alkali metals, in chlorine, and in noble metals such as nickel, platinum, and gold.

Even older than the "Genesis Rock" are *carbonaceous chondrites,* a type of meteorite that has fallen to earth and has been studied. These are some of the most primitive objects of the solar system yet found. The grains making up these objects probably condensed directly out the gaseous nebula from which the sun and planets were born. Most of the condensation of the grains probably was completed within 50,000 years of the time the disk of the nebula was first formed — about 4.6 billion years ago. It is now thought that this type of meteorite may contain a small percentage of presolar dust grains. The relative abundances of the elements of these meteorites are about the same as the abundances found in the solar chromosphere.

The X-ray fluorescent spectrometer sent with the Viking I spacecraft to Mars shows that the Martian soil contains about 12 to 16% iron, 14 to 15% silicon, 3 to 8% calcium, 2 to 7% aluminum, and one-half to 2% titanium. The gas chromatograph — mass spectrometer on Viking II found no trace of organic compounds that should be present if life ever existed there.

F. W. Clarke and others have carefully studied the composition of rocks making up the crust of the earth. Oxygen accounts for about 47% of the crust, by weight, while silicon comprises about 28% and aluminum about 8%. These elements, plus iron, calcium, sodium, potassium, and magnesium, account for about 99% of the composition of the crust.

Many elements such as tin, copper, zinc, lead, mercury, silver, platinum, antimony, arsenic, and gold, which are so essential to our needs and civilization, are among some of the rarest elements in the earth's crust. These are made available to us only by the processes of concentration in ore bodies. Some of the so-called *rare-earth* elements have been found to be much more plentiful than originally thought and are about as abundant as uranium, mercury, lead, or bismuth. The least abundant rare-earth or *lanthanide* element, thulium, is now believed to be more plentiful on earth than silver, cadmium, gold, or iodine, for example. Rubidium, the 16th most abundant element, is more plentiful than chlorine while its compounds are little known in chemistry and commerce.

It is now thought that at least 24 elements are essential to living matter. The four most abundant in the human body are hydrogen, oxygen, carbon, and nitrogen. The seven next most common, in order of abundance, are calcium, phosphorus, chlorine, potassium, sulfur, sodium, and magnesium. Iron, copper, zinc, silicon, iodine, cobalt, manganese, molybdenum, fluorine, tin, chromium, selenium, and vanadium are needed and play a role in living matter. Boron is also thought essential for some plants, and it is possible that aluminum, nickel, and germanium may turn out to be necessary.

Ninety-one elements occur naturally on earth. Minute traces of plutonium-244 have been discovered in rocks mined in Southern California. This discovery supports the theory that heavy elements were produced during creation of the solar system. While technetium and promethium have not yet been found naturally on earth, they have been found to be present in stars. Technetium has been identified in the spectra of certain "late" type stars, and promethium lines have been identified in the spectra of a faintly visible star HR465 in Andromeda. Promethium must have been made very recently near the star's surface for no known isotope of this element has a half-life longer than 17.7 years.

It has been suggested that californium is present in certain stellar explosions known as supernovae; however, this has not been proved. At present no elements are found elsewhere in the universe that cannot be accounted for here on earth.

All atomic mass numbers from 1 to 238 are found naturally on earth except for masses 5 and 8. About 285 relatively stable and 67 naturally radioactive isotopes occur on earth totaling 352. In addition, the neutron, technetium, promethium, and the transuranic elements (lying beyond uranium) have now been produced artificially. Scientists at the Lawrence Berkeley National Laboratory, in June 1999, reported they had found evidence of an isotope of Element 118 and its immediate decay products, Element Nos. 116 and 114. The sequence of events tend to reinforce the theories that have predicted, since the 1970s, an "island of stability" for nuclei with approximately 114 protons and 184 neutrons. This "island" refers to nuclei in which the decay lasts for a period of time instead of a decay that occurs instantly.

Laboratory processes have now extended the radioactive element mass numbers beyond 238 to 293. Each element from atomic numbers 1 to 110 is known to have at least one radioactive isotope. As of December 1999, 3288 isotopes and isomers were thought to be known and recognized. Many stable and radioactive isotopes are now produced and distributed by the Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A., to customers licensed by the U.S. Department of Energy.

THE ELEMENTS (continued)

The nucleus of an atom is characterized by the number of protons it contains, denoted by *Z*, and by the number of neutrons, *N*. Isotopes of an element have the same value of *Z*, but different values of *N*. The *mass number A*, is the sum of *Z* and *N*. For example, Uranium-238 has a mass number of 238, and contains 92 protons and 146 neutrons.

There is evidence that the definition of chemical elements must be broadened to include the electron. Several compounds known as *electrides,* have recently been made of alkaline metal elements and electrons. A relatively stable combination of a positron and electron, known as *positronium,* has also been studied.

In addition to the proton, neutron, and electron, there are considerably more than 100 other fundamental particles which have been discovered or hypothesized. The majority of these fall into one of two classes, *leptons* or *hadrons.* The leptons comprise just four known particles, the *electron,* the *muon* (μ meson), and two kinds of *neutrinos.* The muon is essentially similar to the electron and has a charge of –1, but it is 200 times heavier. The neutrino is either of two stable particles of small (probably zero) rest mass, carrying no charge. Also there are four *antileptons,* identical to the corresponding leptons in some respects, such as mass, but they have properties exactly opposite those of the leptons. The *positron,* for example, is an antilepton, with a charge of +1. Leptons cannot be broken into smaller units and are considered to be elementary. On the other hand, hadrons are complex and thought to have internal structure. Protons and neutrons, which make up atomic nuclei, are hadrons.

Elementary particle physics is not yet clearly understood, but groupings and arrangements of these particles have been made resembling the periodic table of chemical elements. This has led to the speculation that hadrons are composed of simpler components called *quarks.* Quarks are presumed to be elementary particles. Quarks come in a variety of "flavors". Two kinds of quarks — up and down — combine to form the protons and neutrons of ordinary matter. Three other quarks, known as {strange", "charm", and "bottom", are found in particle accelerators, and one of these may exist in the center of very dense, massive stars. Theorists have thought that a sixth "top" quark, much more massive than the others, should exist to complete the quark family of sub-atomic particles. In 1994, scientists using Fermilab's Tevatron accelerator may have "glimpsed" the top quark. There is presently no evidence that quarks exist in isolation. Many physicists now hold that all the matter and energy in the universe is controlled by four fundamental natural forces: the electromagnetic force, gravity, a weak nuclear force, and a strong nuclear force. Each of these natural forces is passed back and forth among the basic particles of matter by unique force-carrying particles. The electromagnetic force is carried by the *photon,* the weak nuclear force by the intermediate vector *boson,* and gravity by the *gravitron.* There is now evidence of the existence of a particle, known as the *gluon,* that binds quarks together by carrying the strong nuclear force. *Hadrons* are thought to be particles composed of quarks and gluons.

The available evidence leads to the conclusion that elements 89 (actinium) through 103 (lawrencium) are chemically similar to the rare-earth or lanthanide elements (elements 57 to 71, inclusive). These elements therefore have been named *actinides* after the first member of this series. Those elements beyond uranium that have been produced artificially have the following names and symbols: neptunium, 93 (Np); plutonium, 94 (Pu); americium, 95 (Am); curium, 96 (Cm); berkelium, 97 (Bk); californium, 98 (Cf); einsteinium, 99 (Es); fermium, 100 (Fm); mendelevium, 101 (Md); nobelium, 102 (No); and lawrencium, 103 (Lr). It is now claimed that Elements 104 through 112 have been produced and identified. More recently, Elements 118, 116, and 114 are now thought to be found. In August 1997, the International Union of Pure and Applied Chemistry (IUPAC) gave final approval to the following names for Elements 104 to 109: Element 104 — rutherfordium (Rf); Element 105 — dubnium (Db); Element 106 — seaborgium (Sg); Element 107 — bohrium (Bh); Element 108 — hassium (Hs); and Element 109 — meitnerium (Mt). The recently discovered elements 110, 111, 112, 114, 116, and 118 have not yet been named, but may carry temporary names as designated by the International Union of Pure and Applied Chemistry. IUPAC recommends that until the existence of a new element is proven to their satisfaction, the elements are to have names and symbols derived according to these precise and simple rules: The name is based on the digits in the element's atomic number. Each digit is replaced with these expressions, with the end using the usual –ium suffix as follows: **0 nil, 1 un, 2 bi, 3 tri, 4 quad, 5 pent, 6 hex, 7 sept, 8 oct, 9 enn**. Double letter i's are not used, as for example Ununbiium, but would be Ununbium. The symbol used would be the first letter of the three main syllables. For example, Element 126 would be Unbihexium, with the symbol Ubh. It is thought there is a good possibility of producing elements beyond Element 118, and discovering, in the near future, Elements 117, 115, and 113 by altering the beams of ions and the targets from those now being used.

There are many claims in the literature of the existence of various allotropic modifications of the elements, some of which are based on doubtful or incomplete evidence. Also, the physical properties of an element may change drastically by the presence of small amounts of impurities. With new methods of purification, which are now able to produce elements with 99.9999% purity, it has been necessary to restudy the properties of the elements. For example, the melting point of thorium changes by several hundred degrees by the presence of a small percentage of ThO_2 as an impurity. Ordinary commercial tungsten is brittle and can be worked only with difficulty. Pure tungsten, however, can be cut with a hacksaw, forged, spun, drawn, or extruded. In general, the value of a physical property given here applies to the pure element, when it is known.

Many of the chemical elements and their compounds are toxic and should be handled with due respect and care. In recent years there has been a greatly increased knowledge and awareness of the health hazards associated with chemicals, radioactive materials, and other agents. Anyone working with the elements and certain of their compounds should become thoroughly familiar with the proper safeguards to be taken. Information on specific hazards and recommended exposure limits may also be found in Section 16. Reference should also be made to publications such as the following:

1. *Code of Federal Regulations, Title 29, Labor.* With additions found in issues of the *Federal Register*.
2. *Code of Federal Regulations, Title 10, Energy.* With additions found in issues of the *Federal Register*. (Published by the U.S. Government Printing Office. Supt. of Documents.)
3. *Occupational Safety and Health Reporter* (latest edition with amendments and corrections), Bureau of National Affairs, Washington, D.C.
4. *Atomic Energy Law Reporter,* Commerce Clearing House, Chicago, IL.
5. *Nuclear Regulation Reporter,* Commerce Clearing House, Chicago, IL.
6. *TLVs® Threshold Limit Values for Chemical Substances and Physical Agents* is issued annually be the American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio.
7. *The Sigma Aldrich Library of Regulatory and Safety Data. Vol. 3,* Robert E. Lenga and Kristine L. Volonpal, Sigma Chemical Co. and Aldrich Chemical Co., Inc. 1993.
8. *Hazardous Chemicals Desk Reference,* Richard J. Lewis, Sr., 4th ed., John Wiley & Sons, New York, Dec. 1997.

The prices of elements as indicated in this article are intended to be only a rough guide. Prices may vary, over time, widely with supplier, quantity, and purity.

Actinium — (Gr. *aktis, aktinos,* beam or ray), Ac; at. wt. (227); at. no. 89; m.p. 1051°C, b.p. 3200 ± 300°C (est.); sp. gr. 10.07 (calc.). Discovered by Andre Debierne in 1899 and independently by F. Giesel in 1902. Occurs naturally in association with uranium minerals. Thirty four isotopes and isomers are now recognized. All are radioactive. Actinium-227, a decay product of uranium-235, is an alpha and beta emitter with a 21.77-year half-life. Its principal decay products are thorium-227 (18.72-day half-life), radium-223 (11.4-day half-life), and a number of short-lived products including radon, bismuth, polonium, and lead isotopes. In equilibrium with its decay products, it is a powerful source of alpha rays. Actinium metal has been prepared by the reduction of actinium fluoride with lithium vapor at about 1100 to 1300°C. The chemical behavior of actinium is similar to that of the rare earths, particularly lanthanum. Purified actinium comes into equilibrium with its decay products at the end of 185 days, and then decays according to its 21.77-year half-life. It is about 150 times as active as radium, making it of value in the production of neutrons. Actinium-225, with a purity of 99%, is available from the Oak Ridge National Laboratory to holders of a permit for about $500/millicurie, plus packing charges.

Aluminum — (L. *alumen, alum*), Al; at. wt. 26.981539(5); at. no. 13; f.p. 660.323°C; b.p. 2519°C; sp. gr. 2.6989 (20°C); valence 3. The ancient Greeks and Romans used *alum* in medicine as an astringent, and as a mordant in dyeing. In 1761 de Morveau proposed the name *alumine* for the base in alum, and Lavoisier, in 1787, thought this to be the oxide of a still undiscovered metal. Wohler is generally credited with having isolated the metal in 1827, although an impure form was prepared by Oersted two years earlier. In 1807, Davy proposed the name *alumium* for the metal, undiscovered at that time, and later agreed to change it to *aluminum*. Shortly thereafter, the name *aluminium* was adopted to conform with the "ium" ending of most elements, and this spelling is now in use elsewhere in the world. *Aluminium* was also the accepted spelling in the U.S. until 1925, at which time the American Chemical Society officially decided to use the name *aluminum* thereafter in their publications. The method of obtaining aluminum metal by the electrolysis of alumina dissolved in *cryolite* was discovered in 1886 by Hall in the U.S. and at about the same time by Heroult in France. Cryolite, a natural ore found in Greenland, is no longer widely used in commercial production, but has been replaced by an artificial mixture of sodium, aluminum, and calcium fluorides. *Bauxite,* an impure hydrated oxide ore, is found in large deposits in Jamaica, Australia, Suriname, Guyana, Russia, Arkansas, and elsewhere. The Bayer process is most commonly used today to refine bauxite so it can be accommodated in the Hall-Heroult refining process, used to make most aluminum. Aluminum can now be produced from clay, but the process is not economically feasible at present. Aluminum is the most abundant metal to be found in the earth's crust (8.1%), but is never found free in nature. In addition to the minerals mentioned above, it is found in feldspars, granite, and in many other common minerals. Twenty-two isotopes and isomers are known. Natural aluminum is made of one isotope, ^{27}Al. Pure aluminum, a silvery-white metal, possesses many desirable characteristics. It is light, nontoxic, has a pleasing appearance, can easily be formed, machined, or cast, has a high thermal conductivity, and has excellent corrosion resistance. It is nonmagnetic and nonsparking, stands second among metals in the scale of malleability, and sixth in ductility. It is extensively used for kitchen utensils, outside building decoration, and in thousands of industrial applications where a strong, light, easily constructed material is needed. Although its electrical conductivity is only about 60% that of copper, it is used in electrical transmission lines because of its light weight. Pure aluminum is soft and lacks strength, but it can be alloyed with small amounts of copper, magnesium, silicon, manganese, and other elements to impart a variety of useful properties. These alloys are of vital importance in the construction of modern aircraft and rockets. Aluminum, evaporated in a vacuum, forms a highly reflective coating for both visible light and radiant heat. These coatings soon form a thin layer of the protective oxide and do not deteriorate as do silver coatings. They have found application in coatings for telescope mirrors, in making decorative paper, packages, toys, and in many other uses. The compounds of greatest importance are aluminum oxide, the sulfate, and the soluble sulfate with potassium (alum). The oxide, alumina, occurs naturally as ruby, sapphire, corundum, and emery, and is used in glassmaking and refractories. Synthetic ruby and sapphire have found application in the construction of lasers for producing coherent light. In 1852, the price of aluminum was about $1200/kg, and just before Hall's discovery in 1886, about $25/kg. The price rapidly dropped to 60¢ and has been as low as 33¢/kg. The price in December 1999 was about $1.50/kg.

Americium — (the Americas), Am; at. wt. 243; at. no. 95; m.p. 1176°C; b.p. 2011°C; sp. gr. 13.67 (20°C); valence 2, 3, 4, 5, or 6. Americium was the fourth transuranium element to be discovered; the isotope ^{241}Am was identified by Seaborg, James, Morgan, and Ghiorso late in 1944 at the wartime Metallurgical Laboratory of the University of Chicago as the result of successive neutron capture reactions by plutonium isotopes in a nuclear reactor:

$$^{239}\mathrm{Pu}(n,\gamma)\rightarrow{}^{240}\mathrm{Pu}(n,\gamma)\rightarrow{}^{241}\mathrm{Pu}\xrightarrow{\beta}{}^{241}\mathrm{Am}$$

Since the isotope ^{241}Am can be prepared in relatively pure form by extraction as a decay product over a period of years from strongly neutron-bombarded plutonium, ^{241}Pu, this isotope is used for much of the chemical investigation of this element. Better suited is the isotope ^{243}Am due to its longer half-life (7.37×10^3 years as compared to 432.2 years for ^{241}Am). A mixture of the isotopes ^{241}Am, ^{242}Am, and ^{243}Am can be prepared by intense neutron irradiation of ^{241}Am according to the reactions ^{241}Am (n, γ) → ^{242}Am (n, γ) → ^{243}Am. Nearly isotopically pure ^{243}Am can be prepared by a sequence of neutron bombardments and chemical separations as follows: neutron bombardment of ^{241}Am yields ^{242}Pu by the reactions ^{241}Am (n, γ) → ^{242}Am → ^{242}Pu, after chemical separation the ^{242}Pu can be transformed to ^{243}Am via the reactions ^{242}Pu (n, γ) → ^{243}Pu → ^{243}Am, and the ^{243}Am can be chemically separated. Fairly pure ^{242}Pu can be prepared more simply by very intense neutron irradiation of ^{239}Pu as the result of successive neutron-capture reactions. Seventeen radioactive isotopes and isomers are now recognized. Americium metal has been prepared by reducing the trifluoride with barium vapor at 1000 to 1200°C or the dioxide by lanthanum metal. The luster of freshly prepared americium metal is white and more silvery than plutonium or neptunium prepared in the same manner. It appears to be more malleable than uranium or neptunium and tarnishes slowly in dry air at room temperature. Americium is thought to exist in two forms: an alpha form which has a double hexagonal close-packed structure and a loose-packed cubic beta form. Americium must be handled with great care to avoid personal contamination. As little as 0.03 μCi of ^{241}Am is the maximum permissible total body burden. The alpha activity from ^{241}Am is about three times that of radium. When gram quantities of ^{241}Am are handled, the intense gamma activity makes exposure a serious problem. Americium dioxide, AmO_2, is the most important oxide. AmF_3, AmF_4, $AmCl_3$, $AmBr_3$, AmI_3, and other compounds have been prepared. The isotope ^{241}Am has been used as a portable source for gamma radiography. It has also been used

as a radioactive glass thickness gage for the flat glass industry, and as a source of ionization for smoke detectors. Americum-243 (99%) is available from the Oak Ridge National Laboratory at a cost of about $750/g plus packing charges.

Antimony — (Gr. *anti* plus *monos* — a metal not found alone), Sb; at. wt. 121.760(1); at. no. 51; m.p. 630.63°C; b.p. 1587°C; sp. gr. 6.691 (20°C); valence 0, –3, +3, or +5. Antimony was recognized in compounds by the ancients and was known as a metal at the beginning of the 17th century and possibly much earlier. It is not abundant, but is found in over 100 mineral species. It is sometimes found native, but more frequently as the sulfide, *stibnite* (Sb_2S_3); it is also found as antimonides of the heavy metals, and as oxides. It is extracted from the sulfide by roasting to the oxide, which is reduced by salt and scrap iron; from its oxides it is also prepared by reduction with carbon. Two allotropic forms of antimony exist: the normal stable, metallic form, and the amorphous gray form. The so-called explosive antimony is an ill-defined material always containing an appreciable amount of halogen; therefore, it no longer warrants consideration as a separate allotrope. The yellow form, obtained by oxidation of *stibine,* SbH_3, is probably impure, and is not a distinct form. Natural antimony is made of two stable isotopes, ^{121}Sb and ^{123}Sb. Forty five other radioactive isotopes and isomers are now recognized. Metallic antimony is an extremely brittle metal of a flaky, crystalline texture. It is bluish white and has a metallic luster. It is not acted on by air at room temperature, but burns brilliantly when heated with the formation of white fumes of Sb_2O_3. It is a poor conductor of heat and electricity, and has a hardness of 3 to 3.5. Antimony, available commercially with a purity of 99.999 + %, is finding use in semiconductor technology for making infrared detectors, diodes, and Hall-effect devices. Commercial-grade antimony is widely used in alloys with percentages ranging from 1 to 20. It greatly increases the hardness and mechanical strength of lead. Batteries, antifriction alloys, type metal, small arms and tracer bullets, cable sheathing, and minor products use about half the metal produced. Compounds taking up the other half are oxides, sulfides, sodium antimonate, and antimony trichloride. These are used in manufacturing flame-proofing compounds, paints, ceramic enamels, glass, and pottery. Tartar emetic (hydrated potassium antimonyl tartate) has been used in medicine. Antimony and many of its compounds are toxic. Antimony costs about $140/kg or about $12/g (99.999%).

Argon — (Gr. *argos,* inactive), Ar; at. wt. 39.948(1); at. no. 18; m.p. –189.35°C; b.p. –185.85°C; t_c -122.28; density 1.7837 g/l. Its presence in air was suspected by Cavendish in 1785, discovered by Lord Rayleigh and Sir William Ramsay in 1894. The gas is prepared by fractionation of liquid air, the atmosphere containing 0.94% argon. The atmosphere of Mars contains 1.6% of ^{40}Ar and 5 p.p.m. of ^{36}Ar. Argon is two and one half times as soluble in water as nitrogen, having about the same solubility as oxygen. It is recognized by the characteristic lines in the red end of the spectrum. It is used in electric light bulbs and in fluorescent tubes at a pressure of about 400 Pa, and in filling photo tubes, glow tubes, etc. Argon is also used as an inert gas shield for arc welding and cutting, as a blanket for the production of titanium and other reactive elements, and as a protective atmosphere for growing silicon and germanium crystals. Argon is colorless and odorless, both as a gas and liquid. It is available in high-purity form. Commercial argon is available at a cost of about 3¢ per cubic foot. Argon is considered to be a very inert gas and is not known to form true chemical compounds, as do krypton, xenon, and radon. However, it does form a hydrate having a dissociation pressure of 105 atm at 0°C. Ion molecules such as $(ArKr)^+$, $(ArXe)^+$, $(NeAr)^+$ have been observed spectroscopically. Argon also forms a clathrate with β-hydroquinone. This clathrate is stable and can be stored for a considerable time, but a true chemical bond does not exist. Van der Waals' forces act to hold the argon. Naturally occurring argon is a mixture of three isotopes. Seventeen other radioactive isotopes are now known to exist. Commercial argon is priced at about $70/300 cu. ft. or 8.5 cu. meters.

Arsenic — (L. *arsenicum,* Gr. *arsenikon,* yellow orpiment, identified with *arsenikos,* male, from the belief that metals were different sexes; Arabic, *Az-zernikh,* the orpiment from Persian *zerni-zar,* gold), As; at. wt. 74.92160(2); at. no. 33; valence –3, 0, +3 or +5. Elemental arsenic occurs in two solid modifications: yellow, and gray or metallic, with specific gravities of 1.97, and 5.73, respectively. Gray arsenic, the ordinary stable form, has a triple point of 817°C and sublimes at 614°C and has a critical temperature of 1400°C. Several other allotropic forms of arsenic are reported in the literature. It is believed that Albertus Magnus obtained the element in 1250 A.D. In 1649 Schroeder published two methods of preparing the element. It is found native, in the sulfides *realgar* and *orpiment,* as arsenides and sulfarsenides of heavy metals, as the oxide, and as arsenates. *Mispickel,* arsenopyrite, (FeSAs) is the most common mineral, from which on heating the arsenic sublimes leaving ferrous sulfide. The element is a steel gray, very brittle, crystalline, semimetallic solid; it tarnishes in air, and when heated is rapidly oxidized to arsenous oxide (As_2O_3) with the odor of garlic. Arsenic and its compounds are poisonous. Exposure to arsenic and its compounds should not exceed 0.2 mg/m^3 as elemental As during an 8-h work day. These values, however, are being studied, and may be lowered. Arsenic is also used in bronzing, pyrotechny, and for hardening and improving the sphericity of shot. The most important compounds are white arsenic (As_2O_3), the sulfide, Paris green $3Cu(AsO_2)_2 \cdot Cu(C_2H_3O_2)_2$, calcium arsenate, and lead arsenate; the last three have been used as agricultural insecticides and poisons. Marsh's test makes use of the formation and ready decomposition of arsine (AsH_3). Arsenic is available in high-purity form. It is finding increasing uses as a doping agent in solid-state devices such as transistors. Gallium arsenide is used as a laser material to convert electricity directly into coherent light. Natural arsenic is made of one isotope ^{75}As. Thirty other radioactive isotopes and isomers are known. Arsenic (99%) costs about $175/kg. Purified arsenic (99.9995%) costs about $3.50/g.

Astatine — (Gr. *astatos,* unstable), At; at. wt. (210); at. no. 85; m.p. 300°C (est.); valence probably 1, 3, 5, or 7. Synthesized in 1940 by D. R. Corson, K. R. MacKenzie, and E. Segre at the University of California by bombarding bismuth with alpha particles. The longest-lived isotope, ^{210}At, has a half-life of only 8.1 hours. Thirty-six other isotopes and isomers are now known. Minute quantities of ^{215}At, ^{218}At, and ^{219}At exist in equilibrium in nature with naturally occurring uranium and thorium isotopes, and traces of ^{217}At are equilibrium with ^{233}U and ^{239}Np resulting from interaction of thorium and uranium with naturally produced neutrons. The total amount of astatine present in the earth's crust, however, is probably less than 1 oz. Astatine can be produced by bombarding bismuth with energetic alpha particles to obtain the relatively long-lived $^{209–211}At$, which can be distilled from the target by heating it in air. Only about 0.05 μg of astatine has been prepared to date. The "time of flight" mass spectrometer has been used to confirm that this highly radioactive halogen behaves chemically very much like other halogens, particularly iodine. The interhalogen compounds AtI, AtBr, and AtCl are known to form, but it is not yet known if astatine forms diatomic astatine molecules. HAt and CH_3At (methyl astatide) have been detected. Astatine is said to be more metallic that iodine, and, like iodine, it probably accumulates in the thyroid gland. Workers at the Brookhaven National Laboratory have recently used reactive scattering in crossed molecular beams to identify and measure elementary reactions involving astatine.

Barium — (Gr. *barys,* heavy), Ba; at. wt. 137.327(7), at. no. 56; m.p. 727°C; b.p. 1897°C; sp. gr. 3.5 (20°C); valence 2. Baryta was distinguished from lime by Scheele in 1774; the element was discovered by Sir Humphrey Davy in 1808. It is found only in combination with other elements, chiefly in *barite* or *heavy spar* (sulfate) and *witherite* (carbonate) and is prepared by electrolysis of the chloride. Large deposits of barite are found in China, Germany, India, Morocco, and in the U.S. Barium is a metallic element, soft, and when pure is silvery white like lead; it belongs to the alkaline earth group, resembling calcium chemically. The metal oxidizes very easily and should be kept under petroleum or other suitable oxygen-free liquids to

exclude air. It is decomposed by water or alcohol. The metal is used as a "getter" in vacuum tubes. The most important compounds are the peroxide (BaO_2), chloride, sulfate, carbonate, nitrate, and chlorate. Lithopone, a pigment containing barium sulfate and zinc sulfide, has good covering power, and does not darken in the presence of sulfides. The sulfate, as permanent white or *blanc fixe,* is also used in paint, in X-ray diagnostic work, and in glassmaking. *Barite* is extensively used as a weighting agent in oilwell drilling fluids, and also in making rubber. The carbonate has been used as a rat poison, while the nitrate and chlorate give green colors in pyrotechny. The impure sulfide phosphoresces after exposure to the light. The compounds and the metal are not expensive. Barium metal (99.2 + % pure) costs about $3/g. All barium compounds that are water or acid soluble are poisonous. Naturally occurring barium is a mixture of seven stable isotopes. Thirty six other radioactive isotopes and isomers are known to exist.

Berkelium — (*Berkeley,* home of the University of California), Bk; at. wt. (247); at. no. 97; m.p. 1050°C; valence 3 or 4; sp. gr. 14 (est.). Berkelium, the eighth member of the actinide transition series, was discovered in December 1949 by Thompson, Ghiorso, and Seaborg, and was the fifth transuranium element synthesized. It was produced by cyclotron bombardment of milligram amounts of ^{241}Am with helium ions at Berkeley, California. The first isotope produced had a mass number of 243 and decayed with a half-life of 4.5 hours. Thirteen isotopes are now known and have been synthesized. The existence of ^{249}Bk, with a half-life of 320 days, makes it feasible to isolate berkelium in weighable amounts so that its properties can be investigated with macroscopic quantities. One of the first visible amounts of a pure berkelium compound, berkelium chloride, was produced in 1962. It weighed 3 billionth of a gram. Berkelium probably has not yet been prepared in elemental form, but it is expected to be a silvery metal, easily soluble in dilute mineral acids, and readily oxidized by air or oxygen at elevated temperatures to form the oxide. X-ray diffraction methods have been used to identify the following compounds: BkO_2, BkO_3, BkF_3, BkCl, and BkOCl. As with other actinide elements, berkelium tends to accumulate in the skeletal system. The maximum permissible body burden of ^{249}Bk in the human skeleton is about 0.0004 μg. Because of its rarity, berkelium presently has no commercial or technological use. Berkelium most likely resembles terbium with respect to chemical properties. Berkelium-249 is available from O.R.N.L. at a cost of $185/μg plus packing charges.

Beryllium — (Gr. *beryllos, beryl;* also called Glucinium or Glucinum, Gr. *glykys,* sweet), Be; at. wt. 9.012182(3); at no. 4; m.p. 1287°C; b.p. 2471°C; sp. gr. 1.848 (20°C); valence 2. Discovered as the oxide by Vauquelin in beryl and in emeralds in 1798. The metal was isolated in 1828 by Wohler and by Bussy independently by the action of potassium on beryllium chloride. Beryllium is found in some 30 mineral species, the most important of which are *bertrandite, beryl, chrysoberyl,* and *phenacite. Aquamarine* and *emerald* are precious forms of *beryl.* Beryllium minerals are found in the U.S., Brazil, Russia, Kazakhstan, and elsewhere. Colombia is known for its emeralds. *Beryl* ($3BeO \cdot Al_2O_3 \cdot 6SiO_2$) and *bertrandite* ($4BeO \cdot 2SiO_2 \cdot H_2O$) are the most important commercial sources of the element and its compounds. Most of the metal is now prepared by reducing beryllium fluoride with magnesium metal. Beryllium metal did not become readily available to industry until 1957. The metal, steel gray in color, has many desirable properties. It is one of the lightest of all metals, and has one of the highest melting points of the light metals. Its modulus of elasticity is about one third greater than that of steel. It resists attack by concentrated nitric acid, has excellent thermal conductivity, and is nonmagnetic. It has a high permeability to X-rays, and when bombarded by alpha particles, as from radium or polonium, neutrons are produced in the ratio of about 30 neutrons/million alpha particles. At ordinary temperatures beryllium resists oxidation in air, although its ability to scratch glass is probably due to the formation of a thin layer of the oxide. Beryllium is used as an alloying agent in producing beryllium copper which is extensively used for springs, electrical contacts, spot-welding electrodes, and nonsparking tools. It has found application as a structural material for high-speed aircraft, missiles, spacecraft, and communication satellites. It is being used in the windshield frame, brake discs, support beams, and other structural components of the space shuttle. Because beryllium is relatively transparent to X-rays, ultra-thin Be-foil is finding use in X-ray lithography for reproduction of microminiature integrated circuits. Natural beryllium is made of ^{9}Be and is stable. Eight other radioactive isotopes are known.

Beryllium is used in nuclear reactors as a reflector or moderator for it has a low thermal neutron absorption cross section. It is used in gyroscopes, computer parts, and instruments where lightness, stiffness, and dimensional stability are required. The oxide has a very high melting point and is also used in nuclear work and ceramic applications. Beryllium and its salts are toxic and should be handled with the greatest of care. Beryllium and its compounds should not be tasted to verify the sweetish nature of beryllium (as did early experimenters). The metal, its alloys, and its salts can be handled safely if certain work codes are observed, but no attempt should be made to work with beryllium before becoming familiar with proper safeguards. Beryllium metal is available at a cost of about $4.50/g (99.5% pure).

Bismuth — (Ger. *Weisse Masse,* white mass; later *Wisuth* and *Bisemutum*), Bi; at. wt. 208.98038(2); at. no. 83; m.p. 271.4°C; b.p. 1564°C; sp. gr. 9.747 (20°C); valence 3 or 5. In early times bismuth was confused with tin and lead. Claude Geoffroy the Younger showed it to be distinct from lead in 1753. It is a white crystalline, brittle metal with a pinkish tinge. It occurs native. The most important ores are *bismuthinite* or bismuth glance (Bi_2S_3) and *bismite* (Bi_2O_3). Peru, Japan, Mexico, Bolivia, and Canada are major bismuth producers. Much of the bismuth produced in the U.S. is obtained as a by-product in refining lead, copper, tin, silver, and gold ores. Bismuth is the most diamagnetic of all metals, and the thermal conductivity is lower than any metal, except mercury. It has a high electrical resistance, and has the highest Hall effect of any metal (i.e., greatest increase in electrical resistance when placed in a magnetic field). "Bismanol" is a permanent magnet of high coercive force, made of MnBi, by the U.S. Naval Surface Weapons Center. Bismuth expands 3.32% on solidification. This property makes bismuth alloys particularly suited to the making of sharp castings of objects subject to damage by high temperatures. With other metals such as tin, cadmium, etc., bismuth forms low-melting alloys which are extensively used for safety devices in fire detection and extinguishing systems. Bismuth is used in producing malleable irons and is finding use as a catalyst for making acrylic fibers. When bismuth is heated in air it burns with a blue flame, forming yellow fumes of the oxide. The metal is also used as a thermocouple material, and has found application as a carrier for U^{235} or U^{233} fuel in atomic reactors. Its soluble salts are characterized by forming insoluble basic salts on the addition of water, a property sometimes used in detection work. Bismuth oxychloride is used extensively in cosmetics. Bismuth subnitrate and subcarbonate are used in medicine. Natural bismuth contains only one isotope ^{209}Bi. Forty-four isotopes and isomers of bismuth are known. Bismuth metal (99.5%) costs about $250/kg.

Bohrium — (Named after Niels Bohr [1885-1962], Danish atomic and nuclear physicist.) Bh; at.wt. [262]. at.no. 107. Bohrium is expected to have chemical properties similar to rhenium. This element was synthesized and unambiguously identified in 1981 using the Universal Linear Accelerator (UNILAC) at the Gesellschaft für Schwerionenforschung (G.S.I.) in Darmstadt, Germany. The discovery team was led by Armbruster and Münzenberg. The reaction producing the element was proposed and applied earlier by a Dubna Group led by Oganessian in 1976. A target of ^{209}Bi was bombarded by a beam of ^{54}Cr ions. In 1983 experiments at Dubna using the 157-inch cyclotron, produced $^{262}107$ by the reaction $^{209}Bi + ^{54}Cr$. The alpha decay of ^{246}Cf, the sixth member in the decay chain of $^{262}107$, served to establish a 1-neutron reaction channel. The IUPAC adopted the name ***Bohrium*** with the symbol Bh for Element 107 in August 1997. Five isotopes of bohrium are now recognized. One isotope of bohrium appears to have

a relatively long life of 15 seconds. Work on this relatively long-lived isotope has been performed with the 88-inch cyclotron at the Lawrence-Berkeley National Laboratory.

Boron — (Ar. *Buraq,* Pers. *Burah*), B; at. wt. 10.811(7); at. no. 5; m.p. 2075°C; b.p. 4000°C; sp. gr. of crystals 2.34, of amorphous variety 2.37; valence 3. Boron compounds have been known for thousands of years, but the element was not discovered until 1808 by Sir Humphry Davy and by Gay-Lussac and Thenard. The element is not found free in nature, but occurs as orthoboric acid usually in certain volcanic spring waters and as borates in *borax* and *colemanite. Ulexite,* another boron mineral, is interesting as it is nature's own version of "fiber optics." Important sources of boron are the ores *rasorite (kernite)* and *tincal (borax ore).* Both of these ores are found in the Mojave Desert. *Tincal* is the most important source of boron from the Mojave. Extensive *borax* deposits are also found in Turkey. Boron exists naturally as 19.9% ^{10}B isotope and 80.1% ^{11}B isotope. Ten other isotopes of boron are known. High-purity crystalline boron may be prepared by the vapor phase reduction of boron trichloride or tribromide with hydrogen on electrically heated filaments. The impure, or amorphous, boron, a brownish-black powder, can be obtained by heating the trioxide with magnesium powder. Boron of 99.9999% purity has been produced and is available commercially. Elemental boron has an energy band gap of 1.50 to 1.56 eV, which is higher than that of either silicon or germanium. It has interesting optical characteristics, transmitting portions of the infrared, and is a poor conductor of electricity at room temperature, but a good conductor at high temperature. Amorphous boron is used in pyrotechnic flares to provide a distinctive green color, and in rockets as an igniter. By far the most commercially important boron compound in terms of dollar sales is $Na_2B_4O_7 \cdot 5H_2O$. This pentahydrate is used in very large quantities in the manufacture of insulation fiberglass and sodium perborate bleach. Boric acid is also an important boron compound with major markets in textile fiberglass and in cellulose insulation as a flame retardant. Next in order of importance is borax ($Na_2B_4O_7 \cdot 10H_2O$) which is used principally in laundry products. Use of borax as a mild antiseptic is minor in terms of dollars and tons. Boron compounds are also extensively used in the manufacture of borosilicate glasses. The isotope boron-10 is used as a control for nuclear reactors, as a shield for nuclear radiation, and in instruments used for detecting neutrons. Boron nitride has remarkable properties and can be used to make a material as hard as diamond. The nitride also behaves like an electrical insulator but conducts heat like a metal. It also has lubricating properties similar to graphite. The hydrides are easily oxidized with considerable energy liberation, and have been studied for use as rocket fuels. Demand is increasing for boron filaments, a high-strength, lightweight material chiefly employed for advanced aerospace structures. Boron is similar to carbon in that it has a capacity to form stable covalently bonded molecular networks. Carboranes, metalloboranes, phosphacarboranes, and other families comprise thousands of compounds. Crystalline boron (99.5%) costs about $30/g. Amorphous boron (94–96%) costs about $1.50/g. Elemental boron and the borates are not considered to be toxic, and they do not require special care in handling. However, some of the more exotic boron hydrogen compounds are definitely toxic and do require care.

Bromine — (Gr. *bromos,* stench), Br; at. wt. 79.904(1); at. no. 35; m.p. –7.2°C; b.p. 58.8°C; t_c 315°C; density of gas 7.59 g/l, liquid 3.12 (20°C); valence 1, 3, 5, or 7. Discovered by Balard in 1826, but not prepared in quantity until 1860. A member of the halogen group of elements, it is obtained from natural brines from wells in Michigan and Arkansas. Little bromine is extracted today from seawater, which contains only about 85 ppm. Bromine is the only liquid nonmetallic element. It is a heavy, mobile, reddish-brown liquid, volatilizing readily at room temperature to a red vapor with a strong disagreeable odor, resembling chlorine, and having a very irritating effect on the eyes and throat; it is readily soluble in water or carbon disulfide, forming a red solution, is less active than chlorine but more so than iodine; it unites readily with many elements and has a bleaching action; when spilled on the skin it produces painful sores. It presents a serious health hazard, and maximum safety precautions should be taken when handling it. Much of the bromine output in the U.S. was used in the production of ethylene dibromide, a lead scavenger used in making gasoline antiknock compounds. Lead in gasoline, however, has been drastically reduced, due to environmental considerations. This will greatly affect future production of bromine. Bromine is also used in making fumigants, flameproofing agents, water purification compounds, dyes, medicinals, sanitizers, inorganic bromides for photography, etc. Organic bromides are also important. Natural bromine is made of two isotopes, ^{79}Br and ^{81}Br. Thirty-four isotopes and isomers are known. Bromine costs about $100/kg.

Cadmium — (L. *cadmia;* Gr. *kadmeia* — ancient name for calamine, zinc carbonate), Cd; at. wt. 112.411(8); at. no. 48; m.p. 321.07°C; b.p. 767°C; sp. gr. 8.65 (20°C); valence 2. Discovered by Stromeyer in 1817 from an impurity in zinc carbonate. Cadmium most often occurs in small quantities associated with zinc ores, such as *sphalerite* (ZnS). *Greenockite* (CdS) is the only mineral of any consequence bearing cadmium. Almost all cadmium is obtained as a by-product in the treatment of zinc, copper, and lead ores. It is a soft, bluish-white metal which is easily cut with a knife. It is similar in many respects to zinc. It is a component of some of the lowest melting alloys; it is used in bearing alloys with low coefficients of friction and great resistance to fatigue; it is used extensively in electroplating, which accounts for about 60% of its use. It is also used in many types of solder, for standard E.M.F. cells, for Ni-Cd batteries, and as a barrier to control atomic fission. The market for Ni-Cd batteries is expected to grow significantly in the next few years. Cadmium compounds are used in black and white television phosphors and in blue and green phosphors for color TV tubes. It forms a number of salts, of which the sulfate is most common; the sulfide is used as a yellow pigment. Cadmium and solutions of its compounds are toxic. Failure to appreciate the toxic properties of cadmium may cause workers to be unwittingly exposed to dangerous fumes. Some silver solders, for example, contain cadmium and should be handled with care. Serious toxicity problems have been found from long-term exposure and work with cadmium plating baths. Cadmium is present in certain phosphate rocks. This has raised concerns that the long-term use of certain phosphate fertilizers might pose a health hazard from levels of cadmium that might enter the food chain. In 1927 the International Conference on Weights and Measures redefined the meter in terms of the wavelength of the red cadmium spectral line (i.e. 1 m = 1,553,164.13 wavelengths). This definition has been changed (see under Krypton). The current price of cadmium is about $2/g (99.5%). It is available in high purity form for about $300/kg. Natural cadmium is made of eight isotopes. Thirty four other isotopes and isomers are now known and recognized.

Calcium — (L. *calx,* lime), Ca; at. wt. 40.078(4); at. no. 20; m.p. 842°C; b.p. 1484°C; sp. gr. 1.55 (20°C); valence 2. Though lime was prepared by the Romans in the first century under the name calx, the metal was not discovered until 1808. After learning that Berzelius and Pontin prepared calcium amalgam by electrolyzing lime in mercury, Davy was able to isolate the impure metal. Calcium is a metallic element, fifth in abundance in the earth's crust, of which it forms more than 3%. It is an essential constituent of leaves, bones, teeth, and shells. Never found in nature uncombined, it occurs abundantly as *limestone* ($CaCO_3$), *gypsum* ($CaSO_4 \cdot 2H_2O$), and *fluorite* (CaF_2); *apatite* is the fluorophosphate or chlorophosphate of calcium. The metal has a silvery color, is rather hard, and is prepared by electrolysis of the fused chloride to which calcium fluoride is added to lower the melting point. Chemically it is one of the alkaline earth elements; it readily forms a white coating of oxide in air, reacts with water, burns with a yellow-red flame, forming largely the oxide. The metal is used as a reducing agent in preparing other metals such as thorium, uranium, zirconium, etc., and is used as a deoxidizer, desulfurizer, and inclusion modifier for various ferrous and nonferrous alloys. It is also used as an alloying agent for aluminum,

beryllium, copper, lead, and magnesium alloys, and serves as a "getter" for residual gases in vacuum tubes, etc. Its natural and prepared compounds are widely used. Quicklime (CaO), made by heating limestone and changed into slaked lime by the careful addition of water, is the great cheap base of chemical industry with countless uses. Mixed with sand it hardens as mortar and plaster by taking up carbon dioxide from the air. Calcium from limestone is an important element in Portland cement. The solubility of the carbonate in water containing carbon dioxide causes the formation of caves with stalactites and stalagmites and is responsible for hardness in water. Other important compounds are the carbide (CaC_2), chloride ($CaCl_2$), cyanamide ($CaCN_2$), hypochlorite ($Ca(OCl)_2$), nitrate ($Ca(NO_3)_2$), and sulfide (CaS). Calcium sulfide is phosphorescent after being exposed to light. Natural calcium contains six isotopes. Sixteen other radioactive isotopes are known. Metallic calcium (99.5%) costs about $225/kg.

Californium — (State and University of California), Cf; at. wt. (251); m.p. 900°C; at. no. 98. Californium, the sixth transuranium element to be discovered, was produced by Thompson, Street, Ghioirso, and Seaborg in 1950 by bombarding microgram quantities of ^{242}Cm with 35 MeV helium ions in the Berkeley 60-inch cyclotron. Californium (III) is the only ion stable in aqueous solutions, all attempts to reduce or oxidize californium (III) having failed. The isotope ^{249}Cf results from the beta decay of ^{249}Bk while the heavier isotopes are produced by intense neutron irradiation by the reactions:

$$^{249}Bk(n,\gamma)\rightarrow {}^{250}Bk \xrightarrow{\beta} {}^{250}Cf \text{ and } {}^{249}Cf(n,\gamma)\rightarrow {}^{250}Cf$$

followed by

$$^{250}Cf(n,\gamma)\rightarrow {}^{251}Cf(n,\gamma)\rightarrow {}^{252}Cf$$

The existence of the isotopes ^{249}Cf, ^{250}Cf, ^{251}Cf, and ^{252}Cf makes it feasible to isolate californium in weighable amounts so that its properties can be investigated with macroscopic quantities. Californium-252 is a very strong neutron emitter. One microgram releases 170 million neutrons per minute, which presents biological hazards. Proper safeguards should be used in handling californium. Twenty isotopes of californium are now recognized. ^{249}Cf and ^{252}Cf have half-lives of 351 years and 900 years, respectively. In 1960 a few tenths of a microgram of californium trichloride, $CfCl_3$, californium oxychloride, CfOCl, and californium oxide, Cf_2O_3, were first prepared. Reduction of californium to its metallic state has not yet been accomplished. Because californium is a very efficient source of neutrons, many new uses are expected for it. It has already found use in neutron moisture gages and in well-logging (the determination of water and oil-bearing layers). It is also being used as a portable neutron source for discovery of metals such as gold or silver by on-the-spot activation analysis. ^{252}Cf is now being offered for sale by the Oak Ridge National Laboratory (O.R.N.L.) at a cost of $60/μg and ^{249}Cf at a cost of $185/μg plus packing charges. It has been suggested that californium may be produced in certain stellar explosions, called *supernovae*, for the radioactive decay of ^{254}Cf (55-day half-life) agrees with the characteristics of the light curves of such explosions observed through telescopes. This suggestion, however, is questioned. Californium is expected to have chemical properties similar to dysprosium.

Carbon — (L. *carbo*, charcoal), C; at. wt. 12.0107(8); at. no. 6; sublimes at 3642°C; triple point (graphite-liquid-gas), 4492°C at a pressure of 101.325 kPa; sp. gr. amorphous 1.8 to 2.1, graphite 1.9 to 2.3, diamond 3.15 to 3.53 (depending on variety); gem diamond 3.513 (25°C); valence 2, 3, or 4. Carbon, an element of prehistoric discovery, is very widely distributed in nature. It is found in abundance in the sun, stars, comets, and atmospheres of most planets. Carbon in the form of microscopic diamonds is found in some meteorites. Natural diamonds are found in *kimberlite* or *lamporite* of ancient formations called "pipes," such as found in South Africa, Arkansas, and elsewhere. Diamonds are now also being recovered from the ocean floor off the Cape of Good Hope. About 30% of all industrial diamonds used in the U.S. are now made synthetically. The energy of the sun and stars can be attributed at least in part to the well-known carbon-nitrogen cycle. Carbon is found free in nature in three allotropic forms: amorphous, graphite, and diamond. A fourth form, known as "white" carbon, is now thought to exist. Graphite is one of the softest known materials while diamond is one of the hardest. Graphite exists in two forms: alpha and beta. These have identical physical properties, except for their crystal structure. Naturally occurring graphites are reported to contain as much as 30% of the rhombohedral (beta) form, whereas synthetic materials contain only the alpha form. The hexagonal alpha type can be converted to the beta by mechanical treatment, and the beta form reverts to the alpha on heating it above 1000°C. In 1969 a new allotropic form of carbon was produced during the sublimation of pyrolytic graphite at low pressures. Under free-vaporization conditions above ~2550 K, "white" carbon forms as small transparent crystals on the edges of the basal planes of graphite. The interplanar spacings of "white" carbon are identical to those of carbon form noted in the graphitic gneiss from the Ries (meteoritic) Crater of Germany. "White" carbon is a transparent birefringent material. Little information is presently available about this allotrope. Of recent interest is the discovery of all-carbon molecules, known as "buckyballs" or fullerenes, which have a number of unusual properties. These interesting molecules, consisting of 60 or 70 carbon atoms linked together, seem capable of withstanding great pressure and trapping foreign atoms inside their network of carbon. They are said to be capable of magnetism and superconductivity and have potential as a nonlinear optical material. Buckyball films are reported to remain superconductive at temperatures as high as 45 K. In combination, carbon is found as carbon dioxide in the atmosphere of the earth and dissolved in all natural waters. It is a component of great rock masses in the form of carbonates of calcium (limestone), magnesium, and iron. Coal, petroleum, and natural gas are chiefly hydrocarbons. Carbon is unique among the elements in the vast number and variety of compounds it can form. With hydrogen, oxygen, nitrogen, and other elements, it forms a very large number of compounds, carbon atom often being linked to carbon atom. There are close to ten million known carbon compounds, many thousands of which are vital to organic and life processes. Without carbon, the basis for life would be impossible. While it has been thought that silicon might take the place of carbon in forming a host of similar compounds, it is now not possible to form stable compounds with very long chains of silicon atoms. The atmosphere of Mars contains 96.2% CO_2. Some of the most important compounds of carbon are carbon dioxide (CO_2), carbon monoxide (CO), carbon disulfide (CS_2), chloroform ($CHCl_3$), carbon tetrachloride (CCl_4), methane (CH_4), ethylene (C_2H_4), acetylene (C_2H_2), benzene (C_6H_6), ethyl alcohol (C_2H_5OH), acetic acid (CH_3COOH), and their derivatives. Carbon has fifteen isotopes. Natural carbon consists of 98.89% ^{12}C and 1.11% ^{13}C. In 1961 the International Union of Pure and Applied Chemistry adopted the isotope carbon-12 as the basis for atomic weights. Carbon-14, an isotope with a half-life of 5715 years, has been widely used to date such materials as wood, archeological specimens, etc. A new brittle form of carbon, known as "glassy carbon", has been developed. It can be obtained with high purity. It has a high resistance to corrosion, has good thermal stability, and is structurally impermeable to both gases and liquids. It has a randomized structure, making it useful in ultra-high technology applications, such as crystal growing, crucibles for high-temperature use, etc. Both Types 1 and 2 glassy carbon are available at a cost of about $35/10gms.

Cerium — (named for the asteroid *Ceres,* which was discovered in 1801 only 2 years before the element), Ce; at. wt. 140.115(4); at. no. 58; m.p. 798°C; b.p. 3424°C; sp. gr. 6.770 (25°C); valence 3 or 4. Discovered in 1803 by Klaproth and by Berzelius and Hisinger; metal prepared by Hillebrand and Norton in 1875. Cerium is the most abundant of the metals of the so-called rare earths. It is found in a number of minerals including *allanite* (also known as *orthite*), *monazite, bastnasite, cerite,* and *samarskite.* Monazite and bastnasite are presently the two most important sources of cerium. Large deposits of monazite found on the beaches of Travancore, India, in river sands in Brazil, and deposits of *allanite* in the western United States, and *bastnasite* in Southern California will supply cerium, thorium, and the other rare-earth metals for many years to come. Metallic cerium is prepared by metallothermic reduction techniques, such as by reducing cerous fluoride with calcium, or by electrolysis of molten cerous chloride or other cerous halides. The metallothermic technique is used to produce high-purity cerium. Cerium is especially interesting because of its variable electronic structure. The energy of the inner 4f level is nearly the same as that of the outer or valence electrons, and only small amounts of energy are required to change the relative occupancy of these electronic levels. This gives rise to dual valency states. For example, a volume change of about 10% occurs when cerium is subjected to high pressures or low temperatures. It appears that the valence changes from about 3 to 4 when it is cooled or compressed. The low temperature behavior of cerium is complex. Four allotropic modifications are thought to exist: cerium at room temperature and at atmospheric pressure is known as γ cerium. Upon cooling to –16°C, γ cerium changes to β cerium. The remaining γ cerium starts to change to α cerium when cooled to –172°C, and the transformation is complete at –269°C. α Cerium has a density of 8.16; δ cerium exists above 726°C. At atmospheric pressure, liquid cerium is more dense than its solid form at the melting point. Cerium is an iron-gray lustrous metal. It is malleable, and oxidizes very readily at room temperature, especially in moist air. Except for europium, cerium is the most reactive of the “rare-earth” metals. It slowly decomposes in cold water, and rapidly in hot water. Alkali solutions and dilute and concentrated acids attack the metal rapidly. The pure metal is likely to ignite if scratched with a knife. Ceric salts are orange red or yellowish; cerous salts are usually white. Cerium is a component of misch metal, which is extensively used in the manufacture of pyrophoric alloys for cigarette lighters, etc. Natural cerium is stable and contains four isotopes. Thirty-two other radioactive isotopes and isomers are known. While cerium is not radioactive, the impure commercial grade may contain traces of thorium, which is radioactive. The oxide is an important constituent of incandescent gas mantles and it is emerging as a hydrocarbon catalyst in “self-cleaning” ovens. In this application it can be incorporated into oven walls to prevent the collection of cooking residues. As ceric sulfate it finds extensive use as a volumetric oxidizing agent in quantitative analysis. Cerium compounds are used in the manufacture of glass, both as a component and as a decolorizer. The oxide is finding increased use as a glass polishing agent instead of rouge, for it is much faster than rouge in polishing glass surfaces. Cerium compounds are finding use in automobile exhaust catalysts. Cerium is also finding use in making permanent magnets. Cerium, with other rare earths, is used in carbon-arc lighting, especially in the motion picture industry. It is also finding use as an important catalyst in petroleum refining and in metallurgical and nuclear applications. In small lots, cerium costs about $5/g (99.9%).

Cesium — (L. *caesius,* sky blue), Cs; at. wt. 132.90545(2); at. no. 55; m.p. 28.44°C; b.p. 671°C; sp. gr. 1.873 (20°C); valence 1. Cesium was discovered spectroscopically by Bunsen and Kirchhoff in 1860 in mineral water from Durkheim. Cesium, an alkali metal, occurs in *lepidolite, pollucite* (a hydrated silicate of aluminum and cesium), and in other sources. One of the world’s richest sources of cesium is located at Bernic Lake, Manitoba. The deposits are estimated to contain 300,000 tons of pollucite, averaging 20% cesium. It can be isolated by electrolysis of the fused cyanide and by a number of other methods. Very pure, gas-free cesium can be prepared by thermal decomposition of cesium azide. The metal is characterized by a spectrum containing two bright lines in the blue along with several others in the red, yellow, and green. It is silvery white, soft, and ductile. It is the most electropositive and most alkaline element. Cesium, gallium, and mercury are the only three metals that are liquid at room temperature. Cesium reacts explosively with cold water, and reacts with ice at temperatures above –116°C. Cesium hydroxide, the strongest base known, attacks glass. Because of its great affinity for oxygen the metal is used as a “getter” in electron tubes. It is also used in photoelectric cells, as well as a catalyst in the hydrogenation of certain organic compounds. The metal has recently found application in ion propulsion systems. Cesium is used in atomic clocks, which are accurate to 5 s in 300 years. A second of time is now defined as being the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyper-fine levels of the ground state of the cesium-133 atom. Its chief compounds are the chloride and the nitrate. Cesium has 52 isotopes and isomers with masses ranging from 112 to 148. The present price of cesium is about $65/g (99.98%) sealed in a glass ampoule.

Chlorine — (Gr. *chloros,* greenish yellow), Cl; at. wt. 35.4527(9); at. no. 17; m.p. –101.5°C; b.p. –34.04°C; t_c 143.8°C; density 3.214 g/l; sp. gr. 1.56 (–33.6°C); valence 1, 3, 5, or 7. Discovered in 1774 by Scheele, who thought it contained oxygen; named in 1810 by Davy, who insisted it was an element. In nature it is found in the combined state only, chiefly with sodium as common salt (NaCl), *carnallite* ($KMgCl_3 \cdot 6H_2O$), and *sylvite* (KCl). It is a member of the halogen (salt-forming) group of elements and is obtained from chlorides by the action of oxidizing agents and more often by electrolysis; it is a greenish-yellow gas, combining directly with nearly all elements. At 10°C one volume of water dissolves 3.10 volumes of chlorine, at 30°C only 1.77 volumes. Chlorine is widely used in making many everyday products. It is used for producing safe drinking water the world over. Even the smallest water supplies are now usually chlorinated. It is also extensively used in the production of paper products, dyestuffs, textiles, petroleum products, medicines, antiseptics, insecticides, foodstuffs, solvents, paints, plastics, and many other consumer products. Most of the chlorine produced is used in the manufacture of chlorinated compounds for sanitation, pulp bleaching, disinfectants, and textile processing. Further use is in the manufacture of chlorates, chloroform, carbon tetrachloride, and in the extraction of bromine. Organic chemistry demands much from chlorine, both as an oxidizing agent and in substitution, since it often brings desired properties in an organic compound when substituted for hydrogen, as in one form of synthetic rubber. Chlorine is a respiratory irritant. The gas irritates the mucous membranes and the liquid burns the skin. As little as 3.5 ppm can be detected as an odor, and 1000 ppm is likely to be fatal after a few deep breaths. It was used as a war gas in 1915. Natural chlorine contains two isotopes. Twenty other isotopes and isomers are known.

Chromium — (Gr. *chroma,* color), Cr; at. wt. 51.9961(6); at. no. 24; m.p. 1907°C; b.p. 2671°C; sp. gr. 7.18 to 7.20 (20°C); valence chiefly 2, 3, or 6. Discovered in 1797 by Vauquelin, who prepared the metal the next year, chromium is a steel-gray, lustrous, hard metal that takes a high polish. The principal ore is *chromite* ($FeCr_2O_4$), which is found in Zimbabwe, Russia, South Africa, Turkey, Iran, Albania, Finland, Democratic Republic of Madagascar, the Philippines, and elsewhere. The U.S. has no appreciable chromite ore reserves. The metal is usually produced by reducing the oxide with aluminum. Chromium is used to harden steel, to manufacture stainless steel, and to form many useful alloys. Much is used in plating to produce a hard, beautiful surface and to prevent corrosion. Chromium is used to give glass an emerald green color. It finds wide use as a catalyst. All compounds of chromium are colored; the most important are the chromates of sodium and potassium (K_2CrO_4) and the dichromates ($K_2Cr_2O_7$) and the potassium and ammonium chrome alums, as $KCr(SO_4)_2 \cdot 12H_2O$. The dichromates are used as oxidizing agents in quantitative analysis, also in tanning leather.

Other compounds are of industrial value; lead chromate is chrome yellow, a valued pigment. Chromium compounds are used in the textile industry as mordants, and by the aircraft and other industries for anodizing aluminum. The refractory industry has found chromite useful for forming bricks and shapes, as it has a high melting point, moderate thermal expansion, and stability of crystalline structure. Chromium is an essential trace element for human health. Many chromium compounds, however, are acutely toxic, chronically toxic, and may be carcinogenic. They should be handled with proper safeguards. Natural chromium contains four isotopes. Twenty other isotopes are known. Chromium metal (99.95%) costs about $600/kg. Commercial grade chromium (99%) costs about $75/kg.

Cobalt — (*Kobald,* from the German, goblin or evil spirit, *cobalos,* Greek, mine), Co; at. wt. 58.93320(1); at. no. 27; m.p. 1495°C; b.p. 2927°C; sp. gr. 8.9 (20°C); valence 2 or 3. Discovered by Brandt about 1735. Cobalt occurs in the mineral *cobaltite, smaltite,* and *erythrite,* and is often associated with nickel, silver, lead, copper, and iron ores, from which it is most frequently obtained as a by-product. It is also present in meteorites. Important ore deposits are found in Congo-Kinshasa, Australia, Zambia, Russia, Canada, and elsewhere. The U.S. Geological Survey has announced that the bottom of the north central Pacific Ocean may have cobalt-rich deposits at relatively shallow depths in waters close to the Hawaiian Islands and other U.S. Pacific territories. Cobalt is a brittle, hard metal, closely resembling iron and nickel in appearance. It has a magnetic permeability of about two thirds that of iron. Cobalt tends to exist as a mixture of two allotropes over a wide temperature range; the β-form predominates below 400°C, and the α above that temperature. The transformation is sluggish and accounts in part for the wide variation in reported data on physical properties of cobalt. It is alloyed with iron, nickel and other metals to make Alnico, an alloy of unusual magnetic strength with many important uses. Stellite alloys, containing cobalt, chromium, and tungsten, are used for high-speed, heavy-duty, high temperature cutting tools, and for dies. Cobalt is also used in other magnet steels and stainless steels, and in alloys used in jet turbines and gas turbine generators. The metal is used in electroplating because of its appearance, hardness, and resistance to oxidation. The salts have been used for centuries for the production of brilliant and permanent blue colors in porcelain, glass, pottery, tiles, and enamels. It is the principal ingredient in Sevre's and Thenard's blue. A solution of the chloride ($CoCl_2 \cdot 6H_2O$) is used as sympathetic ink. The cobalt ammines are of interest; the oxide and the nitrate are important. Cobalt carefully used in the form of the chloride, sulfate, acetate, or nitrate has been found effective in correcting a certain mineral deficiency disease in animals. Soils should contain 0.13 to 0.30 ppm of cobalt for proper animal nutrition.Cobalt is found in Vitamin B-12, which is essential for human nutrition. Cobalt of 99.9+% purity is priced at about$500/kg. Cobalt-60, an artificial isotope, is an important gamma ray source, and is extensively used as a tracer and a radiotherapeutic agent. Single compact sources of Cobalt-60 vary from about $1 to $10/curie, depending on quantity and specific activity. Thirty isotopes and isomers of cobalt are known.

Columbium — See Niobium.

Copper — (L. *cuprum,* from the island of Cyprus), Cu; at. wt. 63.546(3); at. no. 29; f.p. 1084.62 °C; b.p. 2562°C; sp. gr. 8.96 (20°C); valence 1 or 2. The discovery of copper dates from prehistoric times. It is said to have been mined for more than 5000 years. It is one of man's most important metals. Copper is reddish colored, takes on a bright metallic luster, and is malleable, ductile, and a good conductor of heat and electricity (second only to silver in electrical conductivity). The electrical industry is one of the greatest users of copper. Copper occasionally occurs native, and is found in many minerals such as *cuprite, malachite, azurite, chalcopyrite,* and *bornite.* Large copper ore deposits are found in the U.S., Chile, Zambia, Zaire, Peru, and Canada. The most important copper ores are the sulfides, oxides, and carbonates. From these, copper is obtained by smelting, leaching, and by electrolysis. Its alloys, brass and bronze, long used, are still very important; all American coins are now copper alloys; monel and gun metals also contain copper. The most important compounds are the oxide and the sulfate, blue vitriol; the latter has wide use as an agricultural poison and as an algicide in water purification. Copper compounds such as Fehling's solution are widely used in analytical chemistry in tests for sugar. High-purity copper (99.999 + %) is readily available commercially. The price of commercial copper has fluctuated widely. The price of copper in December 1999 was about $1.75/kg. Natural copper contains two isotopes. Twenty-six other radioactive isotopes and isomers are known.

Curium — (Pierre and Marie Curie), Cm; at. wt. (247); at. no. 96; m.p. 1345°C; sp. gr. 13.51 (calc.); valence 3 and 4. Although curium follows americium in the periodic system, it was actually known before americium and was the third transuranium element to be discovered. It was identified by Seaborg, James, and Ghiorso in 1944 at the wartime Metallurgical Laboratory in Chicago as a result of helium-ion bombardment of ^{239}Pu in the Berkeley, California, 60-inch cyclotron. Visible amounts (30 μg) of ^{242}Cm, in the form of the hydroxide, were first isolated by Werner and Perlman of the University of California in 1947. In 1950, Crane, Wallmann, and Cunningham found that the magnetic susceptibility of microgram samples of CmF_3 was of the same magnitude as that of GdF_3. This provided direct experimental evidence for assigning an electronic configuration to Cm^{+3}. In 1951, the same workers prepared curium in its elemental form for the first time. Sixteen isotopes of curium are now known. The most stable, ^{247}Cm, with a half-life of 16 million years, is so short compared to the earth's age that any primordial curium must have disappeared long ago from the natural scene. Minute amounts of curium probably exist in natural deposits of uranium, as a result of a sequence of neutron captures and β decays sustained by the very low flux of neutrons naturally present in uranium ores. The presence of natural curium, however, has never been detected. ^{242}Cm and ^{244}Cm are available in multigram quantities. ^{248}Cm has been produced only in milligram amounts. Curium is similar in some regards to gadolinium, its rare-earth homolog, but it has a more complex crystal structure. Curium is silver in color, is chemically reactive, and is more electropositive than aluminum. CmO_2, Cm_2O_3, CmF_3, CmF_4, $CmCl_3$, $CmBr_3$, and CmI_3 have been prepared. Most compounds of trivalent curium are faintly yellow in color. ^{242}Cm generates about three watts of thermal energy per gram. This compares to one-half watt per gram of ^{238}Pu. This suggests use for curium as a power source. ^{244}Cm is now offered for sale by the O.R.N.L. at $185/mg plus packing charges. ^{248}Cm is available at a cost of $160/μg, plus packing charges, from the O.R.N.L. Curium absorbed into the body accumulates in the bones, and is therefore very toxic as its radiation destroys the red-cell forming mechanism. The maximum permissible total body burden of ^{244}Cm (soluble) in a human being is 0.3 μCi (microcurie).

Deuterium, an isotope of hydrogen — see Hydrogen.

Dubnium — (named after the Joint Institute of Nuclear Research in Dubna, Russia). Db; at.wt. [262]; at.no. 105. In 1967 G. N. Flerov reported that a Soviet team working at the Joint Institute for Nuclear Research at Dubna may have produced a few atoms of $^{260}105$ and $^{261}105$ by bombarding ^{243}Am with ^{22}Ne. Their evidence was based on time-coincidence measurements of alpha energies. More recently, it was reported that early in 1970 Dubna scientists synthesized Element 105 and that by the end of April 1970 "had investigated all the types of decay of the new element and had determined its chemical properties." In late April 1970, it was announced that Ghiorso, Nurmia, Harris, K. A. Y. Eskola, and P. L. Eskola, working at the University of California at Berkeley, had positively identified Element 105. The discovery was made by bombarding a target of ^{249}Cf with a beam of 84 MeV nitrogen nuclei in the Heavy Ion Linear Accelerator (HILAC). When a ^{15}N nuclear is absorbed by a ^{249}Cf nucleus, four neutrons are emitted and a new atom of $^{260}105$ with a half-life of 1.6 s is formed. While the first atoms of Element 105 are said to have been detected conclusively

on March 5, 1970, there is evidence that Element 105 had been formed in Berkeley experiments a year earlier by the method described. Ghiorso and his associates have attempted to confirm Soviet findings by more sophisticated methods without success.

In October 1971, it was announced that two new isotopes of Element 105 were synthesized with the heavy ion linear accelerator by A. Ghiorso and co-workers at Berkeley. Element ^{261}105 was produced both by bombarding ^{250}Cf with ^{15}N and by bombarding ^{249}Bk with ^{16}O. The isotope emits 8.93-MeV α particles and decays to ^{257}Lr with a half-life of about 1.8 s. Element ^{262}105 was produced by bombarding ^{249}Bk with ^{18}O. It emits 8.45 MeV α particles and decays to ^{258}Lr with a half-life of about 40 s. Nine isotopes of Dubnium are now recognized. Soon after the discovery the names ***Hahnium*** and ***Joliotium,*** named after Otto Hahn and Jean-Frederic Joliot and Mme. Joliot-Curie, were suggested as names for Element 105. The IUPAC in August 1997 finally resolved the issue, naming Element 105 **Dubnium** with the symbol Db. Dubnium is thought to have properties similar to tantalum.

Dysprosium — (Gr. *dysprositos,* hard to get at), Dy; at. wt. 162.50(3); at. no. 66; m.p. 1412°C; b.p. 2567°C; sp. gr. 8.551 (25°C); valence 3. Dysprosium was discovered in 1886 by Lecoq de Boisbaudran, but not isolated. Neither the oxide nor the metal was available in relatively pure form until the development of ion-exchange separation and metallographic reduction techniques by Spedding and associates about 1950. Dysprosium occurs along with other so-called rare-earth or lanthanide elements in a variety of minerals such as *xenotime, fergusonite, gadolinite, euxenite, polycrase,* and *blomstrandine*. The most important sources, however, are from *monazite* and *bastnasite.* Dysprosium can be prepared by reduction of the trifluoride with calcium. The element has a metallic, bright silver luster. It is relatively stable in air at room temperature, and is readily attacked and dissolved, with the evolution of hydrogen, by dilute and concentrated mineral acids. The metal is soft enough to be cut with a knife and can be machined without sparking if overheating is avoided. Small amounts of impurities can greatly affect its physical properties. While dysprosium has not yet found many applications, its thermal neutron absorption cross-section and high melting point suggest metallurgical uses in nuclear control applications and for alloying with special stainless steels. A dysprosium oxide-nickel cermet has found use in cooling nuclear reactor rods. This cermet absorbs neutrons readily without swelling or contracting under prolonged neutron bombardment. In combination with vanadium and other rare earths, dysprosium has been used in making laser materials. Dysprosium-cadmium chalcogenides, as sources of infrared radiation, have been used for studying chemical reactions. The cost of dysprosium metal has dropped in recent years since the development of ion-exchange and solvent extraction techniques, and the discovery of large ore bodies. Thirty two isotopes and isomers are now known. The metal costs about $5/g (99.9% purity).

Einsteinium — (Albert Einstein [1879–1955]), Es; at. wt. (252); m.p. 860°C (est.); at. no. 99. Einsteinium, the seventh transuranic element of the actinide series to be discovered, was identified by Ghiorso and co-workers at Berkeley in December 1952 in debris from the first large thermonuclear explosion, which took place in the Pacific in November 1952. The isotope produced was the 20-day ^{253}Es isotope. In 1961, a sufficient amount of einsteinium was produced to permit separation of a macroscopic amount of ^{253}Es. This sample weighed about 0.01 μg. A special magnetic-type balance was used in making this determination. ^{253}Es so produced was used to produce mendelevium. About 3 μg of einsteinium has been produced at Oak Ridge National Laboratories by irradiating for several years kilogram quantities of ^{239}Pu in a reactor to produce ^{242}Pu. This was then fabricated into pellets of plutonium oxide and aluminum powder, and loaded into target rods for an initial 1-year irradiation at the Savannah River Plant, followed by irradiation in a HFIR (High Flux Isotopic Reactor). After 4 months in the HFIR the targets were removed for chemical separation of the einsteinium from californium. Nineteen isotopes and isomers of einsteinium are now recognized. ^{254}Es has the longest half-life (276 days). Tracer studies using ^{253}Es show that einsteinium has chemical properties typical of a heavy trivalent, actinide element. Einsteinium is extremely radioactive. Great care must be taken when handling it.

Element 93 — See Neptunium.

Element 94 — See Plutonium.

Element 95 — See Americium.

Element 96 — See Curium.

Element 97 — See Berkelium.

Element 98 — See Californium.

Element 99 — See Einsteinium.

Element 100 — See Fermium (unnilnilium).

Element 101 — See Mendelevium (unnilunium).

Element 102 — See Nobelium (unnilbium).

Element 103 — See Lawrencium (unniltrium).

Element 104 — See Rutherfordium (unnilquadium).

Element 105 — See Dubnium (unnilpentium).

Element 106 — See Seaborgium (unnilhexium).

Element 107 — See Bohrium (unnilseptium).

Element 108 — See Hassium (unniloctium).

Element 109 — See Meitnerium (unnilennium).

Element 110 — In 1987 Oganessian, et al., at Dubna, claimed discovery of this element. Their experiments indicated the spontaneous fissioning nuclide ^{272}110 with a half-life of 10 ms. More recently a group led by Armbruster at G.S.I. in Darmstadt, Germany, reported evidence of ^{269}110, which was produced by bombarding lead for many days with more than 10^{18} nickel atoms. A detector searched each collision for Element 110's distinct decay sequence. On November 9, 1994, evidence of 110 was detected. Berkeley scientists, in 1991, performed similar experiments and reported evidence of 110, but this was not confirmed. Workers at Dubna have experiments underway to produce ^{273}110 by bombarding plutonium with sulfur atoms. Other experiments at G.S.I. and elsewhere are now searching for heavier isotopes. Five isotopes of Element 110 are now recognized. Several years ago the IUPAC suggested the use of the temporary name *ununnilium,* with the symbol Uun, for Element 110 when it was found.

Element 111 — On December 20, 1994, scientists at GSI Darmstadt, Germany announced they had detected three atoms of a new element with 111 protons and 161 neutrons. This element was made by bombarding ^{83}Bi with ^{28}Ni. Signals of Element 111 appeared for less than 0.002 sec, then decayed into lighter elements including Element ^{268}109 and Element ^{264}107. These isotopes had not previously been observed. A name for Element 111 has not been suggested although IUPAC has suggested a temporary name of Unununium, with the symbol Uuu. Element 111 is expected to have properties similar to gold.

Element 112 — In late February 1996, Siguard Hofmann and his collaborators at GSI Darmstadt announced their discovery of Element 112, having 112 protons and 165 neutrons, with an atomic mass of 277. This element was made by bombarding a lead target with high-energy zinc ions. A single nucleus of Element 112 was detected, which decayed after less than 0.001 sec by emitting an α particle, consisting of two protons and two neutrons. This created Element 110_{273}, which in turn decayed by emitting an α particle to form a new isotope of Element 108 and so on. Evidence indicates that nuclei with 162 neutrons are held together more strongly than nuclei with a smaller or larger number of neutrons. This suggests a narrow "peninsula" of relatively stable isotopes around Element 114. GSI scientists are experimenting to bombard targets with ions heavier than zinc to produce Elements 113 and 114. A name has not yet been suggested for Element 112, although the IUPAC suggested the temporary name of ununbium, with the symbol of Uub, when the element was discovered. Element 112 is expected to have properties similar to mercury.

Element 113 — (ununtrium) As of December 1999 this element remains undiscovered.

Element 114 — (ununquadium) Symbol Uuq. Element 114 is the first new element to be discovered since 1996. This element was found by a Russian–American team, including Livermore researchers, by bombarding a sheet of plutonium with a rare form of calcium hoping to make the atoms stick together in a new element. Radiation showed that the new element broke into smaller pieces. Data of radiation collected at the Russian Joint Institute for Nuclear Research in November and December 1998, were analyzed in January 1999. It was found that some of the heavy atoms created when 114 decayed lived up to 30 seconds, which was longr than ever seen before, for such a heavy element. This isotope decayed into a previously unknown isotope of Element 112, which itself lasted 15 minutes. That isotope, in turn, decayed to a previously undiscovered isotope of Element 108, which survived 17 minutes. Isotopes of these and those with longer life-times have been predicted for some time by theorists. It appears that these isotopes are on the edge of the "island of stability", and that some of the isotopes in this region might last long enough for studies of their nuclear behavior and for a chemical evaluation to be made. No name has yet been suggested for Element 114; however, the temporary name of ununquadium with symbol Uuq may be used.

In June 1999 it was announced that Elements 118 and 116 had been discovered. These disintegrated into Element 114 and other elements. See under Element 118.

Element 115— (ununpentium) As of December 1999, this element remains undiscovered.

Element 116— (ununhexium) Symbol Uuh. This element was discovered along with Element 118 in June 1999. See under Element 118.

Element 117— (ununseptium) As of December 1999, this element remains undiscovered.

Element 118— (ununoctium) Symbol Uuo. Victor Nonov of the Lawrence Berkeley National Laboratory led a team of university and government scientists in experiments that led to the discovery of Elements 118 and 116 in June 1999. A lead target was bombarded for more than 10 days with roughly 1 quintillion krypton ions. The team made three atoms of Element 118, which quickly decayed into Elements 116, 114, and other elements. The isotopes of Element 118 lasted only about 200 microseconds, while the isotope of Element 116 lasted only 1.2 milliseconds. Investigations seem to indicate that the investigations are converging on a cluster of very stable super-heavy isotopes, some of which may survive for very long times. Researchers at GSI, in Russia at Dubna, or at the Berkeley Laboratory may soon fire krypton at bismuth to make Element 119, which would decay into the yet-undiscovered Elements 117, 115, and 113.

Erbium — (*Ytterby*, a town in Sweden), Er; at. wt. 167.26(3); at. no. 68; m.p. 1529°C; b.p. 2868°C; sp. gr. 9.066 (25°C); valence 3, Erbium, one of the so-called rare-earth elements of the lanthanide series, is found in the minerals mentioned under dysprosium above. In 1842 Mosander separated "yttria," found in the mineral *gadolinite,* into three fractions which he called *yttria, erbia,* and *terbia.* The names *erbia* and *terbia* became confused in this early period. After 1860, Mosander's *terbia* was known as *erbia,* and after 1877, the earlier known *erbia* became *terbia.* The *erbia* of this period was later shown to consist of five oxides, now known as *erbia, scandia, holmia, thulia* and *ytterbia.* By 1905 Urbain and James independently succeeded in isolating fairly pure Er_2O_3. Klemm and Bommer first produced reasonably pure erbium metal in 1934 by reducing the anhydrous chloride with potassium vapor. The pure metal is soft and malleable and has a bright, silvery, metallic luster. As with other rare-earth metals, its properties depend to a certain extent on the impurities present. The metal is fairly stable in air and does not oxidize as rapidly as some of the other rare-earth metals. Naturally occurring erbium is a mixture of six isotopes, all of which are stable. Twenty-seven radioactive isotopes of erbium are also recognized. Recent production techniques, using ion-exchange reactions, have resulted in much lower prices of the rare-earth metals and their compounds in recent years. The cost of 99.9% erbium metal is about $10/g. Erbium is finding nuclear and metallurgical uses. Added to vanadium, for example, erbium lowers the hardness and improves workability. Most of the rare-earth oxides have sharp absorption bands in the visible, ultraviolet, and near infrared. This property, associated with the electronic structure, gives beautiful pastel colors to many of the rare-earth salts. Erbium oxide gives a pink color and has been used as a colorant in glasses and porcelain enamel glazes.

Europium — (Europe), Eu; at. wt. 151.964(1); at. no. 63; m.p. 822°C; b.p. 1596°C; sp. gr. 5.244 (25°C); valence 2 or 3. In 1890 Boisbaudran obtained basic fractions from samarium-gadolinium concentrates which had spark spectral lines not accounted for by samarium or gadolinium. These lines subsequently have been shown to belong to europium. The discovery of europium is generally credited to Demarcay, who separated the rare earth in reasonably pure form in 1901. The pure metal was not isolated until recent years. Europium is now prepared by mixing Eu_2O_3 with a 10%-excess of lanthanum metal and heating the mixture in a tantalum crucible under high vacuum. The element is collected as a silvery-white metallic deposit on the walls of the crucible. As with other rare-earth metals, except for lanthanum, europium ignites in air at about 150 to 180°C. Europium is about as hard as lead and is quite ductile. It is the most reactive of the rare-earth metals, quickly oxidizing in air. It resembles calcium in its reaction with water. *Bastnasite* and *monazite* are the principal ores containing europium. Europium has been identified spectroscopically in the sun and certain stars. Europium isotopes are good neutron absorbers and are being studied for use in nuclear control applications. Europium oxide is now widely used as a phosphor activator and europium-activated yttrium vanadate is in commercial use as the red phosphor in color TV tubes. Europium-doped plastic has been used as a laser material. With the development of ion-exchange techniques and special processes, the cost of the metal has been greatly reduced in recent years. Natural europium contains two stable isotopes. Thirty five other radioactive isotopes and isomers are known. Europium is one of the rarest and most costly of the rare-earth metals. It is priced at about $50/g (99.9% pure).

Fermium — (Enrico Fermi [1901–1954], nuclear physicist), Fm; at. wt. [257]; at. no. 100; m.p. 1527°C. Fermium, the eighth transuranium element of the actinide series to be discovered, was identified by Ghiorso and co-workers in 1952 in the debris from a thermonuclear explosion in the Pacific in work involving the University of California Radiation Laboratory, the Argonne National Laboratory, and the Los Alamos Scientific Laboratory. The isotope produced was the 20-hour ^{255}Fm. During 1953 and early 1954, while discovery of elements 99 and 100 was withheld from publication for security reasons, a group from the Nobel Institute of Physics in Stockholm bombarded ^{238}U with ^{16}O ions, and isolated a 30-min α-emitter, which

they ascribed to ^{250}100, without claiming discovery of the element. This isotope has since been identified positively, and the 30-min half-life confirmed. The chemical properties of fermium have been studied solely with tracer amounts, and in normal aqueous media only the (III) oxidation state appears to exist. The isotope ^{254}Fm and heavier isotopes can be produced by intense neutron irradiation of lower elements such as plutonium by a process of successive neutron capture interspersed with beta decays until these mass numbers and atomic numbers are reached. Twenty isotopes and isomers of fermium are known to exist. ^{257}Fm, with a half-life of about 100.5 days, is the longest lived. ^{250}Fm, with a half-life of 30 min, has been shown to be a product of decay of Element ^{254}102. It was by chemical identification of ^{250}Fm that production of Element 102 (nobelium) was confirmed. Fermium would probably have chemical properties resembling erbium.

Fluorine — (L. and F. *fluere,* flow, or flux), F; at. wt. 18.9984032(5); at. no. 9; m.p. –219.62°C (1 atm); b.p. –188.12°C (1 atm); t_c -129.02°C; density 1.696 g/L (0°C, 1 atm); liq. den. at b.p. 1.50 g/cm^3; valence 1. In 1529, Georigius Agricola described the use of fluorspar as a flux, and as early as 1670 Schwandhard found that glass was etched when exposed to fluorspar treated with acid. Scheele and many later investigators, including Davy, Gay-Lussac, Lavoisier, and Thenard, experimented with hydrofluoric acid, some experiments ending in tragedy. The element was finally isolated in 1886 by Moisson after nearly 74 years of continuous effort. Fluorine occurs chiefly in *fluorspar* (CaF_2) and *cryolite* (Na_2AlF_6), but is rather widely distributed in other minerals. It is a member of the halogen family of elements, and is obtained by electrolyzing a solution of potassium hydrogen fluoride in anhydrous hydrogen fluoride in a vessel of metal or transparent fluorspar. Modern commercial production methods are essentially variations on the procedures first used by Moisson. Fluorine is the most electronegative and reactive of all elements. It is a pale yellow, corrosive gas, which reacts with practically all organic and inorganic substances. Finely divided metals, glass, ceramics, carbon, and even water burn in fluorine with a bright flame. Until World War II, there was no commercial production of elemental fluorine. The atom bomb project and nuclear energy applications, however, made it necessary to produce large quantities. Safe handling techniques have now been developed and it is possible at present to transport liquid fluorine by the ton. Fluorine and its compounds are used in producing uranium (from the hexafluoride) and more than 100 commercial fluorochemicals, including many well-known high-temperature plastics. Hydrofluoric acid is extensively used for etching the glass of light bulbs, etc. Fluorochloro hydrocarbons have been extensively used in air conditioning and refrigeration. However, in recent years the U.S. and other countries have been phasing out ozone-depleting substances, such as the fluorochloro hydrocarbons that have been used in these applications. It has been suggested that fluorine might be substituted for hydrogen wherever it occurs in organic compounds, which could lead to an astronomical number of new fluorine compounds. The presence of fluorine as a soluble fluoride in drinking water to the extent of 2 ppm may cause mottled enamel in teeth, when used by children acquiring permanent teeth; in smaller amounts, however, fluorides are said to be beneficial and used in water supplies to prevent dental cavities. Elemental fluorine has been studied as a rocket propellant as it has an exceptionally high specific impulse value. Compounds of fluorine with rare gases have now been confirmed. Fluorides of xenon, radon, and krypton are among those known. Elemental fluorine and the fluoride ion are highly toxic. The free element has a characteristic pungent odor, detectable in concentrations as low as 20 ppb, which is below the safe working level. The recommended maximum allowable concentration for a daily 8-hour time-weighted exposure is 1 ppm. Fluorine is known to have fourteen isotopes.

Francium — (France), Fr; at. no. 87; at. wt. [223]; m.p. 27°C; valence 1. Discovered in 1939 by Mlle. Marguerite Perey of the Curie Institute, Paris. Francium, the heaviest known member of the alkali metal series, occurs as a result of an alpha disintegration of actinium. It can also be made artificially by bombarding thorium with protons. While it occurs naturally in uranium minerals, there is probably less than an ounce of francium at any time in the total crust of the earth. It has the highest equivalent weight of any element, and is the most unstable of the first 101 elements of the periodic system. Thirty-six isotopes and isomers of francium are recognized. The longest lived ^{223}Fr(Ac, K), a daughter of ^{227}Ac, has a half-life of 21.8 min. This is the only isotope of francium occurring in nature. Because all known isotopes of francium are highly unstable, knowledge of the chemical properties of this element comes from radiochemical techniques. No weighable quantity of the element has been prepared or isolated. The chemical properties of francium most closely resemble cesium. In 1996, researchers Orozco, Sprouse, and co-workers at the State University of New York, Stony Brook, reported that they had produced francium atoms by bombarding ^{18}O atoms at a gold target heated almost to its melting point. Collisions between gold and oxygen nuclei created atoms of francium-210 which had 87 protons and123 neutrons. This team reported they had generated about 1 million francium-210 ions per second and held 1000 or more atoms at a time for about 20 secs. in a magnetic trap they had devised before the atoms decayed or escaped. Enough francium was trapped so that a video camera could capture the light given off by the atoms as they fluoresced. A cluster of about 10,000 francium atoms appeared as a glowing sphere about 1 mm in diameter. It is thought that the francium atoms could serve as miniature laboratoires for probing interactions between electrons and quarks.

Gadolinium — (*gadolinite,* a mineral named for Gadolin, a Finnish chemist), Gd; at. wt. 157.25(3); at. no. 64; m.p. 1313°C; b.p. 3273°C; sp. gr. 7.901 (25°C); valence 3. Gadolinia, the oxide of gadolinium, was separated by Marignac in 1880 and Lecoq de Boisbaudran independently isolated the element from Mosander's "yttria" in 1886. The element was named for the mineral *gadolinite* from which this rare earth was originally obtained. Gadolinium is found in several other minerals, including *monazite* and *bastnasite,* which are of commercial importance. The element has been isolated only in recent years. With the development of ion-exchange and solvent extraction techniques, the availability and price of gadolinium and the other rare-earth metals have greatly improved. Thirty-one isotopes and isomers of gadolinium are now recognized; seven are stable and occur naturally. The metal can be prepared by the reduction of the anhydrous fluoride with metallic calcium. As with other related rare-earth metals, it is silvery white, has a metallic luster, and is malleable and ductile. At room temperature, gadolinium crystallizes in the hexagonal, close-packed α form. Upon heating to 1235°C, α gadolinium transforms into the β form, which has a body-centered cubic structure. The metal is relatively stable in dry air, but in moist air it tarnishes with the formation of a loosely adhering oxide film which spalls off and exposes more surface to oxidation. The metal reacts slowly with water and is soluble in dilute acid. Gadolinium has the highest thermal neutron capture cross-section of any known element (49,000 barns). Natural gadolinium is a mixture of seven isotopes. Two of these, ^{155}Gd and ^{157}Gd, have excellent capture characteristics, but they are present naturally in low concentrations. As a result, gadolinium has a very fast burnout rate and has limited use as a nuclear control rod material. It has been used in making gadolinium yttrium garnets, which have microwave applications. Compounds of gadolinium are used in making phosphors for color TV tubes. The metal has unusual superconductive properties. As little as 1% gadolinium has been found to improve the workability and resistance of iron, chromium, and related alloys to high temperatures and oxidation. Gadolinium ethyl sulfate has extremely low noise characteristics and may find use in duplicating the performance of amplifiers, such as the maser. The metal is ferromagnetic. Gadolinium is unique for its high magnetic moment and for its special Curie temperature (above which ferromagnetism vanishes) lying just at room temperature. This suggests uses as a magnetic component that senses hot and cold. The price of the metal is about $12/g (99.9% purity).

Gallium — (L. *Gallia*, France; also from Latin, *gallus*, a translation of Lecoq, a cock), Ga; at. wt. 69.723(1); at. no. 31; m.p. 29.76°C; b.p. 2204°C; sp. gr. 5.904 (29.6°C) solid; sp. gr. 6.095 (29.6°C) liquid; valence 2 or 3. Predicted and described by Mendeleev as ekaaluminum, and discovered spectroscopically by Lecoq de Boisbaudran in 1875, who in the same year obtained the free metal by electrolysis of a solution of the hydroxide in KOH. Gallium is often found as a trace element in *diaspore, sphalerite, germanite, bauxite*, and *coal.* Some flue dusts from burning coal have been shown to contain as much as 1.5% gallium. It is the only metal, except for mercury, cesium, and rubidium, which can be liquid near room temperatures; this makes possible its use in high-temperature thermometers. It has one of the longest liquid ranges of any metal and has a low vapor pressure even at high temperatures. There is a strong tendency for gallium to supercool below its freezing point. Therefore, seeding may be necessary to initiate solidification. Ultra-pure gallium has a beautiful, silvery appearance, and the solid metal exhibits a conchoidal fracture similar to glass. The metal expands 3.1% on solidifying; therefore, it should not be stored in glass or metal containers, as they may break as the metal solidifies. Gallium wets glass or porcelain, and forms a brilliant mirror when it is painted on glass. It is widely used in doping semiconductors and producing solid-state devices such as transistors. High-purity gallium is attacked only slowly by mineral acids. Magnesium gallate containing divalent impurities such as Mn^{+2} is finding use in commercial ultraviolet activated powder phosphors. Gallium nitride has been used to produce blue light-emitting diodes. Blue LED's used in compact disc applications can be used to store a 2-h movie, for example, on one 5-in. diameter disc. Extensive use of gallium has found recent application in the **Gallex Detector Experiment** located in the Gran Sasso Underground Laboratory in Italy. This underground facility has been built by the Italian Istituto Nazionale di Fisica Nucleare in the middle of a highway tunnel through the Abruzzese mountains, about 150 km east of Rome. The experiment is shielded by a 3300-m water-equivalent of rock. In this experiment, 30.3 tons of gallium in the form of 110 tons of $GaCl_3$-HCl solution are being used to detect solar neutrinos. The production of ^{71}Ge from gallium is being measured.Gallium arsenide is capable of converting electricity directly into coherent light. Gallium readily alloys with most metals, and has been used as a component in low-melting alloys. Its toxicity appears to be of a low order, but should be handled with care until more data are forthcoming. Natural gallium contains two stable isotopes. Twenty-six other isotopes, one of which is an isomer, are known. The metal can be supplied in ultrapure form (99.99999+%). The cost is about $5/g (99.999%).

Germanium — (L. *Germania*, Germany), Ge; at. wt. 72.61(2); at. no. 32; m.p. 938.25°C; b.p. 2833°C; sp. gr. 5.323 (25°C); valence 2 and 4. Predicted by Mendeleev in 1871 as ekasilicon, and discovered by Winkler in 1886. The metal is found in *argyrodite*, a sulfide of germanium and silver; in *germanite*, which contains 8% of the element; in zinc ores; in coal; and in other minerals. The element is frequently obtained commercially from flue dusts of smelters processing zinc ores, and has been recovered from the by-products of combustion of certain coals. Its presence in coal insures a large reserve of the element in the years to come. Germanium can be separated from other metals by fractional distillation of its volatile tetrachloride. The tetrachloride may then be hydrolyzed to give GeO_2; the dioxide can be reduced with hydrogen to give the metal. Recently developed zone-refining techniques permit the production of germanium of ultra-high purity. The element is a gray-white metalloid, and in its pure state is crystalline and brittle, retaining its luster in air at room temperature. It is a very important semiconductor material. Zone-refining techniques have led to production of crystalline germanium for semiconductor use with an impurity of only one part in 10^{10}. Doped with arsenic, gallium, or other elements, it is used as a transistor element in thousands of electronic applications. Its application in fiber optics and infra-red optical systems now provides the largest use for germanium. Germanium is also finding many other applications including use as an alloying agent, as a phosphor in fluorescent lamps, and as a catalyst. Germanium and germanium oxide are transparent to the infrared and are used in infrared spectroscopes and other optical equipment, including extremely sensitive infrared detectors. Germanium oxide's high index of refraction and dispersion has made it useful as a component of glasses used in wide-angle camera lenses and microscope objectives. The field of organogermanium chemistry is becoming increasingly important. Certain germanium compounds have a low mammalian toxicity, but a marked activity against certain bacteria, which makes them of interest as chemotherapeutic agents. The cost of germanium is about $10/g (99.999% purity). Thirty isotopes and isomers are known, five of which occur naturally.

Gold — (Sanskrit *Jval;* Anglo-Saxon *gold*), Au (L. *aurum*, gold); at. wt. 196.96654(3); at. no. 79; m.p. 1064.18°C; b.p. 2856°C; sp. gr. ~19.3 (20°C); valence 1 or 3. Known and highly valued from earliest times, gold is found in nature as the free metal and in tellurides; it is very widely distributed and is almost always associated with quartz or pyrite. It occurs in veins and alluvial deposits, and is often separated from rocks and other minerals by sluicing and panning operations. About 25% of the world's gold output comes from South Africa, and about two thirds of the total U.S. production now comes from South Dakota and Nevada. The metal is recovered from its ores by cyaniding, amalgamating, and smelting processes. Refining is also frequently done by electrolysis. Gold occurs in sea water to the extent of 0.1 to 2 mg/ton, depending on the location where the sample is taken. As yet, no method has been found for recovering gold from sea water profitably. It is estimated that all the gold in the world, so far refined, could be placed in a single cube 60 ft on a side. Of all the elements, gold in its pure state is undoubtedly the most beautiful. It is metallic, having a yellow color when in a mass, but when finely divided it may be black, ruby, or purple. The Purple of Cassius is a delicate test for auric gold. It is the most malleable and ductile metal; 1 oz. of gold can be beaten out to 300 ft^2. It is a soft metal and is usually alloyed to give it more strength. It is a good conductor of heat and electricity, and is unaffected by air and most reagents. It is used in coinage and is a standard for monetary systems in many countries. It is also extensively used for jewelry, decoration, dental work, and for plating. It is used for coating certain space satellites, as it is a good reflector of infrared and is inert. Gold, like other precious metals, is measured in troy weight; when alloyed with other metals, the term *carat* is used to express the amount of gold present, 24 carats being pure gold. For many years the value of gold was set by the U.S. at $20.67/troy ounce; in 1934 this value was fixed by law at $35.00/troy ounce, 9/10th fine. On March 17, 1968, because of a gold crisis, a two-tiered pricing system was established whereby gold was still used to settle international accounts at the old $35.00/troy ounce price while the price of gold on the private market would be allowed to fluctuate. Since this time, the price of gold on the free market has fluctuated widely. The price of gold on the free market reached a price of $620/troy oz. in January 1980. More recently, the U.K. and other nations, including the I.M.F. have sold or threatened to sell a sizeable portion of their gold reserves. This has caused wide fluctuations in the price of gold. Because this has damaged the economy of some countires, a moretorium for a few years has been declared. This has tended to stabilize temporarily the price of gold. The most common gold compounds are auric chloride ($AuCl_3$) and chlorauric acid ($HAuCl_4$), the latter being used in photography for toning the silver image. Gold has forty-eight recognized isotopes and isomers; ^{198}Au, with a half-life of 2.7 days, is used for treating cancer and other diseases. Disodium aurothiomalate is administered intramuscularly as a treatment for arthritis. A mixture of one part nitric acid with three of hydrochloric acid is called *aqua regia* (because it dissolved gold, the King of Metals). Gold is available commercially with a purity of 99.999+%. For many years the temperature assigned to the freezing point of gold has been 1063.0°C; this has served as a calibration point for the International Temperature Scales (ITS-27 and ITS-48) and the International Practical Temperature Scale (IPTS-

48). In 1968, a new International Practical Temperature Scale (IPTS-68) was adopted, which demanded that the freezing point of gold be changed to 1064.43°C. In 1990 a new International Temperature Scale (ITS-90) was adopted bringing the t.p. (triple point) of H_2O (t_{90} (°C)) to 0.01°C and the freezing point of gold to 1064.18°C.The specific gravity of gold has been found to vary considerably depending on temperature, how the metal is precipitated, and cold-worked. As of December 1999, gold was priced at about $300/troy oz. ($9.50/g).

Hafnium — (*Hafnia,* Latin name for Copenhagen), Hf; at. wt. 178.49(2); at. no. 72; m.p. 2233°C; b.p. 4603°C; sp. gr. 13.31 (20°C); valence 4. Hafnium was thought to be present in various minerals and concentrations many years prior to its discovery, in 1923, credited to D. Coster and G. von Hevesey. On the basis of the Bohr theory, the new element was expected to be associated with zirconium. It was finally identified in *zircon* from Norway, by means of X-ray spectroscopic analysis. It was named in honor of the city in which the discovery was made. Most zirconium minerals contain 1 to 5% hafnium. It was originally separated from zirconium by repeated recrystallization of the double ammonium or potassium fluorides by von Hevesey and Jantzen. Metallic hafnium was first prepared by van Arkel and deBoer by passing the vapor of the tetraiodide over a heated tungsten filament. Almost all hafnium metal now produced is made by reducing the tetrachloride with magnesium or with sodium (Kroll Process). Hafnium is a ductile metal with a brilliant silver luster. Its properties are considerably influenced by the impurities of zirconium present. Of all the elements, zirconium and hafnium are two of the most difficult to separate. Their chemistry is almost identical, however, the density of zirconium is about half that of hafnium. Very pure hafnium has been produced, with zirconium being the major impurity. Natural hafnium contains six isotopes, one of which is slightly radioactive. Hafnium has a total of 41 recognized isotopes and isomers. Because hafnium has a good absorption cross section for thermal neutrons (almost 600 times that of zirconium), has excellent mechanical properties, and is extremely corrosion resistant, it is used for reactor control rods. Such rods are used in nuclear submarines. Hafnium has been successfully alloyed with iron, titanium, niobium, tantalum, and other metals. Hafnium carbide is the most refractory binary composition known, and the nitride is the most refractory of all known metal nitrides (m.p. 3310°C). Hafnium is used in gas-filled and incandescent lamps, and is an efficient "getter" for scavenging oxygen and nitrogen. Finely divided hafnium is pyrophoric and can ignite spontaneously in air. Care should be taken when machining the metal or when handling hot sponge hafnium. At 700°C hafnium rapidly absorbs hydrogen to form the composition $HfH_{1.86}$. Hafnium is resistant to concentrated alkalis, but at elevated temperatures reacts with oxygen, nitrogen, carbon, boron, sulfur, and silicon. Halogens react directly to form tetrahalides. The price of the metal is in the broad range of $1/g to $5/g, depending on purity and quantity. The yearly demand for hafnium in the U.S. is now in excess of 50,000 kg.

Hahnium — A name previously used for Element 105, now named *dubnium*.

Hassium — (named for the German state, Hesse) Hs, at.wt. [265]; at.no. 108. This element was first synthesized and identified in 1964 by the same G.S.I. Darmstadt Group who first identified *Bohrium* and *Meitnerium.* Presumably this element has chemical properties similar to osmium. Isotope $^{265}108$ was produced using a beam of ^{58}Fe projectiles, produced by the Universal Linear Accelerator (UNILAC) to bombard a ^{208}Pb target. Discovery of *Bohrium* and *Meitnerium* was made using detection of isotopes with odd proton and neutron numbers. Elements having even atomic numbers have been thought to be less stable against spontaneous fusion than odd elements. The production of $^{265}108$ in the same reaction as was used at G.S.I. was confirmed at Dubna with detection of the seventh member of the decay chain ^{253}Es. Isotopes of *Hassium* are believed to decay by spontaneous fission, explaining why 109 was produced before 108. Isotope $^{265}108$ and $^{266}108$ are thought to decay to $^{261}106$, which in turn decay to $^{257}104$ and $^{253}102$. The IUPAC adopted the name *Hassium* after the German state of Hesse in September 1997.

Helium — (Gr. *helios,* the sun), He; at. wt. 4.002602(2); at. no. 2; m.p. below — 272.2°C (26 atm); b.p. — 268.93°C; t_c -267.96°C; density 0.1785 g/l (0°C, 1 atm); liquid density 7.62 lb/ft^3 at. b.p.; valence usually 0. Evidence of the existence of helium was first obtained by Janssen during the solar eclipse of 1868 when he detected a new line in the solar spectrum; Lockyer and Frankland suggested the name *helium* for the new element; in 1895, Ramsay discovered helium in the uranium mineral *clevite*, and it was independently discovered in cleveite by the Swedish chemists Cleve and Langlet about the same time. Rutherford and Royds in 1907 demonstrated that α particles are helium nuclei. Except for hydrogen, helium is the most abundant element found throughout the universe. Helium is extracted from natural gas; all natural gas contains at least trace quantities of helium. It has been detected spectroscopically in great abundance, especially in the hotter stars, and it is an important component in both the proton-proton reaction and the carbon cycle, which account for the energy of the sun and stars. The fusion of hydrogen into helium provides the energy of the hydrogen bomb. The helium content of the atmosphere is about 1 part in 200,000. It is present in various radioactive minerals as a decay product. Much of the world's supply of helium is obtained from wells in Texas, Colorado, and Kansas. The only other known helium extraction plants, outside the United States, in 1999 were inPoland, Russia, China, Algeria, and India. The cost of helium has fallen from $2500/ft^3 in 1915 to about 2.5¢/cu.ft. (.028 cu meters) in 1999. Helium has the lowest melting point of any element and has found wide use in cryogenic research, as its boiling point is close to absolute zero. Its use in the study of superconductivity is vital. Using liquid helium, Kurti and co-workers, and others, have succeeded in obtaining temperatures of a few microkelvins by the adiabatic demagnetization of copper nuclei, starting from about 0.01 K. Liquid helium (He^4) exists in two forms: He^4I and He^4II, with a sharp transition point at 2.174 K (3.83 cm Hg). He^4I (above this temperature) is a normal liquid, but He^4II (below it) is unlike any other known substance. It expands on cooling; its conductivity for heat is enormous; and neither its heat conduction nor viscosity obeys normal rules. It has other peculiar properties. Helium is the only liquid that cannot be solidified by lowering the temperature. It remains liquid down to absolute zero at ordinary pressures, but it can readily be solidified by increasing the pressure. Solid ^3He and ^4He are unusual in that both can readily be changed in volume by more than 30% by application of pressure. The specific heat of helium gas is unusually high. The density of helium vapor at the normal boiling point is also very high, with the vapor expanding greatly when heated to room temperature. Containers filled with helium gas at 5 to 10 K should be treated as though they contained liquid helium due to the large increase in pressure resulting from warming the gas to room temperature. While helium normally has a 0 valence, it seems to have a weak tendency to combine with certain other elements. Means of preparing helium diflouride have been studied, and species such as HeNe and the molecular ions He^+ and He^{++} have been investigated. Helium is widely used as an inert gas shield for arc welding; as a protective gas in growing silicon and germanium crystals, and in titanium and zirconium production; as a cooling medium for nuclear reactors, and as a gas for supersonic wind tunnels. A mixture of helium and oxygen is used as an artificial atmosphere for divers and others working under pressure. Different ratios of He/O_2 are used for different depths at which the diver is operating. Helium is extensively used for filling balloons as it is a much safer gas than hydrogen. One of the recent largest uses for helium has been for pressuring liquid fuel rockets. A Saturn booster such as used on the Apollo lunar missions required about 13 million ft^{3}of helium for a firing, plus more for checkouts. Liquid helium's use in magnetic resonance imaging (MRI) continues to increase as the medical profession accepts and develops new uses for the equipment. This equipment is providing accurate diagnoses of problems where exploratory surgery has previously been required to determine problems. Another medical application that is being developed uses MRI to determine by blood analysis whether a patient has any form of cancer. Lifting gas applications are increasing. Various

companies in addition to Goodyear, are now using “blimps” for advertising. The Navy and the Air Force are investigating the use of airships to provide early warning systems to detect low-flying cruise missiles. The Drug Enforcement Agency has used radar-equipped blimps to detect drug smugglers along the southern border of the U.S. In addition, NASA is currently using helium-filled balloons to sample the atmosphere in Antarctica to determine what is depleting the ozone layer that protects Earth from harmful U.V. radiation. Research on and development of materials which become superconductive at temperatures well above the boiling point of helium could have a major impact on the demand for helium. Less costly refrigerants having boiling points considerably higher could replace the present need to cool such superconductive materials to the boiling point of helium. Natural helium contains two stable isotopes ^{3}He and ^{4}He. ^{3}He is present in very small quantities. Six other isotopes of helium are now recognized.

Holmium — (L. *Holmia* , for Stockholm), Ho; at. wt. 164.93032(2); at. no 67; m.p. 1474°C; b.p. 2700°C; sp. gr. 8.795 (25°C); valence + 3. The spectral absorption bands of holmium were noticed in 1878 by the Swiss chemists Delafontaine and Soret, who announced the existence of an “Element X”. Cleve, of Sweden, later independently discovered the element while working on erbia earth. The element is named after Cleve’s native city. Pure holmia, the yellow oxide, was prepared by Homberg in 1911. Holmium occurs in *gadolinite, monazite,* and in other rare-earth minerals. It is commercially obtained from monazite, occurring in that mineral to the extent of about 0.05%. It has been isolated by the reduction of its anhydrous chloride or fluoride with calcium metal. Pure holmium has a metallic to bright silver luster. It is relatively soft and malleable, and is stable in dry air at room temperature, but rapidly oxidizes in moist air and at elevated temperatures. The metal has unusual magnetic properties. Few uses have yet been found for the element. The element, as with other rare earths, seems to have a low acute toxic rating. Natural holmium consists of one isotope ^{165}Ho, which is not radioactive. Holmium has 49 other isotopes known, all of which are radioactive. The price of 99.9% holmium metal is about $35/g.

Hydrogen — (Gr. *hydro,* water, and *genes,* forming), H; at. wt. 1.00794(7); at. no. 1; m.p. –259.34°C; b.p. –252.87°C; t_c -240.18; density 0.08988 g/l; density (liquid) 70.8 g/l (–253°C); density (solid) 70.6 g/l (–262°C); valence 1. Hydrogen was prepared many years before it was recognized as a distinct substance by Cavendish in 1766. It was named by Lavoisier. Hydrogen is the most abundant of all elements in the universe, and it is thought that the heavier elements were, and still are, being built from hydrogen and helium. It has been estimated that hydrogen makes up more than 90% of all the atoms or three quarters of the mass of the universe. It is found in the sun and most stars, and plays an important part in the proton-proton reaction and carbon-nitrogen cycle, which accounts for the energy of the sun and stars. It is thought that hydrogen is a major component of the planet Jupiter and that at some depth in the planet’s interior the pressure is so great that solid molecular hydrogen is converted into solid metallic hydrogen. In 1973, it was reported that a group of Russian experimenters may have produced metallic hydrogen at a pressure of 2.8 Mbar. At the transition the density changed from 1.08 to 1.3 g/cm^3. Earlier, in 1972, a Livermore (California) group also reported on a similar experiment in which they observed a pressure-volume point centered at 2 Mbar. It has been predicted that metallic hydrogen may be metastable; others have predicted it would be a superconductor at room temperature. On earth, hydrogen occurs chiefly in combination with oxygen in water, but it is also present in organic matter such as living plants, petroleum, coal, etc. It is present as the free element in the atmosphere, but only to the extent of less than 1 ppm by volume. It is the lightest of all gases, and combines with other elements, sometimes explosively, to form compounds. Great quantities of hydrogen are required commercially for the fixation of nitrogen from the air in the Haber ammonia process and for the hydrogenation of fats and oils. It is also used in large quantities in methanol production, in hydrodealkylation, hydrocracking, and hydrodesulfurization. It is also used as a rocket fuel, for welding, for production of hydrochloric acid, for the reduction of metallic ores, and for filling balloons. The lifting power of 1 ft^3 of hydrogen gas is about 0.076 lb at 0°C, 760 mm pressure. Production of hydrogen in the U.S. alone now amounts to about 3 billion cubic feet per year. It is prepared by the action of steam on heated carbon, by decomposition of certain hydrocarbons with heat, by the electrolysis of water, or by the displacement from acids by certain metals. It is also produced by the action of sodium or potassium hydroxide on aluminum. Liquid hydrogen is important in cryogenics and in the study of superconductivity, as its melting point is only a 20°C above absolute zero. Hydrogen consists of three isotopes, most of which is ^{1}H. The ordinary isotope of hydrogen, H, is known as *protium*. In 1932, Urey announced the discovery of a stable isotope, deuterium (^{2}H or D) with an atomic weight of 2. Deuterium is present in natural hydrogen to the extent of 0.015%. Two years later an unstable isotope, tritium (^{3}H), with an atomic weight of 3 was discovered. Tritium has a half-life of about 12.32 years. Tritium atoms are also present in natural hydrogen but in much smaller proportion. Tritium is readily produced in nuclear reactors and is used in the production of the hydrogen bomb. It is also used as a radioactive agent in making luminous paints, and as a tracer. Deuterium gas is readily available, without permit, at about $1/l. Heavy water, deuterium oxide (D_2O), which is used as a moderator to slow down neutrons, is available without permit at a cost of 6c to $1/g, depending on quantity and purity. About 1000 tons (4,400,000 kg) of deuterium oxide (heavy water) are now in use at the Sudbury (Ontario) Neutrino Observatory. This observatory is taking data to provide new revolutionary insight into the properties of neutrinos and into the core of the sun. The heavy water is on loan from Atomic Energy of Canada, Ltd. (AECL). The observatory and detectors are located 6800 ft (2072 m) deep in the Creighton mine of the International Nickel Co., near Sudbury. The heavy water is contained in an acrylic vessel, 12 m in diameter. Neutrinos react with the heavy water to produce Cherenkov radiation. This light is then detected with 9600 photomultiplier tubes surrounding the vessel. The detector laboratory is immensely clean to reduce background radiation, which otherwise hide the very weak signals from neutrinos. Quite apart from isotopes, it has been shown that hydrogen gas under ordinary conditions is a mixture of two kinds of molecules, known as *ortho*- and *para*-hydrogen, which differ from one another by the spins of their electrons and nuclei. Normal hydrogen at room temperature contains 25% of the *para* form and 75% of the *ortho* form. The *ortho* form cannot be prepared in the pure state. Since the two forms differ in energy, the physical properties also differ. The melting and boiling points of *para*hydrogen are about 0.1°C lower than those of normal hydrogen. Consideration is being given to an entire economy based on solar- and nuclear-generated hydrogen. Located in remote regions, power plants would electrolyze sea water; the hydrogen produced would travel to distant cities by pipelines. Pollution-free hydrogen could replace natural gas, gasoline, etc., and could serve as a reducing agent in metallurgy, chemical processing, refining, etc. It could also be used to convert trash into methane and ethylene. Public acceptance, high capital investment, and the high present cost of hydrogen with respect to present fuels are but a few of the problems facing establishment of such an economy. Hydrogen is being investigated as a substitute for deep-sea diving applications below 300 m. Hydrogen is readily available from air product suppliers.

Indium — (from the brilliant indigo line in its spectrum),In; at. wt. 114.818(3); at. no. 49; m.p. 156.60°C; b.p. 2072°C; sp. gr. 7.31 (20°C); valence 1, 2, or 3. Discovered by Reich and Richter, who later isolated the metal. Indium is most frequently associated with zinc materials, and it is from these that most commercial indium is now obtained; however, it is also found in iron, lead, and copper ores. Until 1924, a gram or so constituted the world’s supply of this element in isolated form. It is probably about as abundant as silver. About 4 million troy ounces of indium are now produced annually in the Free World. Canada is presently producing more than 1,000,000 troy ounces annually. The present cost of indium is about $2 to $10/g, depending on quantity and purity. It is available in ultrapure form. Indium is a very soft, silvery-white metal with a brilliant luster. The pure metal gives a high-

pitched “cry” when bent. It wets glass, as does gallium. It has found application in making low-melting alloys; an alloy of 24% indium-76% gallium is liquid at room temperature. Indium is used in making bearing alloys, germanium transistors, rectifiers, thermistors, liquid crystal displays, high definition television, batteries, and photoconductors. It can be plated onto metal and evaporated onto glass, forming a mirror as good as that made with silver but with more resistance to atmospheric corrosion. There is evidence that indium has a low order of toxicity; however, care should be taken until further information is available. Seventy isotopes and isomers are now recognized (more than any other element). Natural indium contains two isotopes. One is stable. The other, ^{115}In, comprising 95.71% of natural indium is slightly radioactive with a very long half-life.

Iodine — (Gr. *iodes,* violet), I; at. wt. 126.90447(3); at. no. 53; m.p. 113.7°C; b.p. 184.4°C; t_c 546°C; density of the gas 11.27 g/l; sp. gr. solid 4.93 (20°C); valence 1, 3, 5, or 7. Discovered by Courtois in 1811. Iodine, a halogen, occurs sparingly in the form of iodides in sea water from which it is assimilated by seaweeds, in Chilean saltpeter and nitrate-bearing earth, known as *caliche* in brines from old sea deposits, and in brackish waters from oil and salt wells. Ultrapure iodine can be obtained from the reaction of potassium iodide with copper sulfate. Several other methods of isolating the element are known. Iodine is a bluish-black, lustrous solid, volatilizing at ordinary temperatures into a blue-violet gas with an irritating odor; it forms compounds with many elements, but is less active than the other halogens, which displace it from iodides. Iodine exhibits some metallic-like properties. It dissolves readily in chloroform, carbon tetrachloride, or carbon disulfide to form beautiful purple solutions. It is only slightly soluble in water. Iodine compounds are important in organic chemistry and very useful in medicine. Forty two isotopes and isomers are recognized. Only one stable isotope, ^{127}I is found in nature. The artificial radioisotope ^{131}I, with a half-life of 8 days, has been used in treating the thyroid gland. The most common compounds are the iodides of sodium and potassium (KI) and the iodates (KIO_3). Lack of iodine is the cause of goiter. Iodides, and thyroxin which contains iodine, are used internally in medicine, and a solution of KI and iodine in alcohol is used for external wounds. Potassium iodide finds use in photography. The deep blue color with starch solution is characteristic of the free element. Care should be taken in handling and using iodine, as contact with the skin can cause lesions; iodine vapor is intensely irritating to the eyes and mucous membranes. Elemental iodine costs about 25 to 75¢/g depending on purity and quantity.

Iridium — (L. *iris,* rainbow), Ir; at. wt. 192.217(3); at. no. 77; m.p. 2446°C; b.p. 4428°C; sp. gr. 22.42 (17°C); valence 3 or 4. Discovered in 1803 by Tennant in the residue left when crude platinum is dissolved by aqua regia. The name iridium is appropriate, for its salts are highly colored. Iridium, a metal of the platinum family, is white, similar to platinum, but with a slight yellowish cast. It is very hard and brittle, making it very hard to machine, form, or work. It is the most corrosion-resistant metal known, and was used in making the standard meter bar of Paris, which is a 90% platinum-10% iridium alloy. This meter bar was replaced in 1960 as a fundamental unit of length (see under Krypton). Iridium is not attacked by any of the acids nor by aqua regia, but is attacked by molten salts, such as NaCl and NaCN. Iridium occurs uncombined in nature with platinum and other metals of this family in alluvial deposits. It is recovered as a by-product from the nickel mining industry. The largest reserves and production of the platinum group of metals, which includes iridium, is in South Africa, followed by Russia and Canada. The U.S. has only one active mine, located at Nye, MT. The presence of iridium has recently been used in examining the Cretaceous-Tertiary (K-T) boundary. Meteorites contain small amounts of iridium. Because iridium is found widely distributed at the K-T boundary, it has been suggested that a large meteorite or asteroid collided with the earth, killing the dinosaurs, and creating a large dust cloud and crater. Searches for such a crater point to one in the Yucatan, known as Chicxulub. Iridium has found use in making crucibles and apparatus for use at high temperatures. It is also used for electrical contacts. Its principal use is as a hardening agent for platinum. With osmium, it forms an alloy which is used for tipping pens and compass bearings. The specific gravity of iridium is only very slightly lower than that of osmium, which has been generally credited as being the heaviest known element. Calculations of the densities of iridium and osmium from the space lattices gives values of 22.65 and 22.61 g/cm^3, respectively. These values may be more reliable than actual physical measurements. At present, therefore, we know that either iridium or osmium is the densest known element, but the data do not yet allow selection between the two. Natural iridium contains two stable isotopes. Forty-five other isotopes, all radioactive, are now recognized. Iridium (99.9%) costs about $100/g.

Iron — (Anglo-Saxon, *iron*), Fe (L. *ferrum*); at. wt. 55.845(2); at. no. 26; m.p. 1538°C; b.p. 2861°C; sp. gr. 7.874 (20°C); valence 2, 3, 4, or 6. The use of iron is prehistoric. Genesis mentions that Tubal-Cain, seven generations from Adam, was “an instructor of every artificer in brass and iron.” A remarkable iron pillar, dating to about A.D. 400, remains standing today in Delhi, India. This solid shaft of wrought iron is about $7^1/_4$ m high by 40 cm in diameter. Corrosion to the pillar has been minimal although it has been exposed to the weather since its erection. Iron is a relatively abundant element in the universe. It is found in the sun and many types of stars in considerable quantity. Its nuclei are very stable. It has been suggested that the iron we have here on earth may have originated in a super-nova. Iron is a very difficult element to produce in ordinary nuclear reactions, such as would take place in the sun. Iron is found native as a principal component of a class of iron-nickel meteorites known as *siderites*, and is a minor constituent of the other two classes of meteorites. The core of the earth, 2150 miles in radius, is thought to be largely composed of iron with about 10% occluded hydrogen. The metal is the fourth most abundant element, by weight, making up the crust of the earth. The most common ore is *hematite* (Fe_2O_3). Magnetite (Fe_3O_4) is frequently seen as *black sands* along beaches and banks of streams. *Lodestone* is another form of magnetite. *Taconite* is becoming increasingly important as a commercial ore. Iron is a vital constituent of plant and animal life, and appears in hemoglobin. The pure metal is not often encountered in commerce, but is usually alloyed with carbon or other metals. The pure metal is very reactive chemically, and rapidly corrodes, especially in moist air or at elevated temperatures. It has four allotropic forms, or ferrites, known as α, β, γ, and δ, with transition points at 700, 928, and 1530°C. The α form is magnetic, but when transformed into the β form, the magnetism disappears although the lattice remains unchanged. The relations of these forms are peculiar. Pig iron is an alloy containing about 3% carbon with varying amounts of S, Si, Mn, and P. It is hard, brittle, fairly fusible, and is used to produce other alloys, including steel. Wrought iron contains only a few tenths of a percent of carbon, is tough, malleable, less fusible, and has usually a “fibrous” structure. Carbon steel is an alloy of iron with carbon, with small amounts of Mn, S, P, and Si. Alloy steels are carbon steels with other additives such as nickel, chromium, vanadium, etc. Iron is the cheapest and most abundant, useful, and important of all metals. Natural iron contains four isotopes and isomers. Twenty-six other isotopes and isomers, all radioactive, are now recognized.

Krypton — (Gr. *kryptos*, hidden), Kr; at. wt. 83.80(1); at. no. 36; m.p. –157.36°C; b.p. –153.22 ± 0.10°C; t_c -63.74°C; density 3.733 g/l (0°C); valence usually 0. Discovered in 1898 by Ramsay and Travers in the residue left after liquid air had nearly boiled away. Krypton is present in the air to the extent of about 1 ppm. The atmosphere of Mars has been found to contain 0.3 ppm of krypton. It is one of the “noble” gases. It is characterized by its brilliant green and orange spectral lines. Naturally occurring krypton contains six stable isotopes. Thirty other unstable isotopes and isomers are now recognized. The spectral lines of krypton are easily produced and some are very sharp. In 1960 it was internationally agreed that the fundamental unit of length, the meter, should be defined in terms of the orange-red spectral line of ^{86}Kr. This replaced the standard meter of Paris, which was defined in terms of a bar made of a platinum-iridium alloy. In October 1983 the meter, which originally was defined as being one ten millionth of a quadrant

of the earth's polar circumference, was again redefined by the International Bureau of Weights and Measures as being the length of path traveled by light in a vacuum during a time interval of 1/299,792,458 of a second. Solid krypton is a white crystalline substance with a face-centered cubic structure which is common to all the "rare gases". While krypton is generally thought of as a rare gas that normally does not combine with other elements to form compounds, it now appears that the existence of some krypton compounds is established. Krypton difluoride has been prepared in gram quantities and can be made by several methods. A higher fluoride of krypton and a salt of an oxyacid of krypton also have been reported. Molecule-ions of $ArKr^+$ and KrH^+ have been identified and investigated, and evidence is provided for the formation of KrXe or $KrXe^+$. Krypton clathrates have been prepared with hydroquinone and phenol. ^{85}Kr has found recent application in chemical analysis. By imbedding the isotope in various solids, *kryptonates* are formed. The activity of these kryptonates is sensitive to chemical reactions at the surface. Estimates of the concentration of reactants are therefore made possible. Krypton is used in certain photographic flash lamps for high-speed photography. Uses thus far have been limited because of its high cost. Krypton gas presently costs about $690/100 l.

Kurchatovium — See Rutherfordium.

Lanthanum — (Gr. *lanthanein*, to lie hidden), La; at. wt. 138.9055(2); at. no. 57; m.p. 918°C; b.p. 3464°C; sp. gr. 6.145 (25°C); valence 3. Mosander in 1839 extracted a new earth *lanthana*, from impure cerium nitrate, and recognized the new element. Lanthanum is found in rare-earth minerals such as *cerite, monazite, allanite,* and *bastnasite*. Monazite and bastnasite are principal ores in which lanthanum occurs in percentages up to 25 and 38%, respectively. Misch metal, used in making lighter flints, contains about 25% lanthanum. Lanthanum was isolated in relatively pure form in 1923. Ion-exchange and solvent extraction techniques have led to much easier isolation of the so-called "rare-earth" elements. The availability of lanthanum and other rare earths has improved greatly in recent years. The metal can be produced by reducing the anhydrous fluoride with calcium. Lanthanum is silvery white, malleable, ductile, and soft enough to be cut with a knife. It is one of the most reactive of the rare-earth metals. It oxidizes rapidly when exposed to air. Cold water attacks lanthanum slowly, and hot water attacks it much more rapidly. The metal reacts directly with elemental carbon, nitrogen, boron, selenium, silicon, phosphorus, sulfur, and with halogens. At 310°C, lanthanum changes from a hexagonal to a face-centered cubic structure, and at 865°C it again transforms into a body-centered cubic structure. Natural lanthanum is mixture of two isotopes, one of which is stable and one of which is radioactive with a very long half-life. Thirty other radioactive isotopes are recognized. Rare-earth compounds containing lanthanum are extensively used in carbon lighting applications, especially by the motion picture industry for studio lighting and projection. This application consumes about 25% of the rare-earth compounds produced. La_2O_3 improves the alkali resistance of glass, and is used in making special optical glasses. Small amounts of lanthanum, as an additive, can be used to produce nodular cast iron. There is current interest in hydrogen sponge alloys containing lanthanum. These alloys take up to 400 times their own volume of hydrogen gas, and the process is reversible. Heat energy is released every time they do so; therefore these alloys have possibilities in energy conservation systems. Lanthanum and its compounds have a low to moderate acute toxicity rating; therefore, care should be taken in handling them. The metal costs about $2/g (99.9%).

Lawrencium — (Ernest O. Lawrence [1901–1958], inventor of the cyclotron), Lr; at. no. 103; at. mass no. [262]; valence + 3(?). This member of the 5f transition elements (actinide series) was discovered in March 1961 by A. Ghiorso, T. Sikkeland, A. E. Larsh, and R. M. Latimer.A 3-μg californium target, consisting of a mixture of isotopes of mass number 249, 250, 251, and 252, was bombarded with either ^{10}B or ^{11}B. The electrically charged transmutation nuclei recoiled with an atmosphere of helium and were collected on a thin copper conveyor tape which was then moved to place collected atoms in front of a series of solid-state detectors. The isotope of element 103 produced in this way decayed by emitting an 8.6-MeV alpha particle with a half-life of 8 s. In 1967, Flerov and associates of the Dubna Laboratory reported their inability to detect an alpha emitter with a half-life of 8 s which was assigned by the Berkeley group to $^{257}103$. This assignment has been changed to ^{258}Lr or ^{259}Lr. In 1965, the Dubna workers found a longer-lived lawrencium isotope, ^{256}Lr, with a half-life of 35 s. In 1968, Ghiorso and associates at Berkeley were able to use a few atoms of this isotope to study the oxidation behavior of lawrencium. Using solvent extraction techniques and working very rapidly, they extracted lawrencium ions from a buffered aqueous solution into an organic solvent, completing each extraction in about 30 s. It was found that lawrencium behaves differently from dipositive nobelium and more like the tripositive elements earlier in the actinide series. Ten isotopes of lawrencium are now recognized.

Lead — (Anglo-Saxon *lead*), Pb (L. *plumbum*); at. wt. 207.2(1); at. no. 82; m.p. 327.46°C; b.p. 1749°C; sp. gr. 11.35 (20°C); valence 2 or 4. Long known, mentioned in Exodus. The alchemists believed lead to be the oldest metal and associated it with the planet Saturn. Native lead occurs in nature, but it is rare. Lead is obtained chiefly from *galena* (PbS) by a roasting process. *Anglesite* ($PbSO_4$), *cerussite* ($PbCO_3$), and *minim* (Pb_3O_4) are other common lead minerals. Lead is a bluish-white metal of bright luster, is very soft, highly malleable, ductile, and a poor conductor of electricity. It is very resistant to corrosion; lead pipes bearing the insignia of Roman emperors, used as drains from the baths, are still in service. It is used in containers for corrosive liquids (such as sulfuric acid) and may be toughened by the addition of a small percentage of antimony or other metals. Natural lead is a mixture of four stable isotopes: ^{204}Pb (1.4%), ^{206}Pb (24.1%), ^{207}Pb (22.1%), and ^{208}Pb (52.4%). Lead isotopes are the end products of each of the three series of naturally occurring radioactive elements: ^{206}Pb for the uranium series, ^{207}Pb for the actinium series, and ^{208}Pb for the thorium series. Forty-three other isotopes of lead, all of which are radioactive, are recognized. Its alloys include solder, type metal, and various antifriction metals. Great quantities of lead, both as the metal and as the dioxide, are used in storage batteries. Lead is also used for cable covering, plumbing, and ammunition. The metal is very effective as a sound absorber, is used as a radiation shield around X-ray equipment and nuclear reactors, and is used to absorb vibration. Lead, alloyed with tin, is used in making organ pipes. White lead, the basic carbonate, sublimed white lead ($PbSO_4$), chrome yellow ($PbCrO_4$), red lead (Pb_3O_4), and other lead compounds are used extensively in paints, although in recent years the use of lead in paints has been drastically curtailed to eliminate or reduce health hazards. Lead oxide is used in producing fine "crystal glass" and "flint glass" of a high index of refraction for achromatic lenses. The nitrate and the acetate are soluble salts. Lead salts such as lead arsenate have been used as insecticides, but their use in recent years has been practically eliminated in favor of less harmful organic compounds. Care must be used in handling lead as it is a cumulative poison. Environmental concern with lead poisoning has resulted in a national program to eliminate the lead tetraethyl in gasoline. The U.S. Occupational Safety and Health Administration (OSHA) has recommended that industries limit airborne lead to 50 μgms/cu. meter. Lead is priced at about 90¢/kg (99.9%).

Lithium — (Gr. *lithos*, stone), Li; at. wt. 6.941(2); at. no. 3; m.p. 180.5°C; b.p. 1342°C; sp. gr. 0.534 (20°C); valence 1. Discovered by Arfvedson in 1817. Lithium is the lightest of all metals, with a density only about half that of water. It does not occur free in nature; combined it is found in small amounts in nearly all igneous rocks and in the waters of many mineral springs. *Lepidolite, spodumene, petalite,* and *amblygonite* are the more important minerals containing it. Lithium is presently being recovered from brines of Searles Lake, in California, and from Nevada, Chile, and Argentina. Large deposits of spodumene are found in North Carolina. The metal is produced electrolytically from the fused chloride. Lithium is silvery in appearance,

much like Na and K, other members of the alkali metal series. It reacts with water, but not as vigorously as sodium. Lithium imparts a beautiful crimson color to a flame, but when the metal burns strongly the flame is a dazzling white. Since World War II, the production of lithium metal and its compounds has increased greatly. Because the metal has the highest specific heat of any solid element, it has found use in heat transfer applications; however, it is corrosive and requires special handling. The metal has been used as an alloying agent, is of interest in synthesis of organic compounds, and has nuclear applications. It ranks as a leading contender as a battery anode material as it has a high electrochemical potential. Lithium is used in special glasses and ceramics. The glass for the 200-inch telescope at Mt. Palomar contains lithium as a minor ingredient. Lithium chloride is one of the most hygroscopic materials known, and it, as well as lithium bromide, is used in air conditioning and industrial drying systems. Lithium stearate is used as an all-purpose and high-temperature lubricant. Other lithium compounds are used in dry cells and storage batteries. Seven isotopes of lithium are recognized. Natural lithium contains two isotopes. The metal is priced at about $1.50/g (99.9%).

Lutetium — (Lutetia, ancient name for Paris, sometimes called *cassiopeium* by the Germans), Lu; at. wt. 174.967(1); at. no. 71; m.p. 1663°C; b.p. 3402°C; sp. gr. 9.841 (25°C); valence 3. In 1907, Urbain described a process by which Marignac's ytterbium (1879) could be separated into the two elements, ytterbium (neoytterbium)and lutetium. These elements were identical with "aldebaranium" and "cassiopeium," independently discovered by von Welsbach about the same time. Charles James of the University of New Hampshire also independently prepared the very pure oxide, *lutecia*, at this time. The spelling of the element was changed from *lutecium* to *lutetium* in 1949. Lutetium occurs in very small amounts in nearly all minerals containing yttrium, and is present in *monazite* to the extent of about 0.003%, which is a commercial source. The pure metal has been isolated only in recent years and is one of the most difficult to prepare. It can be prepared by the reduction of anhydrous $LuCl_3$ or LuF_3 by an alkali or alkaline earth metal. The metal is silvery white and relatively stable in air. While new techniques, including ion-exchange reactions, have been developed to separate the various rare-earth elements, lutetium is still the most costly of all rare earths. It is priced at about $100/g (99.9%). ^{176}Lu occurs naturally (97.41%) with ^{175}Lu (2.59%), which is radioactive with a very long half-life. It is radioactive with a half-life of about 4×10^{10} years. Lutetium has 50 isotopes and isomers that are now recognized. Stable lutetium nuclides, which emit pure beta radiation after thermal neutron activation, can be used as catalysts in cracking, alkylation, hydrogenation, and polymerization. Virtually no other commercial uses have been found yet for lutetium. While lutetium, like other rare-earth metals, is thought to have a low toxicity rating, it should be handled with care until more information is available.

Magnesium — (*Magnesia*, district in Thessaly) Mg; at. wt. 24.3050(6); at. no. 12; m.p. 650°C; b.p. 1090°C; sp. gr. 1.738 (20°C); valence 2. Compounds of magnesium have long been known. Black recognized magnesium as an element in 1755. It was isolated by Davy in 1808, and prepared in coherent form by Bussy in 1831. Magnesium is the eighth most abundant element in the earth's crust. It does not occur uncombined, but is found in large deposits in the form of *magnesite, dolomite,* and other minerals. The metal is now principally obtained in the U.S. by electrolysis of fused magnesium chloride derived from brines, wells, and sea water. Magnesium is a light, silvery-white, and fairly tough metal. It tarnishes slightly in air, and finely divided magnesium readily ignites upon heating in air and burns with a dazzling white flame. It is used in flashlight photography, flares, and pyrotechnics, including incendiary bombs. It is one third lighter than aluminium, and in alloys is essential for airplane and missile contruction. The metal improves the mechanical, fabrication, and welding characteristics of aluminum when used as an alloying agent. Magnesium is used in producing nodular graphite in cast iron,and is used as an additive to conventional propellants. It is also used as a reducing agent in the production of pure uranium and other metals from their salts. The hydroxide (*milk of magnesia*), chloride, sulfate (*Epsom salts*), and citrate are used in medicine. Dead-burned magnesite is employed for refractory purposes such as brick and liners in furnaces and converters. Calcined magnesia is also used for water treatment and in the manufacture of rubber, paper, etc. Organic magnesium compounds (Grignard's reagents) are important. Magnesium is an important element in both plant and animal life. Chlorophylls are magnesium-centered porphyrins. The adult daily requirement of magnesium is about 300 mg/day, but this is affected by various factors. Great care should be taken in handling magnesium metal, especially in the finely divided state, as serious fires can occur. Water should not be used on burning magnesium or on magnesium fires. Natural magnesium contains three isotopes. Twelve other isotopes are recognized. Magnesium metal costs about $1.70/kg (99.8%).

Manganese — (L. *magnes*, magnet, from magnetic properties of pyrolusite; It. *manganese*, corrupt form of *magnesia*), Mn; at. wt. 54.938049(9); at. no. 25; m.p. 1246°C; b.p. 2061°C; sp. gr. 7.21 to 7.44, depending on allotropic form; valence 1, 2, 3, 4, 6, or 7. Recognized by Scheele, Bergman, and others as an element and isolated by Gahn in 1774 by reduction of the dioxide with carbon. Manganese minerals are widely distributed; oxides, silicates, and carbonates are the most common. The discovery of large quantities of manganese nodules on the floor of the oceans holds promise as a source of manganese. These nodules contain about 24% manganese together with many other elements in lesser abundance. Most manganese today is obtained from ores found in the Ukraine, Brazil, Australia, Republic of So. Africa, Gabon, China, and India. *Pyrolusite* (MnO_2) and *rhodochrosite* ($MnCO_3$) are among the most common manganese minerals. The metal is obtained by reduction of the oxide with sodium, magnesium, aluminum, or by electrolysis. It is gray-white, resembling iron, but is harder and very brittle. The metal is reactive chemically, and decomposes cold water slowly. Manganese is used to form many important alloys. In steel, manganese improves the rolling and forging qualities, strength, toughness, stiffness, wear resistance, hardness, and hardenability. With aluminum and antimony, especially with small amounts of copper, it forms highly ferromagnetic alloys. Manganese metal is ferromagnetic only after special treatment. The pure metal exists in four allotropic forms. The alpha form is stable at ordinary temperature; gamma manganese, which changes to alpha at ordinary temperatures, is said to be flexible, soft, easily cut, and capable of being bent. The dioxide (pyrolusite) is used as a depolarizer in dry cells, and is used to "decolorize" glass that is colored green by impurities of iron. Manganese by itself colors glass an amethyst color, and is responsible for the color of true amethyst. The dioxide is also used in the preparation of oxygen and chlorine, and in drying black paints. The permanganate is a powerful oxidizing agent and is used in quantitative analysis and in medicine. Manganese is widely distributed throughout the animal kingdom. It is an important trace element and may be essential for utilization of vitamin B_1. Twenty-seven isotopes and isomers are known. Manganese metal (99.95%) is priced at about $400/kg. Metal of 99.6% purity is priced at about $60/kg.

Meitnerium — (named for Lise Meitner [1878–1968], Austrian-Swedish physicist and mathematician), Mt; at. wt [266]; at. no. 109. On August 29, 1992, Element 109 was made and identified by physicists at the Heavy Ion Research Laboratory (G.S.I.), Darmstadt, Germany, by bombarding a target of ^{209}Bi with accelerated nuclei of ^{58}Fe. The production of Element 109 has been extremely small. It took a week of target bombardment (10^{11} nuclear encounters) to produce a single atom of 109. Oganessian and his team at Dubna in 1994 repeated the Darmstadt experiment using a tenfold irradiation dose. One fission event from seven alpha decays of 109 was observed, thus indirectly confirming the existence of isotope ^{266}109. In August 1997, the IUPAC adopted the name *meitnerium* for this element, honoring L. Meitner. Four isotopes of *meitnerium* are now recognized.

Mendelevium — (Dmitri Mendeleev [1834–1907]), Md; at. wt. (258); at. no. 101; m.p. 827°C; valence +2, +3. Mendelevium, the ninth transuranium element of the actinide series to be discovered, was first identified by Ghiorso, Harvey, Choppin, Thompson, and Seaborg early in 1955

as a result of the bombardment of the isotope ^{253}Es with helium ions in the Berkeley 60-inch cyclotron. The isotope produced was ^{256}Md, which has a half-life of 78 min. This first identification was notable in that ^{256}Md was synthesized on a one-atom-at-a-time basis. Nineteen isotopes and isomers are now recognized. ^{258}Md has a half-life of 51.5 days. This isotope has been produced by the bombardment of an isotope of einsteinium with ions of helium. It now appears possible that eventually enough ^{258}Md can be made so that some of its physical properties can be determined. ^{256}Md has been used to elucidate some of the chemical properties of mendelevium in aqueous solution. Experiments seem to show that the element possesses a moderately stable dipositive (II) oxidation state in addition to the tripositive (III) oxidation state,which is characteristic of actinide elements.

Mercury — (Planet *Mercury*), Hg (*hydrargyrum*, liquid silver); at. wt. 200.59(2); at. no. 80; t.p. –38.83°C; b.p. 356.73°C; t_c 1447°C; sp. gr. 13.546 (20°C); valence 1 or 2. Known to ancient Chinese and Hindus; found in Egyptian tombs of 1500 B.C. Mercury is the only common metal liquid at ordinary temperatures. It only rarely occurs free in nature. The chief ore is *cinnabar* (HgS). Spain and China produce about 75% of the world’s supply of the metal. The commercial unit for handling mercury is the “flask,” which weighs 76 lb (34.46 kg). The metal is obtained by heating cinnabar in a current of air and by condensing the vapor. It is a heavy, silvery-white metal; a rather poor conductor of heat, as compared with other metals, and a fair conductor of electricity. It easily forms alloys with many metals, such as gold, silver, and tin, which are called *amalgams*. Its ease in amalgamating with gold is made use of in the recovery of gold from its ores. The metal is widely used in laboratory work for making thermometers, barometers, diffusion pumps, and many other instruments. It is used in making mercury-vapor lamps and advertising signs, etc. and is used in mercury switches and other electrical apparatus. Other uses are in making pesticides, mercury cells for caustic soda and chlorine production, dental preparations, antifouling paint, batteries, and catalysts. The most important salts are mercuric chloride $HgCl_2$ (corrosive sublimate — a violent poison), mercurous chloride Hg_2Cl_2(calomel, occasionally still used in medicine), mercury fulminate ($Hg(ONC)_2$), a detonator widely used in explosives, and mercuric sulfide (HgS, vermillion, a high-grade paint pigment). Organic mercury compounds are important. It has been found that an electrical discharge causes mercury vapor to combine with neon, argon, krypton, and xenon. These products, held together with van der Waals’ forces, correspond to HgNe, HgAr, HgKr, and HgXe. Mercury is a virulent poison and is readily absorbed through the respiratory tract, the gastrointestinal tract, or through unbroken skin. It acts as a cumulative poison and dangerous levels are readily attained in air. Air saturated with mercury vapor at 20°C contains a concentration that exceeds the toxic limit many times. The danger increases at higher temperatures. *It is therefore important that mercury be handled with care.* Containers of mercury should be securely covered and spillage should be avoided. If it is necessary to heat mercury or mercury compounds, it should be done in a well-ventilated hood. Methyl mercury is a dangerous pollutant and is now widely found in water and streams. The triple point of mercury, –38.8344°C, is a fixed point on the International Temperature Scale (ITS-90). Mercury (99.98%) is priced at about $110/kg. Native mercury contains seven isotopes. Thirty-six other isotopes and isomers are known.

Molybdenum — (Gr. *molybdos*, lead), Mo; at. wt. 95.94(1); at. no. 42; m.p. 2623°C; b.p. 4639°C; sp. gr. 10.22 (20°C); valence 2, 3, 4?, 5?, or 6. Before Scheele recognized molybdenite as a distinct ore of a new element in 1778, it was confused with graphite and lead ore. The metal was prepared in an impure form in 1782 by Hjelm. Molybdenum does not occur native, but is obtained principally from *molybdenite* (MoS_2). *Wulfenite* ($PbMoO_4$) and *powellite* ($Ca(MoW)O_4$) are also minor commercial ores. Molybdenum is also recovered as a by-product of copper and tungsten mining operations. The U.S., Canada, Chile, and China produce most of the world’s molybdenum ores. The metal is prepared from the powder made by the hydrogen reduction of purified molybdic trioxide or ammonium molybdate. The metal is silvery white, very hard, but is softer and more ductile than tungsten. It has a high elastic modulus, and only tungsten and tantalum, of the more readily available metals, have higher melting points. It is a valuable alloying agent, as it contributes to the hardenability and toughness of quenched and tempered steels. It also improves the strength of steel at high temperatures. It is used in certain nickel-based alloys, such as the “Hastelloys®” which are heat-resistant and corrosion-resistant to chemical solutions. Molybdenum oxidizes at elevated temperatures. The metal has found recent application as electrodes for electrically heated glass furnaces and forehearths. The metal is also used in nuclear energy applications and for missile and aircraft parts. Molybdenum is valuable as a catalyst in the refining of petroleum. It has found application as a filament material in electronic and electrical applications. Molybdenum is an essential trace element in plant nutrition. Some lands are barren for lack of this element in the soil. Molybdenum sulfide is useful as a lubricant, especially at high temperatures where oils would decompose. Almost all ultra-high strength steels with minimum yield points up to 300,000 psi(lb/in.^{2}) contain molybdenum in amounts from 0.25 to 8%. Natural molybdenum contains seven isotopes. Thirty other isotopes and isomers are known, all of which are radioactive. Molybdenum metal costs about $1/g (99.999% purity). Commercial molybdenum metal (99.9%) costs about $300/kg.

Neodymium — (Gr. *neos*, new, and *didymos*, twin), Nd; at. wt. 144.24(3); at. no. 60; m.p. 1021°C; b.p. 3074°C; sp. gr. 7.008 (25°C); valence 3. In 1841, Mosander, extracted from *cerite* a new rose-colored oxide, which he believed contained a new element. He named the element *didymium*, as it was *an inseparable twin brother of lanthanum*. In 1885 von Welsbach separated didymium into two new elemental components, *neodymia* and *praseodymia*, by repeated fractionation of ammonium didymium nitrate. While the free metal is in *misch metal*, long known and used as a pyrophoric alloy for light flints, the element was not isolated in relatively pure form until 1925. Neodymium is present in misch metal to the extent of about 18%. It is present in the minerals *monazite* and *bastnasite*, which are principal sources of rare-earth metals. The element may be obtained by separating neodymium salts from other rare earths by ion-exchange or solvent extraction techniques, and by reducing anhydrous halides such as NdF_3 with calcium metal. Other separation techniques are possible. The metal has a bright silvery metallic luster. Neodymium is one of the more reactive rare-earth metals and quickly tarnishes in air, forming an oxide that spalls off and exposes metal to oxidation. The metal, therefore, should be kept under light mineral oil or sealed in a plastic material. Neodymium exists in two allotropic forms, with a transformation from a double hexagonal to a body-centered cubic structure taking place at 863°C. Natural neodymium is a mixture of seven isotopes, one of which has a very long half-life. Twenty seven other radioactive isotopes and isomers are recognized. Didymium, of which neodymium is a component, is used for coloring glass to make welder’s goggles. By itself, neodymium colors glass delicate shades ranging from pure violet through wine-red and warm gray. Light transmitted through such glass shows unusually sharp absorption bands. The glass has been used in astronomical work to produce sharp bands by which spectral lines may be calibrated. Glass containing neodymium can be used as a laser material to produce coherent light. Neodymium salts are also used as a colorant for enamels. The element is also being used with iron and boron to produce extremely strong magnets having energy densities as high as 27 to 35 million gauss oersteds. These are the most compact magnets commercially available. The price of the metal is about $4/g. Neodymium has a low-to-moderate acute toxic rating. As with other rare earths, neodymium should be handled with care.

Neon — (Gr. *neos*, new), Ne; at. wt. 20.1797(6); at. no. 10; t.p. –248.59°C; b.p. –246.08°C; t_c -228.7°C (1 atm); density of gas 0.89990 g/l (1 atm, 0°C); density of liquid at b.p. 1.207 g/cm^3; valence 0. Discovered by Ramsay and Travers in 1898. Neon is a rare gaseous element present in the atmosphere to the extent of 1 part in 65,000 of air. It is obtained by liquefaction of air and separated from the other gases by fractional distillation. Natural

neon is a mixture of three isotopes. Fourteen other unstable isotopes are known. It is very inert element; however, it is said to form a compound with fluorine. It is still questionable if true compounds of neon exist, but evidence is mounting in favor of their existence. The following ions are known from optical and mass spectrometric studies: Ne^+, $(NeAr)^+$, $(NeH)^+$, and $(HeNe^+)$. Neon also forms an unstable hydrate. In a vacuum discharge tube, neon glows reddish orange. Of all the rare gases, the discharge of neon is the most intense at ordinary voltages and currents. Neon is used in making the common neon advertising signs, which accounts for its largest use. It is also used to make high-voltage indicators, lightning arrestors, wave meter tubes, and TV tubes. Neon and helium are used in making gas lasers. Liquid neon is now commercially available and is finding important application as an economical cryogenic refrigerant. It has over 40 times more refrigerating capacity per unit volume than liquid helium and more than three times that of liquid hydrogen. It is compact, inert, and is less expensive than helium when it meets refrigeration requirements. Neon costs about $800/80 cu. ft. (2265 l).

Neptunium — (Planet *Neptune*), Np; at. wt. (237); at. no. 93; m.p. 644°C; sp. gr. 20.25 (20°C); valence 3, 4, 5, and 6. Neptunium was the first synthetic transuranium element of the actinide series discovered; the isotope ^{239}Np was produced by McMillan and Abelson in 1940 at Berkeley, California, as the result of bombarding uranium with cyclotron-produced neutrons. The isotope ^{237}Np (half-life of 2.14×10^6 years) is currently obtained in gram quantities as a by-product from nuclear reactors in the production of plutonium. Twenty-three isotopes and isomers of neptunium are now recognized. Trace quantities of the element are actually found in nature due to transmutation reactions in uranium ores produced by the neutrons which are present. Neptunium is prepared by the reduction of NpF_3 with barium or lithium vapor at about 1200°C. Neptunium metal has a silvery appearance, is chemically reactive, and exists in at least three structural modifications: α-neptunium, orthorhombic, density 20.25 g/cm^3, β-neptunium (above 280°C), tetragonal, density (313°C) 19.36 g/cm^3; γ-neptunium (above 577°C), cubic, density (600°C) 18.0 g/cm^3. Neptunium has four ionic oxidation states in solution: Np^{+3} (pale purple), analogous to the rare earth ion Pm^{+3}, Np^{+4} (yellow green); NpO^+ (green blue); and NpO^{++} (pale pink). These latter oxygenated species are in contrast to the rare earths which exhibit only simple ions of the (II), (III), and (IV) oxidation states in aqueous solution. The element forms tri- and tetrahalides such as NpF_3, NpF_4, $NpCl_4$, $NpBr_3$, NpI_3, and oxides of various compositions such as are found in the uranium-oxygen system, including Np_3O_8 and NpO_2.

Nickel — (Ger. *Nickel*, Satan or Old Nick's and from *kupfernickel*, Old Nick's copper), Ni; at. wt. 58.6934(2); at. no. 28; m.p. 1455°C; b.p. 2913°C; sp. gr. 8.902 (25°C); valence 0, 1, 2, 3. Discovered by Cronstedt in 1751 in kupfernickel (*niccolite*). Nickel is found as a constituent in most meteorites and often serves as one of the criteria for distinguishing a meteorite from other minerals. Iron meteorites, or *siderites*, may contain iron alloyed with from 5 to nearly 20% nickel. Nickel is obtained commercially from *pentlandite* and *pyrrhotite* of the Sudbury region of Ontario, a district that produces much of the world's nickel. It is now thought that the Sudbury deposit is the result of an ancient meteorite impact. Large deposits of nickel, cobalt, and copper have recently been developed at Voisey's Bay, Laborador. Other deposits of nickel are found in Russia, New Caledonia, Australia, Cuba, Indonesia, and elsewhere. Nickel is silvery white and takes on a high polish. It is hard, malleable, ductile, somewhat ferromagnetic, and a fair conductor of heat and electricity. It belongs to the iron-cobalt group of metals and is chiefly valuable for the alloys it forms. It is extensively used for making stainless steel and other corrosion-resistant alloys such as Invar®, Monel®, Inconel®, and the Hastelloys®. Tubing made of a copper-nickel alloy is extensively used in making desalination plants for converting sea water into fresh water. Nickel is also now used extensively in coinage and in making nickel steel for armor plate and burglar-proof vaults, and is a component in Nichrome®, Permalloy®, and constantan. Nickel added to glass gives a green color. Nickel plating is often used to provide a protective coating for other metals, and finely divided nickel is a catalyst for hydrogenating vegetable oils. It is also used in ceramics, in the manufacture of Alnico magnets, and in the Edison® storage battery. The sulfate and the oxides are important compounds. Natural nickel is a mixture of five stable isotopes; twenty-five other unstable isotopes are known. Nickel sulfide fume and dust is recognized as having carcinogenic potential. Nickel metal (99.9%) is priced at about $1.25/g or less in larger quantities.

Nielsbohrium — See Bohrium.

Niobium — (*Niobe*, daughter of Tantalus), Nb; or Columbium (*Columbia*, name for America); at. wt. 92.90638(2); at. no. 41; m.p. 2477°C; b.p. 4744°C, sp. gr. 8.57 (20°C); valence 2, 3, 4?, 5. Discovered in 1801 by Hatchett in an ore sent to England more that a century before by John Winthrop the Younger, first governor of Connecticut. The metal was first prepared in 1864 by Blomstrand, who reduced the chloride by heating it in a hydrogen atmosphere. The name *niobium* was adopted by the International Union of Pure and Applied Chemistry in 1950 after 100 years of controversy. Many leading chemical societies and government organizations refer to it by this name. Most metallurgists, leading metal societies, and all but one of the leading U.S. commercial producers, however, still refer to the metal as "columbium". The element is found in *niobite*(or *columbite), niobite-tantalite, pyrochlore,* and *euxenite*. Large deposits of niobium have been found associated with *carbonatites* (carbon-silicate rocks), as a constituent of *pyrochlore*. Extensive ore reserves are found in Canada, Brazil, Congo-Kinshasa, Rwanda, and Australia. The metal can be isolated from tantalum, and prepared in several ways. It is a shiny, white, soft, and ductile metal, and takes on a bluish cast when exposed to air at room temperatures for a long time. The metal starts to oxidize in air at 200°C, and when processed at even moderate temperatures must be placed in a protective atmosphere. It is used in arc-welding rods for stabilized grades of stainless steel. Thousands of pounds of niobium have been used in advance air frame systems such as were used in the Gemini space program. It has also found use in super-alloys for applications such as jet engine components, rocket subassemblies, and heat-resisting equipment. The element has superconductive properties; superconductive magnets have been made with Nb-Zr wire, which retains its superconductivity in strong magnetic fields. This type of application offers hope of direct large-scale generation of electric power. Natural niobium is composed of only one isotope, ^{93}Nb. Forty-seven other isotopes and isomers of niobium are now recognized. Niobium metal (99.9% pure) is priced at about 50¢/g.

Nitrogen — (L. *nitrum*, Gr. *nitron*, native soda; genes, *forming*, N; at. wt. 14.00674(7); at. no. 7; m.p. –210.00°C; b.p. –198.79°C; t_c -146.94°C; density 1.2506 g/l; sp. gr. liquid 0.808 (–195.8°C), solid 1.026 (–252°C); valence 3 or 5. Discovered by Daniel Rutherford in 1772, but Scheele, Cavendish,Priestley, and others about the same time studied "burnt or dephlogisticated air," as air without oxygen was then called. Nitrogen makes up 78% of the air, by volume. The atmosphere of Mars, by comparison, is 2.6% nitrogen. The estimated amount of this element in our atmosphere is more than 4000 trillion tons. From this inexhaustible source it can be obtained by liquefaction and fractional distillation. Nitrogen molecules give the orange-red, blue-green, blue-violet, and deep violet shades to the aurora.The element is so inert that Lavoisier named it *azote*, meaning without life, yet its compounds are so active as to be most important in foods, poisons, fertilizers, and explosives. Nitrogen can be also easily prepared by heating a water solution of ammonium nitrite. Nitrogen, as a gas, is colorless, odorless, and a generally inert element. As a liquid it is also colorless and odorless, and is similar in appearance to water. Two allotropic forms of solid nitrogen exist, with the transition from the α to the β form taking place at –237°C. When nitrogen is heated, it combines directly with magnesium, lithium, or calcium; when mixed with oxygen and subjected to electric sparks, it forms

first nitric oxide (NO) and then the dioxide (NO_2); when heated under pressure with a catalyst with hydrogen, ammonia is formed (Haber process). The ammonia thus formed is of the utmost importance as it is used in fertilizers, and it can be oxidized to nitric acid (Ostwald process). The ammonia industryis the largest consumer of nitrogen. Large amounts of gas are also used by the electronics industry, which uses the gas as a blanketing medium during production of such components as transistors, diodes, etc. Large quantities of nitrogen are used in annealing stainless steel and other steel mill products. The drug industry also uses large quantities. Nitrogen is used as a refrigerant both for the immersion freezing of food products and for transportation of foods. Liquid nitrogen is also used in missile work as a purge for components, insulators for space chambers, etc., and by the oil industry to build up great pressures in wells to force crude oil upward. Sodium and potassium nitrates are formed by the decomposition of organic matter with compounds of the metals present. In certain dry areas of the world these saltpeters are found in quantity. Ammonia, nitric acid, the nitrates, the five oxides (N_2O, NO, N_2O_3, NO_2, and N_2O_5), TNT, the cyanides, etc. are but a few of the important compounds. Nitrogen gas prices vary from 2¢ to $2.75 per 100 ft^3 (2.83 cu. meters), depending on purity, etc. Production of elemental nitrogen in the U.S. is more than 9 million short tons per year. Natural nitrogen contains two isotopes, ^{14}N and ^{15}N. Ten other isotopes are known.

Nobelium — (Alfred Nobel, discoverer of dynamite), No; at. wt. [259]; at. no. 102; valence +2, +3. Nobelium was unambiguously discovered and identified in April 1958 at Berkeley by A. Ghiorso, T. Sikkeland, J. R. Walton, and G. T. Seaborg, who used a new double-recoil technique. A heavy-ion linear accelerator (HILAC) was used to bombard a thin target of curium (95% ^{244}Cm and 4.5% ^{246}Cm) with ^{12}C ions to produce 102^{254} according to the ^{246}Cm (^{12}C, 4*n*) reaction. Earlier in 1957 workers of the U.S., Britain, and Sweden announced the discovery of an isotope of Element 102 with a 10-min half-life at 8.5 MeV, as a result of bombarding ^{244}Cm with ^{13}C nuclei. On the basis of this experiment the name *nobelium* was assigned and accepted by the Commission on Atomic Weights of the International Union of Pure and Applied Chemistry. The acceptance of the name was premature, for both Russian and American efforts now completely rule out the possibility of any isotope of Element 102 having a half-life of 10 min in the vicinity of 8.5 MeV. Early work in 1957 on the search for this element, in Russia at the Kurchatov Institute, was marred by the assignment of 8.9 ± 0.4 MeV alpha radiation with a half-life of 2 to 40 sec, which was too indefinite to support claim to discovery. Confirmatory experiments at Berkeley in 1966 have shown the existence of $^{254}102$ with a 55-s half-life, $^{252}102$ with a 2.3-s half-life, and $^{257}102$ with a 25-s half-life. Twelve isotopes are now recognized, one of which — $^{255}102$ has a half-life of 3.1 min. In view of the discover's traditional right to name an element, the Berkeley group, in 1967, suggested that the hastily given name *nobelium,* along with the symbol No, be retained.

Osmium — (Gr. *osme*, a smell), Os; at. wt. 190.23(3); at. no. 76; m.p. 3033°C; b.p. 5012°C; sp. gr. 22.57; valence 0 to +8, more usually +3, +4, +6, and +8. Discovered in 1803 by Tennant in the residue left when crude platinum is dissolved by *aqua regia.* Osmium occurs in *iridosmine* and in platinum-bearing river sands of the Urals, North America, and South America. It is also found in the nickel-bearing ores of Sudbury, Ontario, region along with other platinum metals. While the quantity of platinum metals in these ores is very small, the large tonnages of nickel ores processed make commercial recovery possible. The metal is lustrous, bluish white, extremely hard, and brittle even at high temperatures. It has the highest melting point and the lowest vapor pressure of the platinum group. The metal is very difficult to fabricate, but the powder can be sintered in a hydrogen atmosphere at a temperature of 2000°C. The solid metal is not affected by air at room temperature, but the powdered or spongy metal slowly gives off osmium tetroxide, which is a powerful oxidizing agent and has a strong smell. The tetroxide is highly toxic, and boils at 130°C (760 mm). Concentrations in air as low as 10^{-7} g/m^3 can cause lung congestion, skin damage, or eye damage. The tetroxide has been used to detect fingerprints and to stain fatty tissue for microscope slides. The metal is almost entirely used to produce very hard alloys, with other metals of the platinum group, for fountain pen tips, instrument pivots, phonograph needles, and electrical contacts. The price of 99.9% pure osmium powder — the form usually supplied commercially — is about $100/g, depending on quantity and supplier. Natural osmium contains seven isotopes, one of which, ^{186}Os, is radioactive with a very long half-life. Thirty four other isotopes and isomers are known, all of which are radioactive.The measured densities of iridium and osmium seem to indicate that osmium is slightly more dense than iridium, so osmium has generally been credited with being the heaviest known element. Calculations of the density from the space lattice, which may be more reliable for these elements than actual measurements, however, give a density of 22.65 for iridium compared to 226.61 for osmium. At present, therefore, we know either iridium or osmium is the heaviest element, but the data do not allow selection between the two.

Oxygen — (Gr. *oxys*, sharp, acid, and *genes*, forming; acid former), O; at. wt. 15.9994(3); at. no. 8; t.p. –218.79°C; t_c -118.56°C; valence 2. For many centuries, workers occasionally realized air was composed of more than one component. The behavior of oxygen and nitrogen as components of air led to the advancement of the phlogiston theory of combustion, which captured the minds of chemists for a century. Oxygen was prepared by several workers, including Bayen and Borch, but they did not know how to collect it, did not study its properties, and did not recognize it as an elementary substance. Priestley is generally credited with its discovery, although Scheele also discovered it independently. Oxygen is the third most abundant element found in the sun, and it plays a part in the carbon-nitrogen cycle, one process thought to give the sun and stars their energy. Oxygen under excited conditions is responsible for the bright red and yellow-green colors of the aurora. Oxygen, as a gaseous element, forms 21% of the atmosphere by volume from which it can be obtained by liquefaction and fractional distillation. The atmosphere of Mars contains about 0.15% oxygen. The element and its compounds make up 49.2%, by weight, of the earth's crust. About two thirds of the human body and nine tenths of water is oxygen. In the laboratory it can be prepared by the electrolysis of water or by heating potassium chlorate with manganese dioxide as a catalyst. The gas is colorless, odorless, and tasteless. The liquid and solid forms are a pale blue color and are strongly paramagnetic. Ozone (O_3), a highly active compound, is formed by the action of an electrical discharge or ultraviolet light on oxygen. Ozone's presence in the atmosphere (amounting to the equivalent of a layer 3 mm thick at ordinary pressures and temperatures) is of vital importance in preventing harmful ultraviolet rays of the sun from reaching the earth's surface. There has been recent concern that pollutants in the atmosphere may have a detrimental effect on this ozone layer. Ozone is toxic and exposure should not exceed 0.2 mg/m^3 (8-hour time-weighted average — 40-hour work week). Undiluted ozone has a bluish color. Liquid ozone is bluish black, and solid ozone is violet-black. Oxygen is very reactive and capable of combining with most elements. It is a component of hundreds of thousands of organic compounds. It is essential for respiration of all plants and animals and for practically all combustion. In hospitals it is frequently used to aid respiration of patients. Its atomic weight was used as a standard of comparison for each of the other elements until 1961 when the International Union of Pure and Applied Chemistry adopted carbon 12 as the new basis. Oxygen has thirteen recognized isotopes. Natural oxygen is a mixture of three isotopes. Oxygen 18 occurs naturally, is stable, and is available commercially. Water (H_2O with 1.5% ^{18}O) is also available. Commercial oxygen consumption in the U.S. is estimated to be 20 million short tons per year and the demand is expected to increase substantially in the next few years. Oxygen enrichment of steel blast furnaces accounts for the greatest use of the gas. Large quantities are also used in making synthesis gas for ammonia and methanol, ethylene oxide, and for oxy-acetylene welding. Air separation plants produce about 99% of the gas, electrolysis plants about 1%. The gas costs 5¢/ft^3 ($1.75/cu. meters) in small quantities.

Palladium — (named after the asteroid *Pallas*, discovered about the same time; Gr. *Pallas*, goddess of wisdom), Pd. at. wt. 106.42(1) at. no. 46; m.p. 1554.9°C; b.p. 2963°C; sp. gr. 12.02 (20°C); valence 2, 3, or 4. Discovered in 1803 by Wollaston. Palladium is found along with platinum and other metals of the platinum group in deposits of Russia, South Africa, Canada (Ontario), and elsewhere. Natural palladium contains six stable isotopes. Twenty-nine other isotopes are recognized, all of which are radioactive. It is frequently found associated with the nickel-copper deposits such as those found in Ontario. Its separation from the platinum metals depends upon the type of ore in which it is found. It is a steel-white metal, does not tarnish in air, and is the least dense and lowest melting of the platinum group of metals. When annealed, it is soft and ductile; cold working greatly increases its strength and hardness. Palladium is attacked by nitric and sulfuric acid. At room temperatures the metal has the unusual property of absorbing up to 900 times its own volume of hydrogen, possibly forming Pd_2H. It is not yet clear if this a true compound. Hydrogen readily diffuses through heated palladium and this provides a means of purifying the gas. Finely divided palladium is a good catalyst and is used for hydrogenation and dehydrogenation reactions. It is alloyed and used in jewelry trades. White gold is an alloy of gold decolorized by the addition of palladium. Like gold, palladium can be beaten into leaf as thin as 1/250,000 in. The metal is used in dentistry, watchmaking, and in making surgical instruments and electrical contacts. Palladium recently has been substituted for higher priced platinum in catalytic converters by some automobile companies. This has caused a large increase in the cost of palladium. The price of the two metals are now, in 1999, about the same. Palladium, however, is less resistant to poisoning by sulfur and lead, than platinum, but it may prove useful in controlling emissions from diesel vehicles. The metal sells for about $425/tr. oz. ($13/g).

Phosphorus — (Gr. *phosphoros*, light bearing; ancient name for the planet Venus when appearing before sunrise), P; at. wt. 30.973762(4); at. no. 15; m.p. (white) 44.15°C; b.p. 280.5°C; sp. gr. (white) 1.82 (red) 2.20, (black) 2.25 to 2.69; valence 3 or 5. Discovered in 1669 by Brand, who prepared it from urine. Phosphorus exists in four or more allotropic forms: white (or yellow), red, and black (or violet). White phosphorus has two modifications: α and β with a transition temperature at –3.8°C. Never found free in nature, it is widely distributed in combination with minerals. Twenty-one isotopes of phosphorus are recognized. *Phosphate* rock, which contains the mineral *apatite*, an impure tri-calcium phosphate, is an important source of the element. Large deposits are found in the Russia,China, Morocco, and in Florida, Tennessee, Utah, Idaho, and elsewhere. Phosphorus in an essential ingredient of all cell protoplasm, nervous tissue, and bones. Ordinary phosphorus is a waxy white solid; when pure it is colorless and transparent. It is insoluble in water, but soluble in carbon disulfide. It takes fire spontaneously in air, burning to the pentoxide. It is very poisonous, 50 mg constituting an approximate fatal dose. Exposure to white phosphorus should not exceed 0.1 mg/m^3 (8-hour time-weighted average — 40-hour work week). White phosphorus should be kept under water, as it is dangerously reactive in air, and it should be handled with forceps, as contact with the skin may cause severe burns. When exposed to sunlight or when heated in its own vapor to 250°C, it is converted to the red variety, which does not phosphoresce in air as does the white variety. This form does not ignite spontaneously and it is not as dangerous as white phosphorus. It should, however, be handled with care as it does convert to the white form at some temperatures and it emits highly toxic fumes of the oxides of phosphorus when heated. The red modification is fairly stable, sublimes with a vapor pressure of 1 atm at 417°C,and is used in the manufacture of safety matches, pyrotechnics, pesticides, incendiary shells, smoke bombs, tracer bullets, etc. White phosphorus may be made by several methods. By one process, tri-calcium phosphate, the essential ingredient of phosphate rock, is heated in the presence of carbon and silica in an electric furnace or fuel-fired furnace. Elementary phosphorus is liberated as vapor and may be collected under water. If desired, the phosphorus vapor and carbon monoxide produced by the reaction can be oxidized at once in the presence of moisture to produce phosphoric acid, an important compound in making super-phosphate fertilizers. In recent years, concentrated phosphoric acids, which may contain as much as 70 to 75% P_2O_5 content, have become of great importance to agriculture and farm production. World-wide demand for fertilizers has caused record phosphate production. Phosphates are used in the production of special glasses, such as those used for sodium lamps. Bone-ash, calcium phosphate, is also used to produce fine chinaware and to produce mono-calcium phosphate used in baking powder. Phosphorus is also important in the production of steels, phosphor bronze, and many other products. Trisodium phosphate is important as a cleaning agent, as a water softener, and for preventing boiler scale and corrosion of pipes and boiler tubes. Organic compounds of phosphorus are important. Amorphous (red) phosphorus costs about $80/kg (99.5%).

Platinum — (It. *platina*, silver), Pt; at. wt. 195.078(2); at. no. 78; m.p. 1768.4°C; b.p. 3825°C; sp. gr. 21.45 (20°C); valence 1?, 2, 3, or 4. Discovered in South America by Ulloa in 1735 and by Wood in 1741. The metal was used by pre-Columbian Indians. Platinum occurs native, accompanied by small quantities of iridium, osmium, palladium, ruthenium, and rhodium, all belonging to the same group of metals. These are found in the alluvial deposits of the Ural mountains and in Columbia. *Sperrylite* ($PtAs_2$), occurring with the nickel-bearing deposits of Sudbury, Ontario, is a source of a considerable amount of metal. The large production of nickel offsets there being only one part of the platinum metals in two million parts of ore. The largest supplier of the platinum group of metals is now South Africa, followed by Russia and Canada. Platinum is a beautiful silvery-white metal, when pure, and is malleable and ductile. It has a coefficient of expansion almost equal to that of soda-lime-silica glass, and is therefore used to make sealed electrodes in glass systems. The metal does not oxidize in air at any temperature, but is corroded by halogens, cyanides, sulfur, and caustic alkalis. It is insoluble in hydrochloric and nitric acid, but dissolves when they are mixed as *aqua regia*, forming chloroplatinic acid (H_2PtCl_6), an important compound. Natural platinum contains six isotopes, one of which, ^{190}Pt, is radioactive with a long half-life. Thirty-seven other radioactive isotopes and isomers are recognized. The metal is extensively used in jewelry, wire, and vessels for laboratory use, and in many valuable instruments including thermocouple elements. It is also used for electrical contacts, corrosion-resistant apparatus, and in dentistry. Platinum-cobalt alloys have magnetic properties. One such alloy made of 76.7% Pt and 23.3% Co, by weight, is an extremely powerful magnet that offers a B-H (max) almost twice that of Alnico V. Platinum resistance wires are used for constructing high-temperature electric furnaces. The metal is used for coating missile nose cones, jet engine fuel nozzles, etc., which must perform reliably for long periods of time at high temperatures. The metal, like palladium, absorbs large volumes, of hydrogen, retaining it at ordinary temperatures but giving it up at red heat. In the finely divided state platinum is an excellent catalyst, having long been used in the contact process for producing sulfuric acid. It is also used as a catalyst in cracking petroleum products. There is also much current interest in the use of platinum as a catalyst in fuel cells and in its use as antipollution devices for automobiles. Platinum anodes are extensively used in cathodic protection systems for large ships and ocean-going vessels, pipelines, steel piers, etc. Pure platinum wire will glow red hot when placed in the vapor of methyl alcohol. It acts here as a catalyst, converting the alcohol to formaldehyde. This phenomenon has been used commercially to produce cigarette lighters and hand warmers. Hydrogen and oxygen explode in the presence of platinum. The price of platinum has varied widely; more than a century ago it was used to adulterate gold. It was nearly eight times as valuable as gold in 1920. The price in December 1999 was about $460/troy oz. ($15/g), somewhat higher than the price of gold.

Plutonium — (Planet *pluto*), Pu; at. wt. (244); at. no. 94; sp. gr. (α modification) 19.84 (25°C); m.p. 640°C; b.p. 3228°C; valence 3, 4, 5, or 6. Plutonium was the second transuranium element of the actinide series to be discovered. The isotope ^{238}Pu was produced in 1940 by Seaborg, McMillan,

Kennedy, and Wahl by deuteron bombardment of uranium in the 60-inch cyclotron at Berkeley, California. Plutonium also exists in trace quantities in naturally occurring uranium ores. It is formed in much the same manner as neptunium, by irradiation of natural uranium with the neutrons which are present. By far of greatest importance is the isotope Pu^{239}, with a half-life of 24,100 years, produced in extensive quantities in nuclear reactors from natural uranium:

$$^{238}U(n,\gamma)\rightarrow {}^{239}U\xrightarrow{\beta}{}^{239}Np\xrightarrow{\beta}{}^{239}Pu$$

Nineteen isotopes of plutonium are now known. Plutonium has assumed the position of dominant importance among the transuranium elements because of its successful use as an explosive ingredient in nuclear weapons and the place which it holds as a key material in the development of industrial use of nuclear power. One kilogram is equivalent to about 22 million kilowatt hours of heat energy. The complete detonation of a kilogram of plutonium produces an explosion equal to about 20,000 tons of chemical explosive. Its importance depends on the nuclear property of being readily fissionable with neutrons and its availability in quantity. The world's nuclear-power reactors are now producing about 20,000 kg of plutonium/yr. By 1982 it was estimated that about 300,000 kg had accumulated. The various nuclear applications of plutonium are well known. ^{238}Pu has been used in the Apollo lunar missions to power seismic and other equipment on the lunar surface. As with neptunium and uranium, plutonium metal can be prepared by reduction of the trifluoride with alkaline-earth metals. The metal has a silvery appearance and takes on a yellow tarnish when slightly oxidized. It is chemically reactive. A relatively large piece of plutonium is warm to the touch because of the energy given off in alpha decay. Larger pieces will produce enough heat to boil water. The metal readily dissolves in concentrated hydrochloric acid, hydroiodic acid, or perchloric acid with formation of the Pu^{+3} ion. The metal exhibits six allotropic modifications having various crystalline structures. The densities of these vary from 16.00 to 19.86 g/cm^3. Plutonium also exhibits four ionic valence states in aqueous solutions: Pu^{+3}(blue lavender), Pu^{+4} (yellow brown), PuO^+ (pink?), and PuO^{+2} (pink orange). The ion PuO^+ is unstable in aqueous solutions, disproportionating into Pu^{+4} and PuO^{+2}. The Pu^{+4} thus formed, however, oxidizes the PuO^+ into PuO^{+2}, itself being reduced to Pu^{+3}, giving finally Pu^{+3} and PuO^{+2}. Plutonium forms binary compounds with oxygen: PuO, PuO_2, and intermediate oxides of variable composition; with the halides: PuF_3, PuF_4, $PuCl_3$, $PuBr_3$, PuI_3; with carbon, nitrogen, and silicon: PuC, PuN, $PuSi_2$. Oxyhalides are also well known: PuOCl, PuOBr, PuOI. Because of the high rate of emission of alpha particles and the element being specifically absorbed by bone marrow, plutonium, as well as all of the other transuranium elements except neptunium, are radiological poisons and must be handled with very special equipment and precautions. Plutonium is a very dangerous radiological hazard. Precautions must also be taken to prevent the unintentional formation of a critical mass. Plutonium in liquid solution is more likely to become critical than solid plutonium. The shape of the mass must also be considered where criticality is concerned. Plutonium-239 is available to authorized users from the O.R.N.L. at a cost of about $4.80/mg (99.9%) plus packing costs.

Polonium — (Poland, native country of Mme. Curie [1867–1934]), Po; at. wt. (209); at. no. 84; m.p. 254°C; b.p. 962°C; sp. gr. (alpha modification) 9.32; valence –2, 0, +2, +3(?), +4, and +6. Polonium was the first element discovered by Mme. Curie in 1898, while seeking the cause of radioactivity of pitchblende from Joachimsthal, Bohemia. The electroscope showed it separating with bismuth. Polonium is also called Radium F. Polonium is a very rare natural element. Uranium ores contain only about 100 μg of the element per ton. Its abundance is only about 0.2% of that of radium. In 1934, it was found that when natural bismuth (^{209}Bi) was bombarded by neutrons, ^{210}Bi, the parent of polonium, was obtained. Milligram amounts of polonium may now be prepared this way, by using the high neutron fluxes of nuclear reactors. Polonium-210 is a low-melting, fairly volatile metal, 50% of which is vaporized in air in 45 hours at 55°C. It is an alpha emitter with a half-life of 138.39 days. A milligram emits as many alpha particles as 5 g of radium. The energy released by its decay is so large (140 W/g) that a capsule containing about half a gram reaches a temperature above 500°C. The capsule also presents a contact gamma-ray dose rate of 0.012 Gy/h. A few curies (1 curie = 3.7×10^{10} Bq) of polonium exhibit a blue glow, caused by excitation of the surrounding gas. Because almost all alpha radiation is stopped within the solid source and its container, giving up its energy, polonium has attracted attention for uses as a lightweight heat source for thermoelectric power in space satellites. Thirty-eight isotopes and isomers of polonium are known, with atomic masses ranging from 192 to 218. All are radioactive. Polonium-210 is the most readily available. Isotopes of mass 209 (half-life 102 years) and mass 208 (half-life 2.9 years) can be prepared by alpha, proton, or deuteron bombardment of lead or bismuth in a cyclotron, but these are expensive to produce. Metallic polonium has been prepared from polonium hydroxide and some other polonium compounds in the presence of concentrated aqueous or anhydrous liquid ammonia. Two allotropic modifications are known to exist. Polonium is readily dissolved in dilute acids, but is only slightly soluble in alkalis. Polonium salts of organic acids char rapidly; halide amines are reduced to the metal. Polonium can be mixed or alloyed with beryllium to provide a source of neutrons. It has been used in devices for eliminating static charges in textile mills, etc.; however, beta sources are more commonly used and are less dangerous. It is also used on brushes for removing dust from photographic films. The polonium for these is carefully sealed and controlled, minimizing hazards to the user. Polonium-210 is very dangerous to handle in even milligram or microgram amounts, and special equipment and strict control is necessary. Damage arises from the complete absorption of the energy of the alpha particle into tissue. The maximum permissible body burden for ingested polonium is only 0.03 μCi, which represents a particle weighing only 6.8×10^{-12} g. Weight for weight it is about 2.5×10^{11} times as toxic as hydrocyanic acid. The maximum allowable concentration for soluble polonium compounds in air is about 2×10^{11} μCi/cm^3. Polonium-209 is available on special order from the Oak Ridge National Laboratory at a cost of $3600/μCi plus packing costs..

Potassium — (English, *potash* — pot ashes; L. *kalium*, Arab. *qali*, alkali), K; at. wt. 39.0983(1); at. no. 19; m.p. 63.38°C; b.p. 759°C; sp. gr. 0.862 (20°C); valence 1. Discovered in 1807 by Davy, who obtained it from caustic potash (KOH); this was the first metal isolated by electrolysis. The metal is the seventh most abundant and makes up about 2.4% by weight of the earth's crust. Most potassium minerals are insoluble and the metal is obtained from them only with great difficulty. Certain minerals, however, such as *sylvite, carnallite, langbeinite,* and *polyhalite* are found in ancient lake and sea beds and form rather extensive deposits from which potassium and its salts can readily be obtained. Potash is mined in Germany, New Mexico, California, Utah, and elsewhere. Large deposits of potash, found at a depth of some 1000 m in Saskatchewan, promise to be important in coming years. Potassium is also found in the ocean, but is present only in relatively small amounts, compared to sodium. The greatest demand for potash has been in its use for fertilizers. Potassium is an essential constituent for plant growth and it is found in most soils. Potassium is never found free in nature, but is obtained by electrolysis of the hydroxide, much in the same manner as prepared by Davy. Thermal methods also are commonly used to produce potassium (such as by reduction of potassium compounds with CaC_2, C, Si, or Na). It is one of the most reactive and electropositive of metals. Except for lithium, it is the lightest known metal. It is soft, easily cut with a knife, and is silvery in appearance immediately after a fresh surface is exposed. It rapidly oxidizes in air and should be preserved in a mineral oil. As with other metals of the alkali group, it decomposes in water with the evolution

of hydrogen. It catches fire spontaneously on water. Potassium and its salts impart a violet color to flames. Twenty one isotopes, one of which is an isomer, of potassium are known. Ordinary potassium is composed of three isotopes, one of which is ^{40}K (0.0117%), a radioactive isotope with a half-life of 1.26×10^9 years. The radioactivity presents no appreciable hazard. An alloy of sodium and potassium (NaK) is used as a heat-transfer medium. Many potassium salts are of utmost importance, including the hydroxide, nitrate, carbonate, chloride, chlorate, bromide, iodide, cyanide, sulfate, chromate, and dichromate. Metallic potassium is available commercially for about $1200/kg (98% purity) or $55/g (99.95% purity).

Praseodymium — (Gr. *prasios,* green, and *didymos*, twin), Pr; at. wt. 140.90765(2); at. no. 59; m.p. 931°C; b.p. 3520°C; sp. gr. 6.773; valence 3. In 1841 Mosander extracted the rare earth *didymia* from *lanthana*; in 1879, Lecoq de Boisbaudran isolated a new earth, *samaria*, from didymia obtained from the mineral *samarskite*. Six years later, in 1885, von Welsbach separated didymia into two others, *praseodymia* and *neodymia*, which gave salts of different colors. As with other rare earths, compounds of these elements in solution have distinctive sharp spectral absorption bands or lines, some of which are only a few Angstroms wide. The element occurs along with other rare-earth elements in a variety of minerals. *Monazite* and *bastnasite* are the two principal commercial sources of the rare-earth metals. Ion-exchange and solvent extraction techniques have led to much easier isolation of the rare earths and the cost has dropped greatly in the past few years. Thirty-seven isotopes and isomers are now recognized. Praseodymium can be prepared by several methods, such as by calcium reduction of the anhydrous chloride of fluoride. Misch metal, used in making cigarette lighters, contains about 5% praseodymium metal. Praseodymium is soft, silvery, malleable, and ductile. It was prepared in relatively pure form in 1931. It is somewhat more resistant to corrosion in air than europium, lanthanum, cerium, or neodymium, but it does develop a green oxide coating that spalls off when exposed to air. As with other rare-earth metals it should be kept under a light mineral oil or sealed in plastic. The rare-earth oxides, including Pr_2O_3, are among the most refractory substances known. Along with other rare earths, it is widely used as a core material for carbon arcs used by the motion picture industry for studio lighting and projection. Salts of praseodymium are used to color glasses and enamels; when mixed with certain other materials, praseodymium produces an intense and unusually clean yellow color in glass. Didymium glass, of which praseodymium is a component, is a colorant for welder's goggles. The metal (99.9% pure) is priced at about $5/g.

Promethium — (*Prometheus*, who, according to mythology, stole fire from heaven), Pm; at. no. 61; at. wt. (145); m.p. 1042°C; b.p. 3000°C (est.); sp. gr. 7.264 (25°C); valence 3. In 1902 Branner predicted the existence of an element between neodymium and samarium, and this was confirmed by Moseley in 1914. Unsuccessful searches were made for this predicted element over two decades, and various investigators proposed the names "illinium", "florentium", and "cyclonium" for this element. In 1941, workers at Ohio State University irradiated neodymium and praseodymium with neutrons, deuterons, and alpha particles, resp., and produced several new radioactivities, which most likely were those of element 61. Wu and Segre, and Bethe, in 1942, confirmed the formation; however, chemical proof of the production of element 61 was lacking because of the difficulty in separating the rare earths from each other at that time. In 1945, Marinsky, Glendenin, and Coryell made the first chemical identification by use of ion-exchange chromatography. Their work was done by fission of uranium and by neutron bombardment of neodymium. These investigators named the newly discovered element. Searches for the element on earth have been fruitless, and it now appears that promethium is completely missing from the earth's crust. Promethium, however, has been reported to be in the spectrum of the star HR^{465} in Andromeda. This element is being formed recently near the star's surface, for no known isotope of promethium has a half-life longer than 17.7 years. Thirty five isotopes and isomers of promethium, with atomic masses from 130 to 158 are now known. Promethium-145,with a half-life of 17.7 years, is the most useful. Promethium-145 has a specific activity of 940 Ci/g. It is a soft beta emitter; although no gamma rays are emitted, X-radiation can be generated when beta particles impinge on elements of a high atomic number, and great care must be taken in handling it. Promethium salts luminesce in the dark with a pale blue or greenish glow, due to their high radioactivity. Ion-exchange methods led to the preparation of about 10 g of promethium from atomic reactor fuel processing wastes in early 1963. Little is yet generally known about the properties of metallic promethium. Two allotropic modifications exist. The element has applications as a beta source for thickness gages, and it can be absorbed by a phosphor to produce light. Light produced in this manner can be used for signs or signals that require dependable operation; it can be used as a nuclear-powered battery by capturing light in photocells which convert it into electric current. Such a battery, using ^{147}Pm, would have a useful life of about 5 years. It is being used for fluorescent lighting starters and coatings for self-luminous watch dials. Promethium shows promise as a portable X-ray source, and it may become useful as a heat source to provide auxiliary power for space probes and satellites. More than 30 promethium compounds have been prepared. Most are colored. Promethium-147 is available upon special order from the Idaho National Engineering Laboratory, Idaho Falls, ID, or from the Westinghouse Hanford Co., Richland, WA.

Protactinium — (Gr. *protos*, first), Pa; at. wt. 231.03588(2); at. no. 91; m.p. 1572°C; sp. gr. 15.37 (calc.); valence 4 or 5. The first isotope of element 91 to be discovered was ^{234}Pa, also known as UX_2, a short-lived member of the naturally occurring ^{238}U decay series. It was identified by K. Fajans and O. H. Gohring in 1913 and they named the new element *brevium*. When the longer-lived isotope ^{231}Pa was identified by Hahn and Meitner in 1918, the name protoactinium was adopted as being more consistent with the characteristics of the most abundant isotope. Soddy, Cranson, and Fleck were also active in this work. The name *protoactinium* was shortened to *protactinium* in 1949. In 1927, Grosse prepared 2 mg of a white powder, which was shown to be Pa_2O_5. Later, in 1934, from 0.1 g of pure Pa_2O_5 he isolated the element by two methods, one of which was by converting the oxide to an iodide and "cracking" it in a high vacuum by an electrically heated filament by the reaction

$$2PaI_5 \rightarrow 2Pa + 5I_2$$

Protactinium has a bright metallic luster which it retains for some time in air. The element occurs in *pitchblende* to the extent of about 1 part ^{231}Pa to 10 million of ore. Ores from Congo-Kinshasa have about 3 ppm. Protactinium has twenty-eight isotopes and isomers, the most common of which is ^{231}Pr with a half-life of 32,500 years. A number of protactinium compounds are known, some of which are colored. The element is superconductive below 1.4 K. The element is a dangerous toxic material and requires precautions similar to those used when handling plutonium. In 1959 and 1961, it was announced that the Great Britain Atomic Energy Authority extracted by a 12-stage process 125 g of 99.9% protactinium, the world's only stock of the metal for many years to come. The extraction was made from 60 tons of waste material at a cost of about $500,000. Protactinium is one of the rarest and most expensive naturally occurring elements.

Radium — (L. *radius*, ray), Ra; at. wt. (226); at. no. 88; m.p. 700°C; sp. gr. 5; valence 2. Radium was discovered in 1898 by M. and Mme. Curie in the *pitchblende* or *uraninite* of North Bohemia (Czech Republic), where it occurs. There is about 1 g of radium in 7 tons of pitchblende. The element was isolated in 1911 by Mme. Curie and Debierne by the electrolysis of a solution of pure radium chloride, employing a mercury cathode; on distillation in an atmosphere of hydrogen this amalgam yielded the pure metal. Originally, radium was obtained from the rich pitchblende ore found at Joachimsthal, Bohemia. The *carnotite* sands of Colorado furnish some radium, but richer ores are found in the Republic of Congo-Kinshasa and the

Great Bear Lake region of Canada. Radium is present in all uranium minerals, and could be extracted, if desired, from the extensive wastes of uranium processing. Large uranium deposits are located in Ontario, New Mexico, Utah, Australia, and elsewhere. Radium is obtained commercially as the bromide or chloride; it is doubtful if any appreciable stock of the isolated element now exists. The pure metal is brilliant white when freshly prepared, but blackens on exposure to air, probably due to formation of the nitride. It exhibits luminescence, as do its salts; it decomposes in water and is somewhat more volatile than barium. It is a member of the alkaline-earth group of metals. Radium imparts a carmine red color to a flame. Radium emits alpha, beta, and gamma rays and when mixed with beryllium produce neutrons. One gram of ^{226}Ra undergoes 3.7×10^{10} disintegrations per s. The *curie (Ci)* is defined as that amount of radioactivity which has the same disintegration rate as 1 g of ^{226}Ra. Thirty-six isotopes are now known; radium 226, the common isotope, has a half-life of 1599 years. One gram of radium produces about 0.0001 ml (stp) of emanation, or radon gas, per day. This is pumped from the radium and sealed in minute tubes, which are used in the treatment of cancer and other diseases. One gram of radium yields about 4186 kJ per year. Radium is used in producing self-luminous paints, neutron sources, and in medicine for the treatment of disease. Some of the more recently discovered radioisotopes, such as ^{60}Co, are now being used in place of radium. Some of these sources are much more powerful, and others are safer to use. Radium loses about 1% of its activity in 25 years, being transformed into elements of lower atomic weight. Lead is a final product of disintegration. Stored radium should be ventilated to prevent build-up of radon. Inhalation, injection, or body exposure to radium can cause cancer and other body disorders. The maximum permissible burden in the total body for ^{226}Ra is 7400 becquerel.

Radon — (from *radium*; called *niton* at first, L. *nitens*, shining), Rn; at. wt. (222); at. no. 86; m.p. –71°C; b.p. –61.7°C; t_c 104°C; density of gas 9.73 g/l; sp. gr. liquid 4.4 at –62°C, solid 4; valence usually 0. The element was discovered in 1900 by Dorn, who called it *radium emanation*. In 1908 Ramsay and Gray, who named it *niton*, isolated the element and determined its density, finding it to be the heaviest known gas. It is essentially inert and occupies the last place in the zero group of gases in the Periodic Table. Since 1923, it has been called radon. Thirty-seven isotopes and isomers are known. Radon-222, coming from radium, has a half-life of 3.823 days and is an alpha emitter; Radon-220, emanating naturally from thorium and called *thoron*, has a half-life of 55.6 s and is also an alpha emitter. Radon-219 emanates from actinium and is called *actinon*. It has a half-life of 3.96 s and is also on alpha emitter. It is estimated that every square mile of soil to a depth of 6 inch contains about 1 g of radium, which releases radon in tiny amounts to the atmosphere. Radon is present in some spring waters, such as those at Hot Springs, Arkansas. On the average, one part of radon is present to 1×10^{21} part of air. At ordinary temperatures radon is a colorless gas; when cooled below the freezing point, radon exhibits a brilliant phosphorescence which becomes yellow as the temperature is lowered and orange-red at the temperature of liquid air. It has been reported that fluorine reacts with radon, forming radon fluoride. Radon clathrates have also been reported. Radon is still produced for therapeutic use by a few hospitals by pumping it from a radium source and sealing it in minute tubes, called seeds or needles, for application to patients. This practice has now been largely discontinued as hospitals can order the seeds directly from suppliers, who make up the seeds with the desired activity for the day of use. Care must be taken in handling radon, as with other radioactive materials. The main hazard is from inhalation of the element and its solid daughters, which are collected on dust in the air. Good ventilation should be provided where radium, thorium, or actinium is stored to prevent build-up of this element. Radon build-up is a health consideration in uranium mines. Recently radon build-up in homes has been a concern. Many deaths from lung cancer are caused by radon exposure. In the U.S. it is recommended that remedial action be taken if the air from radon in homes exceeds 4 pCi/l.

Rhenium — (L. *Rhenus*, Rhine), Re; at. wt. 186.207(1); at. no. 75; m.p. 3186°C; b.p. 5596°C; sp. gr. 21.02 (20°C); valence –1, +1, 2, 3, 4, 5, 6, 7. Discovery of rhenium is generally attributed to Noddack, Tacke, and Berg, who announced in 1925 they had detected the element in platinum ores and *columbite*. They also found the element in *gadolinite* and *molybdenite*. By working up 660 kg of molybdenite they were able in 1928 to extract 1 g of rhenium. The price in 1928 was $10,000/g. Rhenium does not occur free in nature or as a compound in a distinct mineral species. It is, however, widely spread throughout the earth's crust to the extent of about 0.001 ppm. Commercial rhenium in the U.S. today is obtained from molybdenite roaster-flue dusts obtained from copper-sulfide ores mined in the vicinity of Miami, Arizona, and elsewhere in Arizona and Utah. Some molybdenites contain from 0.002 to 0.2% rhenium. It is estimated that in 1999 about 16,000 kg of rhenium was being produced. The total estimated world reserves of rhenium is 11,000,000 kg. The total estimated Free World reserve of rhenium metal is 3500 tons. Natural rhenium is a mixture of two isotopes, one of which has a very long half-life. Thirty nine other unstable isotopes are recognized. Rhenium metal is prepared by reducing ammonium perrhenate with hydrogen at elevated temperatures. The element is silvery white with a metallic luster; its density is exceeded only by that of platinum, iridium, and osmium, and its melting point is exceeded only by that of tungsten and carbon. It has other useful properties. The usual commercial form of the element is a powder, but it can be consolidated by pressing and resistance-sintering in a vacuum or hydrogen atmosphere. This produces a compact shape in excess of 90% of the density of the metal. Annealed rhenium is very ductile, and can be bent, coiled, or rolled. Rhenium is used as an additive to tungsten and molybdenum-based alloys to impart useful properties. It is widely used for filaments for mass spectrographs and ion gages. Rhenium-molybdenum alloys are superconductive at 10 K. Rhenium is also used as an electrical contact material as it has good wear resistance and withstands arc corrosion. Thermocouples made of Re-W are used for measuring temperatures up to 2200°C, and rhenium wire has been used in photoflash lamps for photography. Rhenium catalysts are exceptionally resistant to poisoning from nitrogen, sulfur, and phosphorus, and are used for hydrogenation of fine chemicals, hydrocracking, reforming, and disproportionation of olefins. Rhenium has recently become especially important as a catalyst for petroleum refining and in making super-alloys for jet engines. Rhenium costs about $16/g (99.99% pure). Little is known of its toxicity; therefore, it should be handled with care until more data are available.

Rhodium — (Gr. *rhodon*, rose), Rh; at. wt. 102.90550(3); at. no. 45; m.p. 1964°C; b.p. 3695°C; sp. gr. 12.41 (20°C); valence 2, 3, 4, 5, and 6. Wollaston discovered rhodium in 1803-4 in crude platinum ore he presumably obtained from South America. Rhodium occurs native with other platinum metals in river sands of the Urals and in North and South America. It is also found with other platinum metals in the copper-nickel sulfide ores of the Sudbury, Ontario region. Although the quantity occurring here is very small, the large tonnages of nickel processed make the recovery commercially feasible. The annual world production of rhodium in 1999 was only about 9000 kg. The metal is silvery white and at red heat slowly changes in air to the sesquioxide. At higher temperatures it converts back to the element. Rhodium has a higher melting point and lower density than platinum. Its major use is as an alloying agent to harden platinum and palladium. Such alloys are used for furnace windings, thermocouple elements, bushings for glass fiber production, electrodes for aircraft spark plugs, and laboratory crucibles. It is useful as an electrical contact material as it has a low electrical resistance, a low and stable contact resistance, and is highly resistant to corrosion. Plated rhodium, produced by electroplating or evaporation, is exceptionally hard and is used for optical instruments. It has a high reflectance and is hard and durable. Rhodium is also used for jewelry, for decoration, and as a catalyst. Fifty-two isotopes and isomers are now known. Soluble salts should not exceed 0.01 mg/m^3. Rhodium metal (powder) costs about $180/g (99.9%).

Rubidium — (L. *rubidus*, deepest red), Rb; at. wt. 85.4678(3); at. no. 37; m.p. 39.31°C; b.p. 688°C; sp. gr. (solid) 1.532 (20°C), (liquid) 1.475 (39°C); valence 1, 2, 3, 4. Discovered in 1861 by Bunsen and Kirchoff in the mineral *lepidolite* by use of the spectroscope. The element is much more abundant than was thought several years ago. It is now considered to be the 16th most abundant element in the earth's crust. Rubidium occurs in *pollucite, carnallite, leucite,* and *zinnwaldite*, which contains traces up to 1%, in the form of the oxide. It is found in lepidolite to the extent of about 1.5%, and is recovered commercially from this source. Potassium minerals, such as those found at Searles Lake, California, and potassium chloride recovered from brines in Michigan also contain the element and are commercial sources. It is also found along with cesium in the extensive deposits of *pollucite* at Bernic Lake, Manitoba. Rubidium can be liquid at room temperature. It is a soft, silvery-white metallic element of the alkali group and is the second most electropositive and alkaline element. It ignites spontaneously in air and reacts violently in water, setting fire to the liberated hydrogen. As with other alkali metals, it forms amalgams with mercury and it alloys with gold, cesium, sodium, and potassium. It colors a flame yellowish violet. Rubidium metal can be prepared by reducing rubidium chloride with calcium, and by a number of other methods. It must be kept under a dry mineral oil or in a vacuum or inert atmosphere. Thirty five isotopes and isomers of rubidium are known. Naturally occurring rubidium is made of two isotopes, ^{85}Rb and ^{87}Rb. Rubidium-87 is present to the extent of 27.83% in natural rubidium and is a beta emitter with a half-life of 4.9×10^{10} years. Ordinary rubidium is sufficiently radioactive to expose a photographic film in about 30 to 60 days. Rubidium forms four oxides: Rb_2O, Rb_2O_2, Rb_2O_3, Rb_2O_4. Because rubidium can be easily ionized, it has been considered for use in "ion engines" for space vehicles; however, cesium is somewhat more efficient for this purpose. It is also proposed for use as a working fluid for vapor turbines and for use in a thermoelectric generator using the magnetohydrodynamic principle where rubidium ions are formed by heat at high temperature and passed through a magnetic field. These conduct electricity and act like an armature of a generator thereby generating an electric current. Rubidium is used as a getter in vacuum tubes and as a photocell component. It has been used in making special glasses. $RbAg_4I_5$ is important, as it has the highest room conductivity of any known ionic crystal. At 20°C its conductivity is about the same as dilute sulfuric acid. This suggests use in thin film batteries and other applications. The present cost in small quantities is about $80/g (99.8% pure).

Ruthenium — (L. *Ruthenia*, Russia), Ru; at. wt. 101.07(2); at. no. 44, m.p. 2334°C; b.p. 4150°C; sp. gr. 12.41 (20°C); valence 0, 1, 2, 3, 4, 5, 6, 7, 8. Berzelius and Osann in 1827 examined the residues left after dissolving crude platinum from the Ural mountains in *aqua regia*. While Berzelius found no unusual metals, Osann thought he found three new metals, one of which he named ruthenium. In 1844 Klaus, generally recognized as the discoverer, showed that Osann's ruthenium oxide was very impure and that it contained a new metal. Klaus obtained 6 g of ruthenium from the portion of crude platinum that is insoluble in *aqua regia*. A member of the platinum group, ruthenium occurs native with other members of the group in ores found in the Ural mountains and in North and South America. It is also found along with other platinum metals in small but commercial quantities in *pentlandite* of the Sudbury, Ontario, nickel-mining region, and in *pyroxinite* deposits of South Africa. Natural ruthenium contains seven isotopes. Twenty-eight other isotopes and isomers are known, all of which are radioactive. The metal is isolated commercially by a complex chemical process, the final stage of which is the hydrogen reduction of ammonium ruthenium chloride, which yields a powder. The powder is consolidated by powder metallurgy techniques or by argon-arc welding. Ruthenium is a hard, white metal and has four crystal modifications. It does not tarnish at room temperatures, but oxidizes in air at about 800°C. The metal is not attacked by hot or cold acids or *aqua regia*, but when potassium chlorate is added to the solution, it oxidizes explosively. It is attacked by halogens, hydroxides, etc. Ruthenium can be plated by electrodeposition or by thermal decomposition methods. The metal is one of the most effective hardeners for platinum and palladium, and is alloyed with these metals to make electrical contacts for severe wear resistance. A ruthenium-molybdenum alloy is said to be superconductive at 10.6 K. The corrosion resistance of titanium is improved a hundredfold by addition of 0.1% ruthenium. It is a versatile catalyst. Hydrogen sulfide can be split catalytically by light using an aqueous suspension of CdS particles loaded with ruthenium dioxide. It is thought this may have application to removal of H_2S from oil refining and other industrial processes. Compounds in at least eight oxidation states have been found, but of these, the +2. +3. and +4 states are the most common. Ruthenium tetroxide, like osmium tetroxide, is highly toxic. In addition, it may explode. Ruthenium compounds show a marked resemblance to those of osmium. The metal is priced at about $30/g (99.95% pure).

Rutherfordium — (named for Ernest Rutherford [1871–1937], New Zealand, Canadian, and British physicist); Rf; at. wt. [261]; at. no. 104. In 1964, workers of the Joint Nuclear Research Institute at Dubna (Russia) bombarded plutonium with accelerated 113 to 115 MeV neon ions. By measuring fission tracks in a special glass with a microscope, they detected an isotope that decays by spontaneous fission. They suggested that this isotope, which has a half-life of 0.3 ± 0.1 s, might be $^{260}104$, produced by the following reaction:

$$^{242}_{94}\mathrm{Pu} + ^{22}_{10}\mathrm{Ne} \rightarrow ^{260}104 + 4\mathrm{n}$$

Element 104, the first *transactinide* element, is expected to have chemical properties similar to those of hafnium. It would, for example, form a relatively volatile compound with chlorine (a tetrachloride). The Soviet scientists have performed experiments aimed at chemical identification, and have attempted to show that the 0.3-s activity is more volatile than that of the relatively nonvolatile actinide trichlorides. This experiment does not fulfill the test of chemically separating the new element from all others, but it provides important evidence for evaluation. New data, reportedly issued by Soviet scientists, have reduced the half-life of the isotope they worked with from 0.3 to 0.15 s. The Dubna scientists suggest the name *kurchatovium* and symbol *Ku* for Element 104, in honor of Igor Vasilevich Kurchatov (1903—1960), late Head of Soviet Nuclear Research. The Dubna Group also has proposed the name *dubnium* for Element 104. In 1969, Ghiorso, Nurmia, Harris, K. A. Y. Eskola, and P. L. Eskola of the University of California at Berkeley reported they had positively identified two, and possibly three, isotopes of Element 104. The group also indicated that after repeated attempts so far they have been unable to produce isotope $^{260}104$ reported by the Dubna groups in 1964. The discoveries at Berkeley were made by bombarding a target of ^{249}Cf with ^{12}C nuclei of 71 MeV, and ^{13}C nuclei of 69 MeV. The combination of ^{12}C with ^{249}Cf followed by instant emission of four neutrons produced Element $^{257}104$. This isotope has a half-life of 4 to 5 s, decaying by emitting an alpha particle into ^{253}No, with a half-life of 105 s. The same reaction, except with the emission of three neutrons, was thought to have produced $^{258}104$ with a half-life of about 1/100 s. Element $^{259}104$ is formed by the merging of a ^{13}C nuclei with ^{249}Cf, followed by emission of three neutrons. This isotope has a half-life of 3 to 4 s, and decays by emitting an alpha particle into ^{255}No, which has a half-life of 185 s. Thousands of atoms of $^{257}104$ and $^{259}104$ have been detected. The Berkeley group believe their identification of $^{258}104$ was correct. Eleven isotopes of Element 104 have now been identified. The Berkeley group proposed for the new element the name *rutherfordium* (symbol Rf), in honor of Ernest Rutherford. This name was formally adapted by IUPAC in August 1997.

Samarium — (*Samarskite* a mineral), Sm; at. wt. 150.36(3); at. no. 62; m.p. 1074°C; b.p. 1794°C; sp. gr (α) 7.520 (25°C); valence 2 or 3. Discovered spectroscopically by its sharp absorption lines in 1879 by Lecoq de Boisbaudran in the mineral *samarskite*, named in honor of a Russian mine official, Col. Samarski. Samarium is found along with other members of the rare-earth elements in many minerals, including *monazite* and *bastnasite*, which are commercial sources. The largest producer of rare earth minerals is now China, followed by the U.S., India, and Russia. It occurs in monazite to the extent of 2.8%. While *misch metal* containing about 1% of samarium metal, has long been used, samarium has not been isolated in relatively pure form until recent years. Ion-exchange and solvent extraction techniques have recently simplified separation of the rare earths from one another; more recently, electrochemical deposition, using an electrolytic solution of lithium citrate and a mercury electrode, is said to be a simple, fast, and highly specific way to separate the rare earths. Samarium metal can be produced by reducing the oxide with barium or lanthanum. Samarium has a bright silver luster and is reasonably stable in air. Three crystal modifications of the metal exist, with transformations at 734 and 922°C. The metal ignites in air at about 150°C. Thirty-three isotopes and isomers of samarium are now recognized. Natural samarium is a mixture of seven isotopes, three of which are unstable but have long half-lives. Samarium, along with other rare earths, is used for carbon-arc lighting for the motion picture industry. The sulfide has excellent high-temperature stability and good thermoelectric efficiencies up to 1100°C. $SmCo_5$ has been used in making a new permanent magnet material with the highest resistance to demagnetization of any known material. It is said to have an intrinsic coercive force as high as 2200 kA/m. Samarium oxide has been used in optical glass to absorb the infrared. Samarium is used to dope calcium fluoride crystals for use in optical masers or lasers. Compounds of the metal act as sensitizers for phosphors excited in the infrared; the oxide exhibits catalytic properties in the dehydration and dehydrogenation of ethyl alcohol. It is used in infrared absorbing glass and as a neutron absorber in nuclear reactors. The metal is priced at about $3.50/g (99.9%). Little is known of the toxicity of samarium; therefore, it should be handled carefully.

Scandium — (L. *Scandia*, Scandinavia), Sc; at. wt. 44.955910(8); at. no. 21; m.p. 1541°C; b.p. 2836°C; sp. gr. 2.989 (25°C); valence 3. On the basis of the Periodic System, Mendeleev predicted the existence of *ekaboron*, which would have an atomic weight between 40 of calcium and 48 of titanium. The element was discovered by Nilson in 1878 in the minerals *euxenite* and *gadolinite*, which had not yet been found anywhere except in Scandinavia. By processing 10 kg of euxenite and other residues of rare-earth minerals, Nilson was able to prepare about 2 g of scandium oxide of high purity. Cleve later pointed out that Nilson's scandium was identical with Mendeleev's ekaboron. Scandium is apparently a much more abundant element in the sun and certain stars than here on earth. It is about the 23rd most abundant element in the sun, compared to the 50th most abundant on earth. It is widely distributed on earth, occurring in very minute quantities in over 800 mineral species. The blue color of beryl (aquamarine variety) is said to be due to scandium. It occurs as a principal component in the rare mineral *thortveitite*, found in Scandinavia and Malagasy. It is also found in the residues remaining after the extraction of tungsten from Zinnwald *wolframite*, and in *wiikite* and *bazzite*. Most scandium is presently being recovered from *thortveitite* or is extracted as a by-product from uranium mill tailings. Metallic scandium was first prepared in 1937 by Fischer, Brunger, and Grieneisen, who electrolyzed a eutectic melt of potassium, lithium, and scandium chlorides at 700 to 800°C. Tungsten wire and a pool of molten zinc served as the electrodes in a graphite crucible. Pure scandium is now produced by reducing scandium fluoride with calcium metal. The production of the first pound of 99% pure scandium metal was announced in 1960. Scandium is a silver-white metal which develops a slightly yellowish or pinkish cast upon exposure to air. It is relatively soft, and resembles yttrium and the rare-earth metals more than it resembles aluminum or titanium. It is a very light metal and has a much higher melting point than aluminum, making it of interest to designers of spacecraft. Scandium is not attacked by a 1:1 mixture of conc. HNO_3 and 48% HF. Scandium reacts rapidly with many acids. Twenty-three isotopes and isomers of scandium are recognized. The metal is expensive, costing about $200/g with a purity of about 99.9%. About 20 kg of scandium (as Sc_2O_3) are now being used yearly in the U.S. to produce high-intensity lights, and the radioactive isotope ^{46}Sc is used as a tracing agent in refinery crackers for crude oil, etc. Scandium iodide added to mercury vapor lamps produces a highly efficient light source resembling sunlight, which is important for indoor or night-time color TV. Little is yet known about the toxicity of scandium; therefore, it should be handled with care.

Seaborgium — (named for Glenn T. Seaborg [1912–1999], American chemist and nuclear physicist). Sg; at. wt. [263]; at no. 106. The discovery of *Seaborgium*, Element 106, took place in 1974 almost simultaneously at the Lawrence-Berkeley Laboratory and at the Joint Institute for Nuclear Research at Dubna, Russia. The Berkeley Group, under direction of Ghiorso, used the Super-Heavy Ion Linear Accelerator (Super HILAC) as a source of heavy ^{18}O ions to bombard a 259-μg target of ^{249}Cf. This resulted in the production and positive identification of $^{263}106$, which decayed with a half-life of 0.9 ± 0.2 s by the emission of alpha particles as follows:

$$^{263}106 \xrightarrow{\alpha} {}^{259}104 \xrightarrow{\alpha} {}^{255}\mathrm{No} \xrightarrow{\alpha}.$$

The Dubna Team, directed by Flerov and Organessian, produced heavy ions of ^{54}Cr with their 310-cm heavy-ion cyclotron to bombard ^{207}Pb and ^{208}Pb and found a product that decayed with a half-life of 7 ms. They assigned $^{259}106$ to this isotope. It is now thought seven isotopes of *Seaborgium* have been identified. Two of the isotopes are believed to have half-lives of about 30 s. *Seaborgium* most likely would have properties resembling tungsten. The IUPAC adopted the name *Seaborgium* in August 1997. Normally the naming of an element is not given until after the death of the person for which the element is named; however, in this case, it was named while Dr. Seaborg was still alive.

Selenium — (Gr. *Selene*, moon), Se; at. wt. 78.96(3); at. no. 34; m.p. (gray) 221°C; b.p. (gray) 685°C; sp. gr. (gray) 4.79, (vitreous) 4.28; valence –2, +4, or +6. Discovered by Berzelius in 1817, who found it associated with tellurium, named for the earth. Selenium is found in a few rare minerals, such as *crooksite* and *clausthalite*. In years past it has been obtained from flue dusts remaining from processing copper sulfide ores, but the anode muds from electrolytic copper refineries now provide the source of most of the world's selenium. Selenium is recovered by roasting the muds with soda or sulfuric acid, or by smelting them with soda and niter. Selenium exists in several allotropic forms. Three are generally recognized, but as many as six have been claimed. Selenium can be prepared with either an amorphous or crystalline structure. The color of amorphous selenium is either red, in powder form, or black, in vitreous form. Crystalline monoclinic selenium is a deep red; crystalline hexagonal selenium, the most stable variety, is a metallic gray. Natural selenium contains six stable isotopes. Twenty-nine other isotopes and isomers have been characterized. The element is a member of the sulfur family and resembles sulfur both in its various forms and in its compounds. Selenium exhibits both photovoltaic action, where light is converted directly into electricity, and photoconductive action, where the electrical resistance decreases with increased illumination. These properties make selenium useful in the production of photocells and exposure meters for photographic use, as well as solar cells. Selenium is also able to convert a.c. electricity to d.c., and is extensively used in rectifiers. Below its melting point selenium is a p-type semiconductor and is finding many uses in

electronic and solid-state applications. It is used in Xerography for reproducing and copying documents, letters, etc., but recently its use in this application has been decreasing in favor of certain organic compounds. It is used by the glass industry to decolorize glass and to make ruby-colored glasses and enamels. It is also used as a photographic toner, and as an additive to stainless steel. Elemental selenium has been said to be practically nontoxic and is considered to be an essential trace element; however, hydrogen selenide and other selenium compounds are extremely toxic, and resemble arsenic in their physiological reactions. Hydrogen selenide in a concentration of 1.5 ppm is intolerable to man. Selenium occurs in some soils in amounts sufficient to produce serious effects on animals feeding on plants, such as locoweed, grown in such soils. Selenium (99.5%) is priced at about $250/kg. It is also available in high-purity form at a cost of about $750/kg (99.999%).

Silicon — (L. *silex, silicis*, flint), Si; at. wt. 28.0855(3); at. no. 14; m.p. 1414°C; b.p. 3265°C; sp. gr. 2.33 (25°C); valence 4. Davy in 1800 thought silica to be a compound and not an element; later in 1811, Gay Lussac and Thenard probably prepared impure amorphous silicon by heating potassium with silicon tetrafluoride. Berzelius, generally credited with the discovery, in 1824 succeeded in preparing amorphous silicon by the same general method as used earlier, but he purified the product by removing the fluosilicates by repeated washings. Deville in 1854 first prepared crystalline silicon, the second allotropic form of the element. Silicon is present in the sun and stars and is a principal component of a class of meteorites known as "aerolites". It is also a component of *tektites*, a natural glass of uncertain origin. Natural silicon contains three isotopes. Twenty-four other radioactive isotopes are recognized. Silicon makes up 25.7% of the earth's crust, by weight, and is the second most abundant element, being exceeded only by oxygen. Silicon is not found free in nature, but occurs chiefly as the oxide and as silicates. *Sand, quartz, rock crystal, amethyst, agate, flint, jasper,* and *opal* are some of the forms in which the oxide appears. *Granite, hornblende, asbestos, feldspar, clay mica,* etc. are but a few of the numerous silicate minerals. Silicon is prepared commercially by heating silica and carbon in an electric furnace, using carbon electrodes. Several other methods can be used for preparing the element. Amorphous silicon can be prepared as a brown powder, which can be easily melted or vaporized. Crystalline silicon has a metallic luster and grayish color. The Czochralski process is commonly used to produce single crystals of silicon used for solid-state or semiconductor devices. Hyperpure silicon can be prepared by the thermal decomposition of ultra-pure trichlorosilane in a hydrogen atmosphere, and by a vacuum float zone process. This product can be doped with boron, gallium, phosphorus, or arsenic to produce silicon for use in transistors, solar cells, rectifiers, and other solid-state devices which are used extensively in the electronics and space-age industries. Hydrogenated amorphous silicon has shown promise in producing economical cells for converting solar energy into electricity. Silicon is a relatively inert element, but it is attacked by halogens and dilute alkali. Most acids except hydrofluoric, do not affect it. Silicones are important products of silicon. They may be prepared by hydrolyzing a silicon organic chloride, such as dimethyl silicon chloride. Hydrolysis and condensation of various substituted chlorosilanes can be used to produce a very great number of polymeric products, or silicones, ranging from liquids to hard, glasslike solids with many useful properties. Elemental silicon transmits more than 95% of all wavelengths of infrared, from 1.3 to 6.7 μm. Silicon is one of man's most useful elements. In the form of sand and clay it is used to make concrete and brick; it is a useful refractory material for high-temperature work, and in the form of silicates it is used in making enamels, pottery, etc. Silica, as sand, is a principal ingredient of glass, one of the most inexpensive of materials with excellent mechanical, optical, thermal, and electrical properties. Glass can be made in a very great variety of shapes, and is used as containers, window glass, insulators, and thousands of other uses. Silicon tetrachloride can be used to iridize glass. Silicon is important in plant and animal life. Diatoms in both fresh and salt water extract silica from the water to build up their cell walls. Silica is present in ashes of plants and in the human skeleton. Silicon is an important ingredient in steel; silicon carbide is one of the most important abrasives and has been used in lasers to produce coherent light of 4560 Å. A remarkable material, first discovered in 1930, is *Aerogel,* developed and now used by NASA in their *Stardust* mission, which is expected to encounter Comet Wild 2 in 2004, returning cometary and interplanet dust to Earth in 2006. *Aerogel* is a highly insulative material that has the lowest density of any known solid. One form of *Aerogel* is 99.9% air and 0.1% SiO_2, by volume. It is 1000 times less dense than glass. It has been called "blue smoke" or "solid smoke". A block of *Aerogel* as large as a person may weigh less than a pound and yet support the weight of 1000 lbs (455 kg). This material is expected to trap cometary particles traveling at speeds of 32 km/sec. *Aerogel* is said to be non-toxic and non-inflammable. It has high thermal insulating qualities that could be used in home insulation. Its light weight may have aircraft applications. Regular grade silicon (99.5%) costs about $160/kg. Silicon (99.9999%) pure costs about $250/kg; hyperpure silicon is available at a higher cost. Miners, stonecutters, and other engaged in work where siliceous dust is breathed in large quantities often develop a serious lung disease known as *silicosis*.

Silver — (Anglo-Saxon, *Seolfor siolfur*), Ag (L. argentum), at. wt. 107.8682(2); at. no. 47; m.p. 961.78°C; b.p. 2162°C; sp. gr. 10.50 (20°C); valence 1, 2. Silver has been known since ancient times. It is mentioned in Genesis. Slag dumps in Asia Minor and on islands in the Aegean Sea indicate that man learned to separate silver from lead as early as 3000 B.C. Silver occurs native and in ores such as *argentite* (Ag_2S) and *horn silver* (AgCl); lead, lead-zinc, copper, gold, and copper-nickel ores are principal sources. Mexico, Canada, Peru, and the U.S. are the principal silver producers in the western hemisphere. Silver is also recovered during electrolytic refining of copper. Commercial fine silver contains at least 99.9% silver. Purities of 99.999+% are available commercially. Pure silver has a brilliant white metallic luster. It is a little harder than gold and is very ductile and malleable, being exceeded only by gold and perhaps palladium. Pure silver has the highest electrical and thermal conductivity of all metals, and possesses the lowest contact resistance. It is stable in pure air and water, but tarnishes when exposed to ozone, hydrogen sulfide, or air containing sulfur. The alloys of silver are important. Sterling silver is used for jewelry, silverware, etc. where appearance is paramount. This alloy contains 92.5% silver, the remainder being copper or some other metal. Silver is of utmost importance in photography, about 30% of the U.S. industrial consumption going into this application. It is used for dental alloys. Silver is used in making solder and brazing alloys, electrical contacts, and high capacity silver-zinc and silver-cadmium batteries. Silver paints are used for making printed circuits. It is used in mirror production and may be deposited on glass or metals by chemical deposition, electrodeposition, or by evaporation. When freshly deposited, it is the best reflector of visible light known, but is rapidly tarnishes and loses much of its reflectance. It is a poor reflector of ultraviolet. Silver fulminate ($Ag_2C_2N_2O_2$), a powerful explosive, is sometimes formed during the silvering process. Silver iodide is used in seeding clouds to produce rain. Silver chloride has interesting optical properties as it can be made transparent; it also is a cement for glass. Silver nitrate, or *lunar caustic,* the most important silver compound, is used extensively in photography. While silver itself is not considered to be toxic, most of its salts are poisonous. Natural silver contains two stable isotopes. Fifty-six other radioactive isotopes and isomers are known. Silver compounds can be absorbed in the circulatory system and reduced silver deposited in the various tissues of the body. A condition, known as *argyria*, results with a greyish pigmentation of the skin and mucous membranes. Silver has germicidal effects and kills many lower organisms effectively without harm to higher animals. Silver for centuries has been used traditionally for coinage by many countries of the world. In recent times, however, consumption of silver has at times greatly exceeded the output. In 1939, the price of silver was fixed by the U.S. Treasury at 71¢/troy oz., and at 90.5¢/troy oz. in 1946. In November 1961 the U.S. Treasury suspended sales of nonmonetized silver, and the price stabilized

for a time at about $1.29, the melt-down value of silver U.S. coins. The Coinage Act of 1965 authorized a change in the metallic composition of the three U.S. subsidiary denominations to clad or composite type coins. This was the first change in U.S. coinage since the monetary system was established in 1792. Clad dimes and quarters are made of an outer layer of 75% Cu and 25% Ni bonded to a central core of pure Cu. The composition of the one- and five-cent pieces remains unchanged. One-cent coins are 95% Cu and 5% Zn. Five-cent coins are 75% Cu and 25% Ni. Old silver dollars are 90% Ag and 10% Cu. Earlier subsidiary coins of 90% Ag and 10% Cu officially were to circulate alongside the clad coins; however, in practice they have largely disappeared (Gresham's Law), as the value of the silver is now greater than their exchange value. Silver coins of other countries have largely been replaced with coins made of other metals. On June 24, 1968, the U.S. Government ceased to redeem U.S. Silver Certificates with silver. Since that time, the price of silver has fluctuated widely. As of December 1999, the price of silver was about $5.20/troy oz. (17¢/g); however the price has fluctuated considerably due to market instability. The price of silver in 1999 was only about five times the cost of the metal about 150 years ago. This has largely been caused by Central Banks disposing of some of their silver reserves and the development of more productive mines with better refining methods. Also, silver has been displaced by other metals or processes, such as digital photography.

Sodium — (English, *soda*; Medieval Latin, *sodanum,* headache remedy), Na (L. *natrium*); at. wt. 22.989770(2); at. no. 11; m.p. 97.80°C; b.p. 883°C; sp. gr. 0.971 (20°C); valence 1. Long recognized in compounds, sodium was first isolated by Davy in 1807 by electrolysis of caustic soda. Sodium is present in fair abundance in the sun and stars. The D lines of sodium are among the most prominent in the solar spectrum. Sodium is the sixth most abundant element on earth, comprising about 2.6% of the earth's crust; it is the most abundant of the alkali group of metals of which it is a member. The most common compound is sodium chloride, but it occurs in many other minerals, such as *soda niter, cryolite, amphibole, zeolite, sodalite,*etc. It is a very reactive element and is never found free in nature. It is now obtained commercially by the electrolysis of absolutely dry fused sodium chloride. This method is much cheaper than that of electrolyzing sodium hydroxide, as was used several years ago. Sodium is a soft, bright, silvery metal which floats on water, decomposing it with the evolution of hydrogen and the formation of the hydroxide. It may or may not ignite spontaneously on water, depending on the amount of oxide and metal exposed to the water. It normally does not ignite in air at temperatures below 115°C. Sodium should be handled with respect, as it can be dangerous when improperly handled. Metallic sodium is vital in the manufacture of sodamide and esters, and in the preparation of organic compounds. The metal may be used to improve the structure of certain alloys, to descale metal, to purify molten metals, and as a heat transfer agent. An alloy of sodium with potassium, NaK, is also an important heat transfer agent. Sodium compounds are important to the paper, glass, soap, textile, petroleum, chemical, and metal industries. Soap is generally a sodium salt of certain fatty acids. The importance of common salt to animal nutrition has been recognized since prehistoric times. Among the many compounds that are of the greatest industrial importance are common salt (NaCl), soda ash (Na_2CO_3), baking soda ($NaHCO_3$), caustic soda (NaOH), Chile saltpeter ($NaNO_3$), di- and tri-sodium phosphates, sodium thiosulfate (hypo, $Na_2S_2O_3 \cdot 5H_2O$), and borax ($Na_2B_4O_7 \cdot 10H_2O$). Seventeen isotopes of sodium are recognized. Metallic sodium is priced at about $130/kg (99.95%). On a volume basis, it is the cheapest of all metals. Sodium metal should be handled with great care. It should be kept in an inert atmosphere and contact with water and other substances with which sodium reacts should be avoided.

Strontium — (*Strontian*, town in Scotland), Sr; at. wt. 87.62(1); at. no. 38; m.p. 777°C; b.p. 1382°C; sp. gr. 2.54; valence 2. Isolated by Davey by electrolysis in 1808; however, Adair Crawford in 1790 recognized a new mineral (strontianite) as differing from other barium minerals (baryta). Strontium is found chiefly as *celestite* ($SrSO_4$) and *strontianite* ($SrCO_3$). *Celestite* is found in Mexico, Turkey, Iran, Spain, Algeria, and in the U.K. The U.S. has no active *celestite* mines. The metal can be prepared by electrolysis of the fused chloride mixed with potassium chloride, or is made by reducing strontium oxide with aluminum in a vacuum at a temperature at which strontium distills off. Three allotropic forms of the metal exist, with transition points at 235 and 540°C. Strontium is softer than calcium and decomposes water more vigorously. It does not absorb nitrogen below 380°C. It should be kept under mineral oil to prevent oxidation. Freshly cut strontium has a silvery appearance, but rapidly turns a yellowish color with the formation of the oxide. The finely divided metal ignites spontaneously in air. Volatile strontium salts impart a beautiful crimson color to flames, and these salts are used in pyrotechnics and in the production of flares. Natural strontium is a mixture of four stable isotopes. Thirty-two other unstable isotopes and isomers are known to exist. Of greatest importance is ^{90}Sr with a half-life of 29 years. It is a product of nuclear fallout and presents a health problem. This isotope is one of the best long-lived high-energy beta emitters known, and is used in SNAP (Systems for Nuclear Auxiliary Power) devices. These devices hold promise for use in space vehicles, remote weather stations, navigational buoys, etc., where a lightweight, long-lived, nuclear-electric power source is needed. The major use for strontium at present is in producing glass for color television picture tubes. All color TV and cathode ray tubes sold in the U.S. are required by law to contain strontium in the face plate glass to block X-ray emission. Strontium also improves the brilliance of the glass and the quality of the picture. It has also found use in producing ferrite magnets and in refining zinc. Strontium titanate is an interesting optical material as it has an extremely high refractive index and an optical dispersion greater than that of diamond. It has been used as a gemstone, but it is very soft. It does not occur naturally. Strontium metal (99% pure) costs about $220/kg.

Sulfur — (Sanskrit, *sulvere*; L. *sulphurium*), S; at. wt. 32.066(6); at. no. 16; m.p. 115.21°C; b.p. 444.60°C; t_c 1041°C; sp. gr. (rhombic) 2.07, (monoclinic) 1.957 (20°C); valence 2, 4, or 6. Known to the ancients; referred to in Genesis as *brimstone*. Sulfur is found in meteorites. A dark area near the crater Aristarchus on the moon has been studied by R. W. Wood with ultraviolet light. This study suggests strongly that it is a sulfur deposit. Sulfur occurs native in the vicinity of volcanoes and hot springs. It is widely distributed in nature as *iron pyrites, galena, sphalerite, cinnabar, stibnite, gypsum, Epsom salts, celestite, barite,*etc. Sulfur is commercially recovered from wells sunk into the salt domes along the Gulf Coast of the U.S. It is obtained from these wells by the Frasch process, which forces heated water into the wells to melt the sulfur, which is then brought to the surface. Sulfur also occurs in natural gas and petroleum crudes and must be removed from these products. Formerly this was done chemically, which wasted the sulfur. New processes now permit recovery, and these sources promise to be very important. Large amounts of sulfur are being recovered from Alberta gas fields. Sulfur is a pale yellow, odorless, brittle solid, which is insoluble in water but soluble in carbon disulfide. In every state, whether gas, liquid or solid, elemental sulfur occurs in more than one allotropic form or modification; these present a confusing multitude of forms whose relations are not yet fully understood. Amorphous or "plastic" sulfur is obtained by fast cooling of the crystalline form. X-ray studies indicate that amorphous sulfur may have a helical structure with eight atoms per spiral. Crystalline sulfur seems to be made of rings, each containing eight sulfur atoms, which fit together to give a normal X-ray pattern. Twenty-one isotopes of sulfur are now recognized. Four occur in natural sulfur, none of which is radioactive. A finely divided form of sulfur, known as *flowers of sulfur*, is obtained by sublimation. Sulfur readily forms sulfides with many elements. Sulfur is a component of black gunpowder, and is used in the vulcanization of natural rubber and a fungicide. It is also used extensively is making phosphatic fertilizers. A tremendous tonnage is used to produce sulfuric acid, the most important manufactured chemical. It is used in making sulfite paper and other papers, as a fumigant, and in the bleaching of dried fruits. The element is a good electrical insulator. Organic compounds containing

sulfur are very important. Calcium sulfate, ammonium sulfate, carbon disulfide, sulfur dioxide, and hydrogen sulfide are but a few of the many other important compounds of sulfur. Sulfur is essential to life. It is a minor constituent of fats, body fluids, and skeletal minerals. Carbon disulfide, hydrogen sulfide, and sulfur dioxide should be handled carefully. Hydrogen sulfide in small concentrations can be metabolized, but in higher concentrations it quickly can cause death by respiratory paralysis. It is insidious in that it quickly deadens the sense of smell. Sulfur dioxide is a dangerous component in atmospheric air pollution. In 1975, University of Pennsylvania scientists reported synthesis of polymeric sulfur nitride, which has the properties of a metal, although it contains no metal atoms. The material has unusual optical and electrical properties.

Tantalum — (Gr. *Tantalos*, mythological character, father of *Niobe*), Ta; at. wt. 180.9479(1); at. no. 73; m.p. 3017°C; b.p. 5458°C; sp. gr. 16.654; valence 2?, 3, 4?, or 5. Discovered in 1802 by Ekeberg, but many chemists thought niobium and tantalum were identical elements until Rose, in 1844, and Marignac, in1866, showed that niobic and tantalic acids were two different acids. The early investigators only isolated the impure metal. The first relatively pure ductile tantalum was produced by von Bolton in 1903. Tantalum occurs principally in the mineral *columbite-tantalite* $(Fe, Mn)(Nb, Ta)_2O_6$. Tantalum ores are found in Australia, Brazil, Rwanda, Zimbabwe, Congo-Kinshasa, Nigeria, and Canada. Separation of tantalum from niobium requires several complicated steps. Several methods are used to commercially produce the element, including electrolysis of molten potassium fluorotantalate, reduction of potassium fluorotantalate with sodium, or reacting tantalum carbide with tantalum oxide. Thirty four isotopes and isomers of tantalum are known to exist. Natural tantalum contains two isotopes, one of which is radioactive with a very long half-life. Tantalum is a gray, heavy, and very hard metal. When pure, it is ductile and can be drawn into fine wire, which is used as a filament for evaporating metals such as aluminum. Tantalum is almost completely immune to chemical attack at temperatures below 150°C, and is attacked only by hydrofluoric acid, acidic solutions containing the fluoride ion, and free sulfur trioxide. Alkalis attack it only slowly. At high temperatures, tantalum becomes much more reactive. The element has a melting point exceeded only by tungsten and rhenium. Tantalum is used to make a variety of alloys with desirable properties such as high melting point, high strength, good ductility, etc. Scientists at Los Alamos have produced a tantalum carbide graphite composite material, which is said to be one of the hardest materials ever made. The compound has a melting point of 3738°C. Tantalum has good "gettering" ability at high temperatures, and tantalum oxide films are stable and have good rectifying and dielectric properties. Tantalum is used to make electrolytic capacitors and vacuum furnace parts, which account for about 60% of its use. The metal is also widely used to fabricate chemical process equipment, nuclear reactors, and aircraft and missile parts. Tantalum is completely immune to body liquids and is a nonirritating metal. It has, therefore, found wide use in making surgical appliances. Tantalum oxide is used to make special glass with high index of refraction for camera lenses. The metal has many other uses. The price of (99.9%) tantalum is about $2/g.

Technetium — (Gr. *technetos*, artificial), Tc; at. wt. (98); at. no. 43; m.p. 2157°C; b.p. 4265°C; sp. gr. 11.50 (calc.); valence 0, +2, +4, +5, +6, and +7. Element 43 was predicted on the basis of the periodic table, and was erroneously reported as having been discovered in 1925, at which time it was named *masurium*. The element was actually discovered by Perrier and Segre in Italy in 1937. It was found in a sample of molybdenum, which was bombarded by deuterons in the Berkeley cyclotron, and which E. Lawrence sent to these investigators. Technetium was the first element to be produced artificially. Since its discovery, searches for the element in terrestrial materials have been made without success. If it does exist, the concentration must be very small. Technetium has been found in the spectrum of S-, M-, and N-type stars, and its presence in stellar matter is leading to new theories of the production of heavy elements in the stars. Forty-three isotopes and isomers of technetium, with atomic masses ranging from 86 to 113, are known. ^{97}Tc has a half-life of 2.6×10^6 years. ^{98}Tc has a half-life of 4.2×10^6 years. The isomeric isotope ^{95m}Tc, with a half-life of 61 days, is useful for tracer work, as it produces energetic gamma rays. Technetium metal has been produced in kilogram quantities. The metal was first prepared by passing hydrogen gas at 1100°C over Tc_2S_7. It is now conveniently prepared by the reduction of ammonium pertechnetate with hydrogen. Technetium is a silvery-gray metal that tarnishes slowly in moist air. Until 1960, technetium was available only in small amounts and the price was as high as $2800/g. ^{99}Tc is now commercially available to holders of O.R.N.L. permits at a price of $83/g plus packing charges. ^{99}Tc is available at a cost of $1.56/μCi. The chemistry of technetium is said to be similar to that of rhenium. Technetium dissolves in nitric acid, aqua regia, and conc. sulfuric acid, but is not soluble in hydrochloric acid of any strength. The element is a remarkable corrosion inhibitor for steel. It is reported that mild carbon steels may be effectively protected by as little as 55 ppm of $KTcO_4$ in aerated distilled water at temperatures up to 250°C. This corrosion protection is limited to closed systems, since technetium is radioactive and must be confined. ^{99}Tc has a specific activity of 6.2×10^8 Bq/g. Activity of this level must not be allowed to spread. ^{99}Tc is a contamination hazard and should be handled in a glove box. The metal is an excellent superconductor at 11°K and below.

Tellurium — (L. *tellus*, earth), Te; at. wt. 127.60(3); at. no. 52; m.p. 449.51°C; b.p. 988°C; sp. gr. 6.24 (20°C); valence 2, 4, or 6. Discovered by Muller von Reichenstein in 1782; named by Klaproth, who isolated it in 1798. Tellurium is occasionally found native, but is more often found as the telluride of gold (*calaverite*), and combined with other metals. It is recovered commercially from the anode muds produced during the electrolytic refining of blister copper. The U.S., Canada, Peru, and Japan are the largest Free World producers of the element. Crystalline tellurium has a silvery-white appearance, and when pure exhibits a metallic luster. It is brittle and easily pulverized. Amorphous tellurium is formed by precipitating tellurium from a solution of telluric or tellurous acid. Whether this form is truly amorphous, or made of minute crystals, is open to question. Tellurium is a p-type semiconductor, and shows greater conductivity in certain directions, depending on alignment of the atoms. Its conductivity increases slightly with exposure to light. It can be doped with silver, copper, gold, tin, or other elements. In air, tellurium burns with a greenish-blue flame, forming the dioxide. Molten tellurium corrodes iron, copper, and stainless steel. Tellurium and its compounds are probably toxic and should be handled with care. Workmen exposed to as little as 0.01 mg/m^3 of air, or less, develop "tellurium breath," which has a garlic-like odor. Forty two isotopes and isomers of tellurium are known, with atomic masses ranging from 106 to 138. Natural tellurium consists of eight isotopes, two of which are radioactive with very long half-lives. Tellurium improves the machinability of copper and stainless steel, and its addition to lead decreases the corrosive action of sulfuric acid on lead and improves its strength and hardness. Tellurium catalysts are used in the oxidation of organic compounds and are used in hydrogenation and halogenation reactions. Tellurium is also used in electronic and semi-conductor devices. It is also used as a basic ingredient in blasting caps, and is added to cast iron for chill control. Tellurium is used in ceramics. Bismuth telluride has been used in thermoelectric devices. Tellurium costs about 20¢/g, with a purity of about 99.5%. The metal with a purity of 99.9999% costs about $6/g.

Terbium — (*Ytterby*, village in Sweden), Tb; at. wt. 158.92534(2); at. no. 65; m.p. 1356°C; b.p. 3230°C; sp. gr. 8.230; valence 3, 4. Discovered by Mosander in 1843. Terbium is a member of the lanthanide or "rare earth" group of elements. It is found in *cerite*, *gadolinite*, and other minerals along with other rare earths. It is recovered commercially from *monazite* in which it is present to the extent of 0.03%, from *xenotime*, and from *euxenite*,

a complex oxide containing 1% of more of terbia. Terbium has been isolated only in recent years with the development of ion-exchange techniques for separating the rare-earth elements. As with other rare earths, it can be produced by reducing the anhydrous chloride or fluoride with calcium metal in a tantalum crucible. Calcium and tantalum impurities can be removed by vacuum remelting. Other methods of isolation are possible. Terbium is reasonably stable in air. It is a silver-gray metal, and is malleable, ductile, and soft enough to be cut with a knife. Two crystal modifications exist, with a transformation temperature of 1289°C. Forty-two isotopes and isomers are recognized. The oxide is a chocolate or dark maroon color. Sodium terbium borate is used as a laser material and emits coherent light at 0.546 µm. Terbium is used to dope calcium fluoride, calcium tungstate, and strontium molybdate, used in solid-state devices. The oxide has potential application as an activator for green phosphors used in color TV tubes. It can be used with ZrO_2 as a crystal stabilizer of fuel cells which operate at elevated temperature. Few other uses have been found. The element is priced at about $40/g (99.9%). Little is known of the toxicity of terbium. It should be handled with care as with other lanthanide elements.

Thallium — (Gr. *thallos*, a green shoot or twig), Tl; at. wt. 204.3833(2); at. no. 81; m.p. 304°C; b.p. 1473°C; sp. gr. 11.85 (20°C); valence 1, or 3. Thallium was discovered spectroscopically in 1861 by Crookes. The element was named after the beautiful green spectral line, which identified the element. The metal was isolated both by Crookes and Lamy in 1862 about the same time. Thallium occurs in *crooksite, lorandite,* and *hutchinsonite*. It is also present in *pyrites* and is recovered from the roasting of this ore in connection with the production of sulfuric acid. It is also obtained from the smelting of lead and zinc ores. Extraction is somewhat complex and depends on the source of the thallium. Manganese nodules, found on the ocean floor, contain thallium. When freshly exposed to air, thallium exhibits a metallic luster, but soon develops a bluish-gray tinge, resembling lead in appearance. A heavy oxide builds up on thallium if left in air, and in the presence of water the hydroxide is formed. The metal is very soft and malleable. It can be cut with a knife. Forty-seven isotopes of thallium, with atomic masses ranging from 179 to 210 are recognized. Natural thallium is a mixture of two isotopes. The element and its compounds are toxic and should be handled carefully. Contact of the metal with skin is dangerous, and when melting the metal adequate ventilation should be provided. Thallium is suspected of carcinogenic potential for man. Thallium sulfate has been widely employed as a rodenticide and ant killer. It is odorless and tasteless, giving no warning of its presence. Its use, however, has been prohibited in the U.S. since 1975 as a household insecticide and rodenticide. The electrical conductivity of thallium sulfide changes with exposure to infrared light, and this compound is used in photocells. Thallium bromide-iodide crystals have been used as infrared optical materials. Thallium has been used, with sulfur or selenium and arsenic, to produce low melting glasses which become fluid between 125 and 150°C. These glasses have properties at room temperatures similar to ordinary glasses and are said to be durable and insoluble in water. Thallium oxide has been used to produce glasses with a high index of refraction. Thallium has been used in treating ringworm and other skin infections; however, its use has been limited because of the narrow margin between toxicity and therapeutic benefits. A mercury-thallium alloy, which forms a eutectic at 8.5% thallium, is reported to freeze at –60°C, some 20° below the freezing point of mercury. Thallium metal (99.999%) costs about $2/g.

Thorium — (*Thor*, Scandinavian god of war), Th; at. wt. 232.0381(1); at. no. 90; m.p. 1750°C; b.p. 4788°C; sp. gr. 11.72; valence +2(?), +3(?), +4. Discovered by Berzelius in 1828. Thorium occurs in *thorite* ($ThSiO_4$) and in *thorianite* ($ThO_2 + UO_2$). Large deposits of thorium minerals have been reported in New England and elsewhere, but these have not yet been exploited. Thorium is now thought to be about three times as abundant as uranium and about as abundant as lead or molybdenum. The metal is a source of nuclear power. There is probably more energy available for use from thorium in the minerals of the earth's crust than from both uranium and fossil fuels. Any sizable demand for thorium as a nuclear fuel is still several years in the future. Work has been done in developing thorium cycle converter-reactor systems. Several prototypes, including the HTGR (high-temperature gas-cooled reactor) and MSRE (molten salt converter reactor experiment), have operated. While the HTGR reactors are efficient, they are not expected to become important commercially for many years because of certain operating difficulties. Thorium is recovered commercially from the mineral *monazite*, which contains from 3 to 9% ThO_2 along with rare-earth minerals. Much of the internal heat the earth produces has been attributed to thorium and uranium. Several methods are available for producing thorium metal: it can be obtained by reducing thorium oxide with calcium, by electrolysis of anhydrous thorium chloride in a fused mixture of sodium and potassium chlorides, by calcium reduction of thorium tetrachloride mixed with anhydrous zinc chloride, and by reduction of thorium tetrachloride with an alkali metal. Thorium was originally assigned a position in Group IV of the periodic table. Because of its atomic weight, valence, etc., it is now considered to be the second member of the *actinide* series of elements. When pure, thorium is a silvery-white metal which is air-stable and retains its luster for several months. When contaminated with the oxide, thorium slowly tarnishes in air, becoming gray and finally black. The physical properties of thorium are greatly influenced by the degree of contamination with the oxide. The purest specimens often contain several tenths of a percent of the oxide. High-purity thorium has been made. Pure thorium is soft, very ductile, and can be cold-rolled, swaged, and drawn. Thorium is dimorphic, changing at 1400°C from a cubic to a body-centered cubic structure. Thorium oxide has a melting point of 3300°C, which is the highest of all oxides. Only a few elements, such as tungsten, and a few compounds, such as tantalum carbide, have higher melting points. Thorium is slowly attacked by water, but does not dissolve readily in most common acids, except hydrochloric. Powdered thorium metal is often pyrophoric and should be carefully handled. When heated in air, thorium turnings ignite and burn brilliantly with a white light. The principal use of thorium has been in the preparation of the Welsbach mantle, used for portable gas lights. These mantles, consisting of thorium oxide with about 1% cerium oxide and other ingredients, glow with a dazzling light when heated in a gas flame. Thorium is an important alloying element in magnesium, imparting high strength and creep resistance at elevated temperatures. Because thorium has a low work-function and high electron emission, it is used to coat tungsten wire used in electronic equipment. The oxide is also used to control the grain size of tungsten used for electric lamps; it is also used for high-temperature laboratory crucibles. Glasses containing thorium oxide have a high refractive index and low dispersion. Consequently, they find application in high quality lenses for cameras and scientific instruments. Thorium oxide has also found use as a catalyst in the conversion of ammonia to nitric acid, in petroleum cracking, and in producing sulfuric acid. Thorium has not found many uses due to its radioactive nature and its handling and disposal problems. Thirty isotopes of thorium are known with atomic masses ranging from 210 to 237. All are unstable. ^{232}Th occurs naturally and has a half-life of 1.4×10^{10} years. It is an alpha emitter. ^{232}Th goes through six alpha and four beta decay steps before becoming the stable isotope ^{208}Pb. ^{232}Th is sufficiently radioactive to expose a photographic plate in a few hours. Thorium disintegrates with the production of "thoron" (^{220}Rn), which is an alpha emitter and presents a radiation hazard. Good ventilation of areas where thorium is stored or handled is therefore essential. Thorium metal (99.8%) costs about $25/g.

Thulium — (*Thule*, the earliest name for Scandinavia), Tm; at. wt. 168.93421(3); at. no. 69; m.p. 1545°C; b.p. 1950°C; sp. gr. 9.321 (25°C); valence 3. Discovered in 1879 by Cleve. Thulium occurs in small quantities along with other rare earths in a number of minerals. It is obtained commercially from *monazite*, which contains about 0.007% of the element. Thulium is the least abundant of the rare earth elements, but with new sources recently discovered, it is now considered to be about as rare as silver, gold, or cadmium. Ion-exchange and solvent extraction techniques have recently permitted

much easier separation of the rare earths, with much lower costs. Only a few years ago, thulium metal was not obtainable at any cost; in 1996 the oxide cost \$20/g. Thulium metal powder now costs \$70/g (99.9%). Thulium can be isolated by reduction of the oxide with lanthanum metal or by calcium reduction of the anhydrous fluoride. The pure metal has a bright, silvery luster. It is reasonably stable in air, but the metal should be protected from moisture in a closed container. The element is silver-gray, soft, malleable, and ductile, and can be cut with a knife. Forty-one isotopes and isomers are known, with atomic masses ranging from 146 to 176. Natural thulium, which is 100% ^{169}Tm, is stable. Because of the relatively high price of the metal, thulium has not yet found many practical applications. ^{169}Tm bombarded in a nuclear reactor can be used as a radiation source in portable X-ray equipment. ^{171}Tm is potentially useful as an energy source. Natural thulium also has possible use in *ferrites* (ceramic magnetic materials) used in microwave equipment. As with other lanthanides, thulium has a low-to-moderate acute toxic rating. It should be handled with care.

Tin — (anglo-Saxon, *tin*), Sn (L. *stannum*); at. wt. 118.710(7); at. no. 50; m.p. 231.93°C; b.p. 2602°C; sp. gr. (gray) 5.75, (white) 7.31; valence 2, 4. Known to the ancients. Tin is found chiefly in *cassiterite* (SnO_2). Most of the world's supply comes from China, Indonesia, Peru, Brazil, and Bolivia. The U.S. produces almost none, although occurrences have been found in Alaska and Colorado. Tin is obtained by reducing the ore with coal in a reverberatory furnace. Ordinary tin is composed of ten stable isotopes; thirty-six unstable isotopes and isomers are also known. Ordinary tin is a silver-white metal, is malleable, somewhat ductile, and has a highly crystalline structure. Due to the breaking of these crystals, a "tin cry" is heard when a bar is bent. The element has two allotropic forms at normal pressure. On warming, gray, or α tin, with a cubic structure, changes at 13.2°C into white, or β tin, the ordinary form of the metal. White tin has a tetragonal structure. When tin is cooled below 13.2°C, it changes slowly from white to gray. This change is affected by impurities such as aluminum and zinc, and can be prevented by small additions of antimony or bismuth. This change from the α to β form is called the tin pest. Tin-lead alloys are used to make organ pipes. There are few if any uses for gray tin. Tin takes a high polish and is used to coat other metals to prevent corrosion or other chemical action. Such tin plate over steel is used in the so-called tin can for preserving food. Alloys of tin are very important. Soft solder, type metal, fusible metal, pewter, bronze, bell metal, Babbitt metal, White metal, die casting alloy, and phosphor bronze are some of the important alloys using tin. Tin resists distilled sea and soft tap water, but is attacked by strong acids, alkalis, and acid salts. Oxygen in solution accelerates the attack. When heated in air, tin forms SnO_2, which is feebly acid, forming stannate salts with basic oxides. The most important salt is the chloride ($SnCl_2 \cdot H_2O$), which is used as a reducing agent and as a mordant in calico printing. Tin salts sprayed onto glass are used to produce electrically conductive coatings. These have been used for panel lighting and for frost-free windshields. Most window glass is now made by floating molten glass on molten tin (float glass) to produce a flat surface (Pilkington process). Of recent interest is a crystalline tin-niobium alloy that is superconductive at very low temperatures. This promises to be important in the construction of superconductive magnets that generate enormous field strengths but use practically no power. Such magnets, made of tin-niobium wire, weigh but a few pounds and produce magnetic fields that, when started with a small battery, are comparable to that of a 100 ton electromagnet operated continuously with a large power supply. The small amount of tin found in canned foods is quite harmless. The agreed limit of tin content in U.S. foods is 300 mg/kg. The trialkyl and triaryl tin compounds are used as biocides and must be handled carefully. Over the past 25 years the price of commercial tin has varied from 50¢/lb (\$1.10/kg) to its present price of about \$9/kg as of December 1999.

Titanium — (L. *Titans*, the first sons of the Earth, myth.), Ti; at. wt. 47.867(1); at. no. 22; m.p. 1668°C; b.p. 3287°C; sp. gr. 4.54; valence 2, 3, or 4. Discovered by Gregor in 1791; named by Klaproth in 1795. Impure titanium was prepared by Nilson and Pettersson in 1887; however, the pure metal (99.9%) was not made until 1910 by Hunter by heating $TiCl_4$ with sodium in a steel bomb. Titanium is present in meteorites and in the sun. Rocks obtained during the Apollo 17 lunar mission showed presence of 12.1% TiO_2. Analyses of rocks obtained during earlier Apollo missions show lower percentages. Titanium oxide bands are prominent in the spectra of M-type stars. The element is the ninth most abundant in the crust of the earth. Titanium is almost always present in igneous rocks and in the sediments derived from them. It occurs in the minerals *rutile, ilmenite*, and *sphene*, and is present in titanates and in many iron ores. Deposits of ilmenite and rutile are found in Florida, California, Tennessee, and New York. Australia, Norway, Malaysia, India, and China are also large suppliers of titanium minerals. Titanium is present in the ash of coal, in plants, and in the human body. The metal was a laboratory curiosity until Kroll, in 1946, showed that titanium could be produced commercially by reducing titanium tetrachloride with magnesium. This method is largely used for producing the metal today. The metal can be purified by decomposing the iodide. Titanium, when pure, is a lustrous, white metal. It has a low density, good strength, is easily fabricated, and has excellent corrosion resistance. It is ductile only when it is free of oxygen. The metal burns in air and is the only element that burns in nitrogen. Titanium is resistant to dilute sulfuric and hydrochloric acid, most organic acids, moist chlorine gas, and chloride solutions. Natural titanium consists of five isotopes with atomic masses from 46 to 50. All are stable. Eighteen other unstable isotopes are known. The metal is dimorphic. The hexagonal α form changes to the cubic β form very slowly at about 880°C. The metal combines with oxygen at red heat, and with chlorine at 550°C. Titanium is important as an alloying agent with aluminum, molybdenum, manganese, iron, and other metals. Alloys of titanium are principally used for aircraft and missiles where lightweight strength and ability to withstand extremes of temperature are important. Titanium is as strong as steel, but 45% lighter. It is 60% heavier than aluminum, but twice as strong. Titanium has potential use in desalination plants for converting sea water into fresh water. The metal has excellent resistance to sea water and is used for propeller shafts, rigging, and other parts of ships exposed to salt water. A titanium anode coated with platinum has been used to provide cathodic protection from corrosion by salt water. Titanium metal is considered to be physiologically inert; however, titanium powder may be a carcinogenic hazard. When pure, titanium dioxide is relatively clear and has an extremely high index of refraction with an optical dispersion higher than diamond. It is produced artificially for use as a gemstone, but it is relatively soft. Star sapphires and rubies exhibit their asterism as a result of the presence of TiO_2. Titanium dioxide is extensively used for both house paint and artist's paint, as it is permanent and has good covering power. Titanium oxide pigment accounts for the largest use of the element. Titanium paint is an excellent reflector of infrared, and is extensively used in solar observatories where heat causes poor seeing conditions. Titanium tetrachloride is used to iridize glass. This compound fumes strongly in air and has been used to produce smoke screens. The price of titanium metal (99.8%) is about \$800/kg.

Tungsten — (Swedish, *tung sten*, heavy stone); also known as *wolfram* (from *wolframite*, said to be named from *wolf rahm* or *spumi lupi*, because the ore interfered with the smelting of tin and was supposed to devour the tin), W; at. wt. 183.84(1); at. no. 74; m.p. 3422°C; b.p. 5555°C; sp. gr. 19.3 (20°C); valence 2, 3, 4, 5, or 6. In 1779 Peter Woulfe examined the mineral now known as *wolframite* and concluded it must contain a new substance. Scheele, in 1781, found that a new acid could be made from *tung sten* (a name first applied about 1758 to a mineral now known as *scheelite*). Scheele and Berman suggested the possibility of obtaining a new metal by reducing this acid. The de Elhuyar brothers found an acid in *wolframite* in 1783 that was identical to the acid of *tungsten*(tungstic acid) of Scheele, and in that year they succeeded in obtaining the element by reduction of this acid with charcoal. Tungsten occurs in *wolframite,* (Fe, Mn)WO_4; *scheelite*, $CaWO_4$; *huebnerite*, $MnWO_4$; and *ferberite*, $FeWO_4$. Important deposits of

tungsten occur in California, Colorado, Bolivia, Russia, and Portugal. China is reported to have about 75% of the world's tungsten resources. Natural tungsten contains five stable isotopes. Thirty two other unstable isotopes and isomers are recognized. The metal is obtained commercially by reducing tungsten oxide with hydrogen or carbon. Pure tungsten is a steel-gray to tin-white metal. Very pure tungsten can be cut with a hacksaw, and can be forged, spun, drawn, and extruded. The impure metal is brittle and can be worked only with difficulty. Tungsten has the highest melting point of all metals, and at temperatures over 1650°C has the highest tensile strength. The metal oxidizes in air and must be protected at elevated temperatures. It has excellent corrosion resistance and is attacked only slightly by most mineral acids. The thermal expansion is about the same as borosilicate glass, which makes the metal useful for glass-to-metal seals. Tungsten and its alloys are used extensively for filaments for electric lamps, electron and television tubes, and for metal evaporation work; for electrical contact points for automobile distributors; X-ray targets; windings and heating elements for electrical furnaces; and for numerous spacecraft and high-temperature applications. High-speed tool steels, Hastelloy®, Stellite®, and many other alloys contain tungsten. Tungsten carbide is of great importance to the metal-working, mining, and petroleum industries.Calcium and magnesium tungstates are widely used in fluorescent lighting; other salts of tungsten are used in the chemical and tanning industries. Tungsten disulfide is a dry, high-temperature lubricant, stable to 500°C. Tungsten bronzes and other tungsten compounds are used in paints. Zirconium tungstate has found recent applications (see under Zirconium). Tungsten powder (99.999%) costs about $2900/kg.

Uranium — (Planet *Uranus*), U; at. wt. 238.0289(1); at. no. 92; m.p. 1135°C; b.p. 4131°C; sp. gr. ~18.95; valence 2, 3, 4, 5, or 6. Yellow-colored glass, containing more than 1% uranium oxide and dating back to 79 A.D., has been found near Naples, Italy. Klaproth recognized an unknown element in *pitchblende* and attempted to isolate the metal in 1789. The metal apparently was first isolated in 1841 by Peligot, who reduced the anhydrous chloride with potassium. Uranium is not as rare as it was once thought. It is now considered to be more plentiful than mercury, antimony, silver, or cadmium, and is about as abundant as molybdenum or arsenic. It occurs in numerous minerals such as *pitchblende, uraninite, carnotite, autunite, uranophane, davidite,* and *tobernite*. It is also found in *phosphate rock, lignite, monazite sands*, and can be recovered commercially from these sources. Large deposits of uranium ore occur in Utah, Colorado, New Mexico, Canada, and elsewhere. Uranium can be made by reducing uranium halides with alkali or alkaline earth metals or by reducing uranium oxides by calcium, aluminum, or carbon at high temperatures. The metal can also be produced by electrolysis of KUF_5 or UF_4, dissolved in a molten mixture of $CaCl_2$ and NaCl. High-purity uranium can be prepared by the thermal decomposition of uranium halides on a hot filament. Uranium exhibits three crystallographic modifications as follows:

$$\alpha \xrightarrow{688°C} \beta \xrightarrow{776°C} \gamma$$

Uranium is a heavy, silvery-white metal which is pyrophoric when finely divided. It is a little softer than steel, and is attacked by cold water in a finely divided state. It is malleable, ductile, and slightly paramagnetic. In air, the metal becomes coated with a layer of oxide. Acids dissolve the metal, but it is unaffected by alkalis. Uranium has twenty three isotopes, one of which is an isomer and all of which are radioactive. Naturally occurring uranium contains 99.2745% by weight ^{238}U, 0.720% ^{235}U, and 0.0055% ^{234}U. Studies show that the percentage weight of ^{235}U in natural uranium varies by as much as 0.1%, depending on the source. The U.S.D.O.E. has adopted the value of 0.711 as being their "official" percentage of ^{235}U in natural uranium. Natural uranium is sufficiently radioactive to expose a photographic plate in an hour or so. Much of the internal heat of the earth is thought to be attributable to the presence of uranium and thorium. ^{238}U with a half-life of 4.46×10^9 years, has been used to estimate the age of igneous rocks. The origin of uranium, the highest member of the naturally occurring elements — except perhaps for traces of neptunium or plutonium — is not clearly understood, although it has been thought that uranium might be a decay product of elements of higher atomic weight, which may have once been present on earth or elsewhere in the universe. These original elements may have been formed as a result of a primordial "creation," known as "the big bang," in a supernova, or in some other stellar processes. The fact that recent studies show that most trans-uranic elements are extremely rare with very short half-lives indicates that it may be necessary to find some alternative explanation for the very large quantities of radioactive uranium we find on earth. Studies of meteorites from other parts of the solar system show a relatively low radioactive content, compared to terrestrial rocks. Uranium is of great importance as a nuclear fuel. ^{238}U can be converted into fissionable plutonium by the following reactions:

$$^{238}U(n,\gamma) \rightarrow {}^{239}U \xrightarrow{\beta} {}^{239}Np \xrightarrow{\beta} {}^{239}Pu$$

This nuclear conversion can be brought about in "breeder" reactors where it is possible to produce more new fissionable material than the fissionable material used in maintaining the chain reaction. ^{235}U is of even greater importance, for it is the key to the utilization of uranium. ^{235}U, while occurring in natural uranium to the extent of only 0.72%, is so fissionable with slow neutrons that a self-sustaining fission chain reaction can be made to occur in a reactor constructed from natural uranium and a suitable moderator, such as heavy water or graphite, alone. ^{235}U can be concentrated by gaseous diffusion and other physical processes, if desired, and used directly as a nuclear fuel, instead of natural uranium, or used as an explosive. Natural uranium, slightly enriched with ^{235}U by a small percentage, is used to fuel nuclear power reactors for the generation of electricity. Natural thorium can be irradiated with neutrons as follows to produce the important isotope ^{233}U.

$$^{232}Th(n,\gamma) \rightarrow {}^{233}Th \xrightarrow{\beta} {}^{233}Pa \xrightarrow{\beta} {}^{233}U$$

While thorium itself is not fissionable, ^{233}U is, and in this way may be used as a nuclear fuel. One pound of completely fissioned uranium has the fuel value of over 1500 tons of coal. The uses of nuclear fuels to generate electrical power, to make isotopes for peaceful purposes, and to make explosives are well known. The estimated world-wide production of the 437 nuclear power reactors in operation in 1998 amounted to about 352,000 Megawatt hours. In 1998 the U.S. had about 107 commercial reactors with an output of about 100,000 Megawatt-hours. Some nuclear-powered electric generating plants have recently been closed because of safety concerns. There are also serious problems with nuclear waste disposal that have not been completely resolved. Uranium in the U.S.A. is controlled by the U.S. Nuclear Regulatory Commission, under the Department of Energy. Uses are being found for the large quantities of "depleted" uranium, now available, where uranium-235 has been lowered to about 0.2%. Depleted uranium has been used for inertial guidance devices, gyrocompasses, counterweights for aircraft control surfaces, ballast for missile reentry vehicles, and as a shielding material for tanks, etc. Concerns, however, have been raised over its low radioactive properties. Uranium metal is used for X-ray targets for production

of high-energy X-rays. The nitrate has been used as photographic toner, and the acetate is used in analytical chemistry. Crystals of uranium nitrate are triboluminescent. Uranium salts have also been used for producing yellow "vaseline" glass and glazes. Uranium and its compounds are highly toxic, both from a chemical and radiological standpoint. Finely divided uranium metal, being pyrophoric, presents a fire hazard. The maximum permissible total body burden of natural uranium (based on radiotoxicity) is 0.2 μCi for soluble compounds. Recently, the natural presence of uranium and thorium in many soils has become of concern to homeowners because of the generation of radon and its daughters (see under Radon). Uranium metal is available commercially at a cost of about $6/g (99.7%) in air-tight glass under argon.

Unilnilium, Unnilbium, etc. — See under the opening paragraphs of this article and also under Elements 110 to 118.

Vanadium — (Scandinavian goddess, *Vanadis*), V; at. wt. 50.9415(1); at. no. 23; m.p. 1910°C; b.p. 3407°C; sp. gr. 6.11 (18.7°C); valence 2, 3, 4, or 5. Vanadium was first discovered by del Rio in 1801. Unfortunately, a French chemist incorrectly declared del Rio's new element was only impure chromium; del Rio thought himself to be mistaken and accepted the French chemist's statement. The element was rediscovered in 1830 by Sefstrom, who named the element in honor of the Scandinavian goddess *Vanadis* because of its beautiful multicolored compounds. It was isolated in nearly pure form by Roscoe, in 1867, who reduced the chloride with hydrogen. Vanadium of 99.3 to 99.8% purity was not produced until 1927. Vanadium is found in about 65 different minerals among which are *carnotite, roscoelite, vanadinite,* and *patronite* important sources of the metal. Vanadium is also found in phosphate rock and certain iron ores, and is present in some crude oils in the form of organic complexes. It is also found in small percentages in meteorites. Commercial production from petroleum ash holds promise as an important source of the element. China, South Africa, and Russia supply much of the world's vanadium ores. High-purity ductile vanadium can be obtained by reduction of vanadium trichloride with magnesium or with magnesium-sodium mixtures. Much of the vanadium metal being produced is now made by calcium reduction of V_2O_5 in a pressure vessel, an adaption of a process developed by McKechnie and Seybolt. Natural vanadium is a mixture of two isotopes, ^{50}V (0.25%) and ^{51}V (99.75%). ^{50}V is slightly radioactive, having a long half-life. Twenty other unstable isotopes are recognized. Pure vanadium is a bright white metal, and is soft and ductile. It has good corrosion resistance to alkalis, sulfuric and hydrochloric acid, and salt water, but the metal oxidizes readily above 660°C. The metal has good structural strength and a low fission neutron cross section, making it useful in nuclear applications. Vanadium is used in producing rust resistant, spring, and highspeed tool steels. It is an important carbide stabilizer in making steels. About 80% of the vanadium now produced is used as ferrovanadium or as a steel additive. Vanadium foil is used as a bonding agent in cladding titanium to steel. Vanadium pentoxide is used in ceramics and as a catalyst. It is also used in producing a superconductive magnet with a field of 175,000 gauss. Vanadium and its compounds are toxic and should be handled with care. Ductile vanadium is commercially available. Vanadium metal (99.7%) costs about $3/g.

Wolfram — see Tungsten.

Xenon — (Gr. *xenon,* stranger), Xe; at. wt. 131.29(2); at. no. 54; m.p. –111.79°C; b.p. –108.12°C; t_c 16.62°C; density (gas) 5.887 ± 0.009 g/l, sp. gr (liquid) 3.52 (–109°C); valence usually 0. Discovered by Ramsay and Travers in 1898 in the residue left after evaporating liquid air components. Xenon is a member of the so-called noble or "inert" gases. It is present in the atmosphere to the extent of about one part in twenty million. Xenon is present in the Martian atmosphere to the extent of 0.08 ppm. The element is found in the gases evolved from certain mineral springs, and is commercially obtained by extraction from liquid air. Natural xenon is composed of nine stable isotopes. In addition to these, thirty five unstable isotopes and isomers have been characterized. Before 1962, it had generally been assumed that xenon and other noble gases were unable to form compounds. Evidence has been mounting in the past few years that xenon, as well as other members of the zero valence elements, do form compounds. Among the "compounds" of xenon now reported are xenon hydrate, sodium perxenate, xenon deuterate, difluoride, tetrafluoride, hexafluoride, and $XePtF_6$ and $XeRhF_6$. Xenon trioxide, which is highly explosive, has been prepared. More than 80 xenon compounds have been made with xenon chemically bonded to fluorine and oxygen. Some xenon compounds are colored. Metallic xenon has been produced, using several hundred kilobars of pressure. Xenon in a vacuum tube produces a beautiful blue glow when excited by an electrical discharge. The gas is used in making electron tubes, stroboscopic lamps, bactericidal lamps, and lamps used to excite ruby lasers for generating coherent light. Xenon is used in the atomic energy field in bubble chambers, probes, and other applications where its high molecular weight is of value. The perxenates are used in analytical chemistry as oxidizing agents. ^{133}Xe and ^{135}Xe are produced by neutron irradiation in air cooled nuclear reactors. ^{133}Xe has useful applications as a radioisotope. The element is available in sealed glass containers for about $20/l of gas at standard pressure. Xenon is not toxic, but its compounds are highly toxic because of their strong oxidizing characteristics.

Ytterbium — (Ytterby, village in Sweden), Yb; at. wt. 173.04(3); at. no. 70; m.p. 819°C; b.p. 1196°C; sp. gr (α) 6.903 (β) 6.966; valence 2, 3. Marignac in 1878 discovered a new component, which he called *ytterbia*, in the earth then known as *erbia*. In 1907, Urbain separated ytterbia into two components, which he called *neoytterbia* and *lutecia*. The elements in these earths are now known as *ytterbium* and *lutetium,* respectively. These elements are identical with *aldebaranium* and *cassiopeium,* discovered independently and at about the same time by von Welsbach. Ytterbium occurs along with other rare earths in a number of rare minerals. It is commercially recovered principally from *monazite sand*, which contains about 0.03%. Ion-exchange and solvent extraction techniques developed in recent years have greatly simplified the separation of the rare earths from one another. The element was first prepared by Klemm and Bonner in 1937 by reducing ytterbium trichloride with potassium. Their metal was mixed, however, with KCl. Daane, Dennison, and Spedding prepared a much purer form in 1953 from which the chemical and physical properties of the element could be determined. Ytterbium has a bright silvery luster, is soft, malleable, and quite ductile. While the element is fairly stable, it should be kept in closed containers to protect it from air and moisture. Ytterbium is readily attacked and dissolved by dilute and concentrated mineral acids and reacts slowly with water. Ytterbium has three allotropic forms with transformation points at –13° and 795°C. The beta form is a room-temperature, face-centered, cubic modification, while the high-temperature gamma form is a body-centered cubic form. Another body-centered cubic phase has recently been found to be stable at high pressures at room temperatures. The beta form ordinarily has metallic-type conductivity, but becomes a semiconductor when the pressure is increased above 16,000 atm. The electrical resistance increases tenfold as the pressure is increased to 39,000 atm and drops to about 80% of its standard temperature-pressure resistivity at a pressure of 40,000 atm. Natural ytterbium is a mixture of seven stable isotopes. Twenty six other unstable isotopes and isomers are known. Ytterbium metal has possible use in improving the grain refinement, strength, and other mechanical properties of stainless steel. One isotope is reported to have been used as a radiation source as a substitute for a portable X-ray machine where electricity is unavailable. Few other uses have been found. Ytterbium metal is available with a purity of about 99.99% for about $20/g. Ytterbium has a low acute toxic rating, but may present a carcinogenic hazard.

Yttrium — (*Ytterby*, village in Sweden near Vauxholm), Y; at. wt. 88.90585(2); at. no. 39; m.p. 1522°C; b.p. 3345°C; sp. gr. 4.469 (25°C); valence 3. *Yttria*, which is an earth containing yttrium, was discovered by Gadolin in 1794. *Ytterby* is the site of a quarry which yielded many unusually minerals

containing rare earths and other elements. This small town, near Stockholm, bears the honor of giving names to *erbium*, *terbium*, and *ytterbium* as well as *yttrium*. In 1843 Mosander showed that yttria could be resolved into the oxides (or earths) of three elements. The name yttria was reserved for the most basic one; the others were named *erbia* and *terbia*. Yttrium occurs in nearly all of the rare-earth minerals. Analysis of lunar rock samples obtained during the Apollo missions show a relatively high yttrium content. It is recovered commercially from *monazite sand,* which contains about 3%, and from *bastnasite*, which contains about 0.2%. Wohler obtained the impure element in 1828 by reduction of the anhydrous chloride with potassium. The metal is now produced commercially by reduction of the fluoride with calcium metal. It can also be prepared by other techniques. Yttrium has a silver-metallic luster and is relatively stable in air. Turnings of the metal, however, ignite in air if their temperature exceeds 400°C, and finely divided yttrium is very unstable in air. Yttrium oxide is one of the most important compounds of yttrium and accounts for the largest use. It is widely used in making YVO_4 europium, and Y_2O_3 europium phosphors to give the red color in color television tubes. Many hundreds of thousands of pounds are now used in this application. Yttrium oxide also is used to produce yttrium-iron-garnets, which are very effective microwave filters. Yttrium iron, aluminum, and gadolinium garnets, with formulas such as $Y_3Fe_5O_{12}$ and $Y_3Al_5O_{12}$, have interesting magnetic properties. Yttrium iron garnet is also exceptionally efficient as both a transmitter and transducer of acoustic energy. Yttrium aluminum garnet, with a hardness of 8.5, is also finding use as a gemstone (simulated diamond). Small amounts of yttrium (0.1 to 0.2%) can be used to reduce the grain size in chromium, molybdenum, zirconium, and titanium, and to increase strength of aluminum and magnesium alloys. Alloys with other useful properties can be obtained by using yttrium as an additive. The metal can be used as a deoxidizer for vanadium and other nonferrous metals. The metal has a low cross section for nuclear capture. ^{90}Y, one of the isotopes of yttrium, exists in equilibrium with its parent ^{90}Sr, a product of atomic explosions. Yttrium has been considered for use as a nodulizer for producing nodular cast iron, in which the graphite forms compact nodules instead of the usual flakes. Such iron has increased ductility. Yttrium is also finding application in laser systems and as a catalyst for ethylene polymerization.It has also potential use in ceramic and glass formulas, as the oxide has a high melting point and imparts shock resistance and low expansion characteristics to glass. Natural yttrium contains but one isotope, ^{89}Y. Forty-three other unstable isotopes and isomers have been characterized. Yttrium metal of 99.9% purity is commercially available at a cost of about $3/g.

Zinc — (Ger. *Zink*, of obscure origin), Zn; at. wt. 65.39(2); at. no. 30; m.p. 419.53°C; b.p. 907°C; sp. gr. 7.133 (25°C); valence 2. Centuries before zinc was recognized as a distinct element, zinc ores were used for making brass. Tubal-Cain, seven generations from Adam, is mentioned as being an "instructor in every artificer in brass and iron." An alloy containing 87% zinc has been found in prehistoric ruins in Transylvania. Metallic zinc was produced in the 13th century A.D. in India by reducing calamine with organic substances such as wool. The metal was rediscovered in Europe by Marggraf in 1746, who showed that it could be obtained by reducing *calamine* with charcoal. The principal ores of zinc are *sphalerite* or *blende* (sulfide), *smithsonite* (carbonate), *calamine* (silicate), and *franklinite* (zinc, manganese, iron oxide). Canada, Japan, Belgium, Germany, and The Netherlands are suppliers of zinc ores. Zinc is also mined in Alaska, Tennessee, Missouri, and elsewhere in the U.S. Zinc can be obtained by roasting its ores to form the oxide and by reduction of the oxide with coal or carbon, with subsequent distillation of the metal. Other methods of extraction are possible. Naturally occurring zinc contains five stable isotopes. Twenty-five other unstable isotopes and isomers are recognized. Zinc is a bluish-white, lustrous metal. It is brittle at ordinary temperatures but malleable at 100 to 150°C. It is a fair conductor of electricity, and burns in air at high red heat with evolution of white clouds of the oxide. The metal is employed to form numerous alloys with other metals. Brass, nickel silver, typewriter metal, commercial bronze, spring brass, German silver, soft solder, and aluminum solder are some of the more important alloys. Large quantities of zinc are used to produce die castings, used extensively by the automotive, electrical, and hardware industries. An alloy called *Prestal®*, consisting of 78% zinc and 22% aluminum is reported to be almost as strong as steel but as easy to mold as plastic. It is said to be so plastic that it can be molded into form by relatively inexpensive die casts made of ceramics and cement. It exhibits superplasticity. Zinc is also extensively used to galvanize other metals such as iron to prevent corrosion. Neither zinc nor zirconium is ferromagnetic; but $ZrZn_2$ exhibits ferromagnetism at temperatures below 35 K. Zinc oxide is a unique and very useful material to modern civilization. It is widely used in the manufacture of paints, rubber products, cosmetics, pharmaceuticals, floor coverings, plastics, printing inks, soap, storage batteries, textiles, electrical equipment, and other products. It has unusual electrical, thermal, optical, and solid-state properties that have not yet been fully investigated. Lithopone, a mixture of zinc sulfide and barium sulfate, is an important pigment. Zinc sulfide is used in making luminous dials, X-ray and TV screens, and fluorescent lights. The chloride and chromate are also important compounds. Zinc is an essential element in the growth of human beings and animals. Tests show that zinc-deficient animals require 50% more food to gain the same weight as an animal supplied with sufficient zinc. Zinc is not considered to be toxic, but when freshly formed ZnO is inhaled a disorder known as the *oxide shakes* or *zinc chills* sometimes occurs. It is recommended that where zinc oxide is encountered good ventilation be provided. The commercial price of zinc was roughly 60¢/lb ($1.30 kg). Zinc metal with a purity of 99.9999% is priced at about $6/g.

Zirconium — (Syriac, *zargun*, color of gold), Zr; at. wt. 91.224(2); at. no. 40; m.p. 1855°C; b.p. 4409°C; sp. gr. 6.506 (20°C); valence +2, +3, and +4. The name *zircon* may have originated from the Syriac word *zargono*, which describes the color of certain gemstones now known as *zircon, jargon, hyacinth, jacinth,* or *ligure.*This mineral, or its variations, is mentioned in biblical writings. These minerals were not known to contain this element until Klaproth, in 1789, analyzed a *jargon* from Sri Lanka and found a new earth, which Werner named zircon (*silex circonius*), and Klaproth called *Zirkonerde (zirconia)*. The impure metal was first isolated by Berzelius in 1824 by heating a mixture of potassium and potassium zirconium fluoride in a small iron tube. Pure zirconium was first prepared in 1914. Very pure zirconium was first produced in 1925 by van Arkel and de Boer by an iodide decomposition process they developed. Zirconium is found in abundance in S-type stars, and has been identified in the sun and meteorites. Analyses of lunar rock samples obtained during the various Apollo missions to the moon show a surprisingly high zirconium oxide content, compared with terrestial rocks. Naturally occurring zirconium contains five isotopes. Thirty-one other radioactive isotopes and isomers are known to exist. *Zircon*, $ZrSiO_4$, the principal ore, is found in deposits in Florida, South Carolina, Australia, South Africa, and elsewhere. *Baddeleyite*, found in Brazil, is an important zirconium mineral. It is principally pure ZrO_2in crystalline form having a hafnium content of about 1%. Zirconium also occurs in some 30 other recognized mineral species. Zirconium is produced commercially by reduction of the chloride with magnesium (the Kroll Process), and by other methods. It is a grayish-white lustrous metal. When finely divided, the metal may ignite spontaneously in air, especially at elevated temperatures. The solid metal is much more difficult to ignite. The inherent toxicity of zirconium compounds is low. Hafnium is invariably found in zirconium ores, and the separation is difficult. Commercial-grade zirconium contains from 1 to 3% hafnium. Zirconium has a low absorption cross section for neutrons, and is therefore used for nuclear energy applications, such as for cladding fuel elements. Commercial nuclear power generation now takes more than 90% of zirconium metal production. Reactors of the size now being made may use as much as a half-million lineal feet of zirconium alloy tubing. Reactor-grade zirconium is essentially free of hafnium. *Zircaloy®* is an important alloy developed specifically for nuclear applications. Zirconium is exceptionally resistant to corrosion by many common acids and alkalis, by sea water, and by other agents. It is used extensively by the chemical

industry where corrosive agents are employed. Zirconium is used as a getter in vacuum tubes, as an alloying agent in steel, in surgical appliances, photoflash bulbs, explosive primers, rayon spinnerets, lamp filaments, etc. It is used in poison ivy lotions in the form of the carbonate as it combines with *urushiol*. With niobium, zirconium is superconductive at low temperatures and is used to make superconductive magnets, which offer hope of direct large-scale generation of electric power. Alloyed with zinc, zirconium becomes magnetic at temperatures below 35 K. Zirconium oxide (zircon) has a high index of refraction and is used as a gem material. The impure oxide, zirconia, is used for laboratory crucibles that will withstand heat shock, for linings of metallurgical furnaces, and by the glass and ceramic industries as a refractory material. Its use as a refractory material accounts for a large share of all zirconium consumed. Zirconium tungstate is an unusual material that shrinks, rather than expands, when heated. While this compound has been known for more than 30 years, it is only now that it is being studied to determine the nature of this unusual behavior. A few other compounds are known to possess this property, but they tend to shrink in one direction, while they stretch out in others in order to maintain an overall volume. Zirconium tungstate shrinks in all directions over a wide temperature range of from near absolute zero to +777°C. This material is being considered for use in very small computer chips, which are subject to severe temperature changes. It is also being considered for use in composite materials where thermal expansion may be a problem. Zirconium of about 99.5% purity is available at a cost of about $2100/kg or about $3/g.

PHYSICAL CONSTANTS OF INORGANIC COMPOUNDS

The compounds in this table were selected on the basis of their laboratory and industrial importance, as well as their value in illustrating trends in the variation of physical properties with position in the periodic table. An effort has been made to include the most frequently encountered inorganic substances; organometallics are not covered, with the exception of metal salts of organic acids. Many, if not most, of the compounds that are solids at ambient temperature can exist in more than one crystalline modification. The information given here applies to the most stable or common crystalline form. In cases where two or more forms are of practical importance, separate entries will be found in the table.

In the default listing, the compounds are arranged primarily in alphabetical order by the most commonly used name. However, adjustments are made in many instances in order to bring closely related compounds together. For example, hydrides of elements such as boron, silicon, and germanium are grouped together immediately following the entry for the parent element, since they would otherwise be scattered throughout the table. Likewise, the oxoacids of an element are given in one group when a strict alphabetical order would separate them (e.g., sulfuric acid and fluorosulfuric acid). The data fields in the table are described below.

- **Name**: Systematic name for the substance. The valence state of a metallic element is indicated by a Roman numeral, e.g., copper in the +2 state is written as copper(II) rather than cupric.
- **Synony**m: Another name in common use.
- **Formula**: The formula as most commonly written (generally, not in Hill order). The formula given does not necessarily specify the actual structure of the compound. For example, aluminum chloride is designated as $AlCl_3$, even though a more accurate representation of the structure in the solid phase (and, under some conditions, in the gas phase) is Al_2Cl_6. A few exceptions are made, such as the use of Hg_2^{+2} for the mercury(I) ion.
- **CAS Reg. No**.: Chemical Abstracts Service Registry Number. An asterisk* following the CAS RN for a hydrate indicates that the number refers to the anhydrous compound. In most cases the generic CAS RN for the compound is given rather than the number for a specific crystalline form or mineral.
- **Mol. Wt.**: Molecular weight (relative molar mass) as calculated with the 1997 IUPAC Recommended Atomic Weights. The number of decimal places corresponds to the number of places in the atomic weight of the least accurately known element (e.g., one place for lead compounds, two places for compounds of selenium, germanium, etc.); a maximum of three places is given. For compounds of radioactive elements for which IUPAC makes no recommendation, the mass number of the isotope with longest half-life is used, and the result is rounded to the nearest integer.
- **Physical Form**: The crystal system is given, when available, for compounds that are solid at room temperature, together with color and other descriptive features.
- **mp**: Normal melting point in °C. The notation "tp" indicates the temperature where solid, liquid, and gas are in equilibrium at a pressure greater than one atmosphere (i.e., the normal melting point does not exist). When available, the triple point pressure is listed.

- **bp**: Normal boiling point in °C (referred to 101.325 kPa or 760 mmHg pressure). The notation "sp" following the number indicates the temperature where the pressure of the vapor in equilibrium with the solid reaches 101.325 kPa. See Reference 8, p. 23, for further discussion of sublimation points and triple points. A notation "sub" without a temperature being given indicates that there is a perceptible sublimation pressure above the solid at ambient temperatures.
- **ρ**: Density. Values for solids and liquids are given in g/cm^3 and can be assumed to refer to temperatures near room temperature unless otherwise stated. Values for gases are the calculated ideal gas densities in g/L at 25°C and 101.325 kPa.
- **Sol**. Aqueous solubility expressed as the number of grams of the compound (excluding any water of hydration) that will dissolve in 100 g of water. The temperature in °C is given as a superscript.
- **Qualitative Sol**: Qualitative information on the solubility in various solvents is given. The abbreviations are:

i	insoluble
sl	slightly soluble
s	soluble
vs	very soluble
reac	reacts

LIST OF ABBREVIATIONS

Ac	acetyl
ace	acetone
acid	acid solutions
alk	alkaline solutions
amorp	amorphous
anh	anhydrous
aq	aqueous
blk	black
brn	brown
bz	benzene
chl	chloroform
col	colorless
conc	concentrated
cry	crystals, crystalline
cub	cubic
cyhex	cyclohexane
dec	decomposes
dil	dilute
diox	dioxane
eth	ethyl ether
EtOH	ethanol
exp	explodes, explosive
flam	flammable

gl	glass, glassy
grn	green
hc	hydrocarbon solvents
hex	hexagonal
hp	heptane
hex	hexane
hyd	hydrate
hyg	hygroscopic
i	insoluble in
liq	liquid
MeOH	methanol
mono	monoclinic
octahed	octahedral
oran	orange
orth	orthorhombic
os	organic solvents
peth	petroleum ether
pow	powder
prec	precipitate
pur	purple
py	pyridine
reac	reacts with
refrac	refractory
rhom	rhombohedral
s	soluble in
silv	silvery
sl	slightly soluble in
soln	solution
sp	sublimation point
stab	stable
subl	sublimes
temp	temperature
tetr	tetragonal
thf	tetrahydrofuran
tol	toluene
tp	triple point
trans	transition, transformation
tricl	triclinic
trig	trigonal
unstab	unstable
viol	violet
visc	viscous
vs	very soluble in
wh	white
xyl	xylene
yel	yellow

REFERENCES

1. Phillips, S. L., and Perry, D.L., *Handbook of Inorganic Compounds*, CRC Press, Boca Raton, FL, 1995.
2. Trotman-Dickenson, A. F., Executive Editor, *Comprehensive Inorganic Chemistry*, Vol. 1-5, Pergamon Press, Oxford, 1973.
3. Greenwood, N. N., and Earnshaw, A., *Chemistry of the Elements, Second Edition*, Butterworth-Heinemann, Oxford, 1997.
4. Budavari, S., Editor, *The Merck Index, Twelfth Edition*, Merck & Co., Rahway, NJ, 1996.
5. *GMELIN Handbook of Inorganic and Organometallic Chemistry*, Springer-Verlag, Heidelberg.
6. Chase, M.W., Davies, C.A., Downey, J.R., Frurip, D. J., McDonald, R.A., and Syverud, A.N.; *JANAF Thermochemical Tables, Third Edition*, *J. Phys. Chem. Ref. Data*, Vol. 14, Suppl. 1, 1985; Chase, M. W., *NIST-JANAF Thermochemical Tables, Fourth Edition, J. Phys. Chem. Ref. Data,* Monograph No. 9, 1998.
7. Donnay, J.D.H., and Ondik, H.M., *Crystal Data Determinative Tables, Third Edition*, Volumes 2 and 4, Inorganic Compounds, Joint Committee on Powder Diffraction Standards, Swarthmore, PA, 1973.
8. Lide, D. R., and Kehiaian, H.V., *CRC Handbook of Thermophysical and Thermochemical Data*, CRC Press, Boca Raton, FL, 1994.
9. *Kirk-Othmer Concise Encyclopedia of Chemical Technology*, Wiley-Interscience, New York, 1985.
10. *Dictionary of Inorganic Compounds*, Chapman & Hall, New York, 1992.
11. Massalski, T. B., ed., *Binary Alloy Phase Diagrams*, *2nd Edition*, ASM International, Metals Park, Ohio, 1990.
12. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, Sixth Edition*, II/4, Caloric Quantities of State, Springer-Verlag, Heidelberg, 1961.
13. Deer, W. A., Howie, R.A., and Zussman, J., An *Introduction to the Rock-Forming Minerals*, 2nd Edition, Longman Scientific & Technical, Harlow, Essex, 1992.
14. Carmichael, R. S., *Practical Handbook of Physical Properties of Rocks and Minerals*, CRC Press, Boca Raton, FL, 1989.
15. Dinsdale, A.T., "SGTE Data for Pure Elements", *CALPHAD*, 15, 317-425, 1991.
16. Madelung, O., *Semiconductors: Group IV Elements and III-IV Compounds*, Springer-Verlag, Heidelberg, 1991.
17. Daubert, T.E., Danner, R. P., Sibul, H.M., and Stebbins, C.C., *Physical and Thermodynamic Properties of Pure Compounds: Data Compilation*, extant 1994 (core with 4 supplements), Taylor & Francis, Bristol, PA.
18. Lidin, R. A., Andreeva, L. L., and Molochko, V. A., *Constants of Inorganic Substances*, Begell House, New York, 1995.
19. Gurvich, L. V., Veyts, I. V., and Alcock, C. B., *Thermodynamic Properties of Individual Substances, Fourth Edition*, Hemisphere Publishing Corp., New York, 1989.
20. *The Combined Chemical Dictionary on CDROM*, Chapman & Hall / CRC Press, Boca Raton & London, 2000.

PHYSICAL PROPERTIES OF THE RARE EARTH METALS

K.A. Gschneidner, Jr.

Table 1
Data for the Trivalent Ions of the Rare Earth Elements

Rare earth	Symbol	Atomic no.	Atomic wt.[a]	Electronic configuration for R^{3+}				Spectroscopic ground state symbol
				No. 4f electrons	*S*	*L*	*J*	
Scandium	Sc	21	44.955910	0	—	—	—	—
Yttrium	Y	39	88.90585	0	—	—	—	—
Lanthanum	La	57	138.9055	0	—	—	—	—
Cerium	Ce	58	140.115	1	1/2	3	5/2	$^2F_{5/2}$
Praseodymium	Pr	59	140.90765	2	1	5	4	$^3H_4$
Neodymium	Nd	60	144.24	3	3/2	6	9/2	$^4I_{9/2}$
Promethium	Pm	61	(145)	4	2	6	4	$^5I_4$
Samarium	Sm	62	150.36	5	5/2	5	5/2	$^6H_{5/2}$
Europium	Eu	63	151.965	6	3	3	0	$^7F_0$
Gadolinium	Gd	64	157.25	7	7/2	0	7/2	$^8S_{7/2}$
Terbium	Tb	65	158.92534	8	3	3	6	$^7F_6$
Dysprosium	Dy	66	162.50	9	5/2	5	15/2	$^6H_{15/2}$
Holmium	Ho	67	164.93032	10	2	6	8	$^5I_8$
Erbium	Er	68	167.26	11	3/2	6	15/2	$^4I_{15/2}$
Thulium	Tm	69	168.93421	12	1	5	6	$^3H_6$
Ytterbium	Yb	70	173.04	13	1/2	3	7/2	$^2F_{7/2}$
Lutetium	Lu	71	174.967	14	—	—	—	—

Note: For additional information, see Goldschmidt, Z.B., in *Handbook on the Physics and Chemistry of Rare Earths,* Vol. 1, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1978; DeLaeter, J.R., and Heumann, K.G., *J. Phys. Chem. Ref. Data,* 20, 1313 , 1991; *Pure Appl. Chem.,* 66, 2423, 1994.

[a] 1993 standard atomic weights.

Table 2
Crystallographic Data for the Rare Earth Metals at 24°C (297 K) or Below

Rare earth metal	Crystal structure[a]	Lattice constants(Å)			Metallic radius CN = 12 (Å)	Atomic volume (cm^3/mol)	Density (g/cm^3)
		a_o	b_o	c_o			
αSc	hcp	3.3088	—	5.2680	1.6406	15.039	2.989
αY	hcp	3.6482	—	5.7318	1.8012	19.893	4.469
αLa	dhcp	3.7740	—	12.171	1.8791	22.602	6.146
αCe[b]	fcc	4.85[b]	—	—	1.72[b]	17.2[b]	8.16[b]
βCe	dhcp	3.6810	—	11.857	1.8321	20.947	6.689
γCe[c]	fcc	5.1610	—	—	1.8247	20.696	6.770
αPr	dhcp	3.6721	—	11.8326	1.8279	20.803	6.773
αNd	dhcp	3.6582	—	11.7966	1.8214	20.583	7.008
αPm	dhcp	3.65	—	11.65	1.811	20.24	7.264
αSm	rhomb[d]	3.6290[d]	—	26.207	1.8041	20.000	7.520
Eu	bcc	4.5827	—	—	2.0418	28.979	5.244
αGd	hcp	3.6336	—	5.7810	1.8013	19.903	7.901
α′Tb[e]	ortho	3.605[e]	6.244[e]	5.706[e]	1.784[e]	19.34[e]	8.219[e]
αTb	hcp	3.6055	—	5.6966	1.7833	19.310	8.230
α′Dy[f]	ortho	3.595[f]	6.184[f]	5.678[f]	1.774[f]	19.00[f]	8.551[f]
αDy	hcp	3.5915	—	5.6501	1.7740	19.004	8.551
Ho	hcp	3.5778	—	5.6178	1.7661	18.752	8.795

Table 2
Crystallographic Data for the Rare Earth Metals at 24°C (297 K) or Below (continued)

Rare earth metal	Crystal structure[a]	Lattice constants(Å) a_o	b_o	c_o	Metallic radius CN = 12 (Å)	Atomic volume (cm^3/mol)	Density (g/cm^3)
Er	hcp	3.5592	—	5.5850	1.7566	18.449	9.066
Tm	hcp	3.5375	—	5.5540	1.7462	18.124	9.321
αYb[g]	hcp	3.8799[g]	—	6.3859[g]	1.9451[g]	25.067[g]	6.903[g]
βYb	fcc	5.4848	—	—	1.9392	24.841	6.966
Lu	hcp	3.5052	—	5.5494	1.7349	17.779	9.841

Note: For additional information, see Gschneidner, K.A., Jr. and Calderwood, F.W., in *Handbook on the Physics and Chemistry of Rare Earths*, Vol. 8, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1986; Gschneidner, K.A., Jr., Pecharsky, V.K., Cho, Jaephil and Martin, S.W., *Scripta Mater.*, 1996, to be published.

[a] hcp = hexagonal close-packed; $P6_3/mmc$, hP2, A3, Mg-type; dhcp = double-c hexagonal close-packed; $P6_3/mmc$, hP4, A3′, αLa-type; fcc = face-centered cubic; $Fm\bar{3}m$, cF4, A1, Cu-type; rhomb = rhombohedral; $R\bar{3}m$, hR3, αSm-type; bcc = body-centered cubic; $Im\bar{3}m$, cI2, A2, W-type; ortho = orthorhombic; Cmcm, oC4, α′ Dy-type.
[b] At 77 K (–196°C).
[c] Equilibrium room temperature (standard state) phase.
[d] Rhombohedral is the primitive cell. Lattice parameters given are for the nonprimitive hexagonal cell.
[d] At 220 K (–53°C).
[f] At 86 K (–187°C).
[g] At 23°C.

Table 3
Crystallographic Data for Rare Earth Metals at High Temperature

Rare earth metal	Structure	Lattice parameter (Å)	Temp. (°C)	Metallic radius CN = 8 (Å)	CN = 12 (Å)	Atomic volume (cm^3/mol)	Density (g/cm^3)
βSc	bcc	3.73 (est.)	1337	1.62	1.66	15.6	2.88
βY	bcc	4.10[a]	1478	1.78	1.83	20.8	4.28
βLa	fcc	5.303	325	—	1.875	22.45	6.187
γLa	bcc	4.26	887	1.84	1.90	23.3	5.97
δCe	bcc	4.12	757	1.78	1.84	21.1	6.65
βPr	bcc	4.13	821	1.79	1.84	21.2	6.64
βNd	bcc	4.13	883	1.79	1.84	21.2	6.80
βPm	bcc	4.10 (est.)	890	1.78	1.83	20.8	6.99
βSm	hcp	a = 3.6630 c = 5.8448	450[b]	—	1.8176	20.450	7.353
γSm	bcc	4.10 (est.)	922	1.77	1.82	20.8	7.25
βGd	bcc	4.06	1265	1.76	1.81	20.2	7.80
βTb	bcc	4.07[a]	1289	1.76	1.81	20.3	7.82
βDy	bcc	4.03[a]	1381	1.75	1.80	19.7	8.23
γYb	bcc	4.44	763[c]	1.92	1.98	26.4	6.57

Note: The rare earths Eu, Ho, Er, Tm, and Lu are monomorphic. For additional information, see Gschneidner, K.A., Jr. and Calderwood, F.W., in *Handbook on the Physics and Chemistry of Rare Earths*, Vol. 8, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1986, 1.

[a] Determined by extrapolation to 0% solute of a vs. composition data for R-Mg alloys at 24°C and corrected for thermal expansion to temperature given.
[b] The hcp phase was stabilized by impurities and the temperature of measurement was below the equilibrium transition temperature (see Table 4).
[c] The bcc phase was stabilized by impurities and the temperature of measurement was below the equilibrium transition temperature (see Table 4).

PHYSICAL PROPERTIES OF THE RARE EARTH METALS (continued)

Table 4
High Temperature Transition Temperatures and Melting Point of Rare Earth Metals

Rare earth metal	Transition I (α – β)[a] Temp. (°C)	Transition I (α – β)[a] Phases	Transition II (β – γ)[a] Temp. (C°)	Transition II (β – γ)[a] Phases	Melting point (C°)
Sc	1337	hcp 1 bcc	—	—	1541
Y	1478	hcp 1 bcc	—	—	1522
La[b]	310	dhcp → fcc	865	fcc 1 bcc	918
Ce[c,d]	139	dhcp → fcc (β - γ)	726	fcc 1 bcc (γ - δ)	798
Pr	795	dhcp 1 bcc	—	—	931
Nd	863	dhcp 1 bcc	—	—	1021
Pm	890	dhcp 1 bcc	—	—	1042
Sm[e]	734	rhom → hcp	922	hcp 1 bcc	1074
Eu	—	—	—	—	822
Gd	1235	hcp 1 bcc	—	—	1313
Tb	1289	hcp 1 bcc	—	—	1356
Dy	1381	hcp 1 bcc	—	—	1412
Ho	—	—	—	—	1474
Er	—	—	—	—	1529
Tm	—	—	—	—	1545
Yb	795	fcc 1 bcc (β - γ)	—	—	819
Lu	—	—	—	—	1663

Note: For additional information, see Gschneidner, K.A., Jr. and Calderwood, F.W., in *Handbook on the Physics and Chemistry of Rare Earths,* Vol. 8, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1986; Gschneidner, K.A., Jr., Pecharsky, V.K., Cho, Jaephil and Martin, S.W., *Scripta Mater.,* 34, 1717, 1996.

[a] For all the transformations listed, unless otherwise noted.
[b] On cooling, fcc → dhcp (β → α), 260°C.
[c] The β 1 γ equilibrium transition temperature is 10 ± 5°C.
[d] On cooling, fcc → dhcp (γ → β), –16°C.
[e] On cooling, hcp → rhomb (β → α), 727°C.

Table 5
Low Temperature Transition Temperatures of the Rare Earth Metals

Rare earth metal	Cooling Transformation	°C	K	Rare earth metal	Heating Transformation	°C	K
Ce	γ → β[a]	–16	257	Ce	α → β	–148	125
	γ → α	–172	101		α → β + γ	–104	169
	β → α	–228	45		β → γ[a]	139	412
Tb	α → α′	–53	220	Yb	α → β	7	280
Dy	α→ α′	–187	86				
Yb	β → α	–13	260				

Note: For additional information, see Beaudry, B.J. and Gschneidner, K.A., Jr., in *Handbook on the Physics and Chemistry of Rare Earths*, Vol. 1, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1978, 173. Koskenmaki, D.C. and Gschneidner, K.A., Jr., 1978, in *Handbook on the Physics and Chemistry of Rare Earths*, Vol. 1, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1978, 337. Gschneidner, K.A., Jr., Pecharsky, V.K., Cho, Jaephil and Martin, S.W., *Scripta Mater.*, 34, 1717, 1996.

[a] The β 1 γ equilibrium transition temperature is 10 ± 5°C (283 ± 5K).

Table 6
Heat Capacity, Standard Entropy, Heats of Transformation, and Fusion of the Rare Earth Metals

Rare earth metal	Heat capacity at 298 K (J/mol K)	Standard entropy S°_{298} (J/mol K)	Heat of transformation (kJ/mol)				Heat of fusion (kJ/mol)
			trans. 1	ΔH_{tr}^1	trans. 2	ΔH_{tr}^2	
Sc	25.5	34.6	α 1 β	4.00	—	—	14.1
Y	26.5	44.4	α 1 β	4.99	—	—	11.4
La	27.1	56.9	α 1 β	0.36	β 1 γ	3.12	6.20
Ce	26.9	72.0	β 1 γ	0.05	γ 1 δ	2.99	5.46
Pr	27.2	73.2	α 1 β	3.17	—	—	6.89
Nd	27.5	71.5	α 1 β	3.03	—	—	7.14
Pm	27.3[a]	71.6[a]	α 1 β	3.0[a]	—	—	7.7[a]
Sm	29.5	69.6	α 1 β	0.2[a]	β 1 γ	3.11	8.62
Eu	27.7	77.8	—	—	—	—	9.21
Gd	37.0	68.1	α 1 β	3.91	—	—	10.0
Tb	28.9	73.2	α 1 β	5.02	—	—	10.79
Dy	27.7	75.6	α 1 β	4.16	—	—	11.06
Ho	27.2	75.3	—	—	—	—	17.0[a]
Er	28.1	73.2	—	—	—	—	19.9
Tm	27.0	74.0	—	—	—	—	16.8
Yb	26.7	59.9	β 1 γ	1.75	—	—	7.66
Lu	26.9	51.0	—	—	—	—	22[a]

Note: For additional information, see Hultgren, R., Desai, P.D., Hawkins, D.T., Gleiser, M., Kelley, K.K., and Wagman, D.D., *Selected Values of the Thermodynamic Properties of the Elements,* ASM International, Metals Park, Ohio, 1973; Wagman, D.D., Evans, W.H., Parker, V.B., Schumm, R.H., Halow, I., Bailey, S.M., Churney, K.L., and Nuttall, R.L., *The NBS Tables of Chemical Thermodynamic Properties, J. Phys. Chem. Ref. Data,* Vol. 11, Suppl 2, 1982; Amitin, E.B., Bessergenev, W.G., Kovalevskaya, Yu. A., and Paukov, I.E., *J. Chem. Thermodyn.*, 15, 181, 1983; Amitin, E.B., Bessergenev, W.G., Kovalevskaya, Yu. A., and Paukov, I.E., *J. Chem. Thermodyn.*, 15, 181, 1983.

[a] Estimated.

Table 7
Vapor Pressures, Boiling Points, and Heats of Sublimation of Rare Earth Metals

Rare earth metal	Temperature in °C[a] for a vapor pressure of				Boiling point[a] (°C)	Heat of sublimation at 25°C (kJ/mol)
	10^{-8} atm (0.001 Pa)	10^{-6} atm (0.101 Pa)	10^{-4} atm (10.1Pa)	10^{-2} atm (1013 Pa)		
Sc	1036	1243	1533	1999	2836	377.8
Y	1222	1460	1812	2360	3345	424.7
La	1301	1566	1938	2506	3464	431.0
Ce	1290	1554	1926	2487	3443	422.6
Pr	1083	1333	1701	2305	3520	355.6
Nd	955	1175	1500	2029	3074	327.6
Pm	—	—	—	—	3000[b]	348[b]
Sm	508	642	835	1150	1794	206.7
Eu	399	515	685	964	1529	175.3
Gd	1167	1408	1760	2306	3273	397.5
Tb	1124	1354	1698	2237	3230	388.7
Dy	804	988	1252	1685	2567	290.4
Ho	845	1036	1313	1771	2700	300.8
Er	908	1113	1405	1896	2868	317.1
Tm	599	748	964	1300	1950	232.2
Yb	301	400	541	776	1196	152.1
Lu	1241	1483	1832	2387	3402	427.6

Note: For additional information, see Hultgren, R., Desai, P.D., Hawkins, D.T., Gleiser, M., Kelley, K.K., and Wagman, D.D., *Selected Values of the Thermodynamic Properties of the Elements,* ASM International, Metals Park, Ohio, 1973 and Beaudry, B.J. and Gschneidner, K.A., Jr., in *Handbook on the Physics and Chemistry of Rare Earths,* Vol. 1, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1978, 173.

[a] International Temperature Scale of 1990 (ITS-90) values.
[b] Estimated.

Table 8
Magnetic Properties of the Rare Earth Metals

Rare earth metal	$\chi_A \times 10^6$ at 298 K (emu/mol)	Effective magnetic moment: Paramagnetic at ~298 K		Effective magnetic moment: Ferromagnetic at ~0 K		Easy axis	Néel temp. T_N (K)		Curie temp. T_C (K)	θ_p (K)		
		Theory[a]	Obs.	Theory[b]	Obs.		Hex sites	Cubic sites		∥c	⊥c	Polycryst. or avg.
αSc	295.2	—	—	—	—	—	—	—	—	—	—	—
αY	187.7	—	—	—	—	—	—	—	—	—	—	—
αLa	95.9	—	—	—	—	—	—	—	—	—	—	—
βLa	105	—	—	—	—	—	—	—	—	—	—	–
γCe	2,270	2.54	2.52	2.14	—	—	—	14.4	—	—	—	–50
βCe	2,500	2.54	2.61	2.14	—	—	13.7	12.5	—	—	—	–41
αPr	5,530	3.58	3.56	3.20	2.7[c]	**a**	0.03	—	—	—	—	0
αNd	5,930	3.62	3.45	3.27	2.2[c]	**b**	19.9	7.5	—	0	5	3.3
αPm	—	2.68	—	2.40	—	—	—	—	—	—	—	—
αSm	1,278[d]	0.85	1.74	0.71	0.5[c]	**a**	109	14.0	—	—	—	—
Eu	30,900	7.94	8.48	7.0	5.9	<110>	—	90.4	—	—	—	100
αGd	185,000[e]	7.94	7.98	7.0	7.63	30° to **c**	—	—	293.4	317	317	317
αTb	170,000	9.72	9.77	—	—	—	230.0	—	—	195	239	224
α′Tb	—	—	—	9.0	9.34	**b**	—	—	219.5	—	—	—
αDy	98,000	10.64	10.83	—	—	—	180.2	—	—	121	169	153
α′Dy	—	—	—	10.0	10.33	**a**	—	—	90.5[g]	—	—	—
Ho	72,900	10.60	11.2	10.0	10.34	**b**	132	—	19.5	73.0	88.0	83.0
Er	48,000	9.58	9.9	9.0	9.1	30° to **c**	85	—	18.7	61.7	32.5	42.2
Tm	24,700	7.56	7.61	7.0	7.14	**c**	58	—	32.0	41.0	–17.0	2.3
βYb	67[d]	—	—	—	—	—	—	—	—	—	—	—
Lu	182.9	—	—	—	—	—	—	—	—	—	—	—

Note: For additional information, see McEwen, K.A., in *Handbook on the Physics and Chemistry of Rare Earths,* Vol. 1, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1978, 411 and Legvold, S., in *Ferromagnetic Materials,* Vol. 1, Wohlfarth, E.P., Ed., North-Holland Physics, Amsterdam, 1980, 183; Pecharsky, V.K., Gschneidner, K.A., Jr. and Fort, D., *Phys. Rev. B,* 47, 5063, 1993; Pecharsky, V.K., Gschneidner, K.A., Jr. and Fort, D., 1996, to be published; Steward, A.M. and Collocott, S.J., *J. Phys.: Condens. Matter,* 1, 677, 1988.

[a] $g[J(J+1)]^{1/2}$.
[b] gJ.
[c] At 38 T and 4.2 K.
[d] At 290 K.
[e] At 350 K.
[g] On cooling T_C = 89.6 K and on warming T_C = 91.5 K.

Table 9
Room Temperature Coefficient of Thermal Expansion, Thermal Conductivity, Electrical Resistance, and Hall Coefficient

Rare earth metal	Expansion $\alpha_i \times 10^6$ ($°C^{-1}$)			Thermal conductivity (W/cm-K)	Electrical resistance ($\mu\Omega\cdot cm$)			Hall coefficient ($R_i \times 10^{12}$) ($V\cdot cm/A\cdot Oe$)		
	α_a	α_c	α_{poly}		ρ_a	ρ_c	ρ_{poly}	R_a	R_c	R_{poly}
αSc	7.6	15.3	10.2	0.158	70.9	26.9	56.2[a]	—	—	–0.13
αY	6.0	19.7	10.6	0.172	72.5	35.5	59.6	–0.27	–1.6	—
aLa	4.5	27.2	12.1	0.134	—	—	61.5	—	—	–0.35
bCe	—	—	—	—	—	—	82.8	—	—	—
γCe	6.3	—	6.3	0.113	—	—	74.4	—	—	+1.81
αPr	4.5	11.2	6.7	0.125	—	—	70.0	—	—	+0.709
αNd	7.6	13.5	9.6	0.165	—	—	64.3	—	—	+0.971
αPm	9[b]	16[b]	11[b]	0.15[b]	—	—	75[b]	—	—	—
αSm	9.6	19.0	12.7	0.133	—	—	94.0	—	—	–0.21
Eu	35.0	—	35.0	0.139[b]	—	—	90.0	—	—	+24.4
αGd	9.1[c]	10.0[c]	9.4[c]	0.105	135.1	121.7	131.0	–10	–54	–4.48[d]
αTb	9.3	12.4	10.3	0.111	123.5	101.5	115.0	–1.0	–3.7	—
αDy	7.1	15.6	9.9	0.107	111.0	76.6	92.6	–0.3	–3.7	—
Ho	7.0	19.5	11.2	0.162	101.5	60.5	81.4	+0.2	–3.2	—
Er	7.9	20.9	12.2	0.145	94.5	60.3	86.0	+0.3	–3.6	—
Tm	8.8	22.2	13.3	0.169	88.0	47.2	67.6	—	—	–1.8
βYb	26.3	—	26.3	0.385	—	—	25.0	—	—	+3.77
Lu	4.8	20.0	9.9	0.164	76.6	34.7	58.2	+0.45	–2.6	–0.535

Note: For additional information, see Beaudry, B. J. and Gschneidner, K.A., Jr., in *Handbook on the Physics and Chemistry of Rare Earths*, Vol. 1, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1978, 173 and McEwen, K.A., in *Handbook on the Physics and Chemistry of Rare Earths*, Vol. 1, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1978, 411.

[a] Calculated from single crystal values.
[b] Estimated.
[c] At 100°C.
[d] At 77°C.

Table 10
Electronic Specific Heat Constant (γ), Electron-Electron (Coulomb) Coupling Constant (μ*), Electron-Phonon Coupling Constant (λ), Debye Temperature at 0 K(θ_D), and Superconducting Transition Temperature

Rare earth metal	γ (mJ/mol·K^2)	μ*	λ	θ_D (K) from		Superconducting temperature (K)
				Heat capacity	Elastic constants	
αSc	10.334	0.16	0.30	345.3	—	0.050[a]
αY	7.878	0.15	0.30	244.4	258	1.3[b]
αLa	9.45	0.08	0.76	150	154	5.10
βLa	11.5	—	—	140	—	6.00
αCe	12.8	—	—	179	—	0.022[c]
αPr	20	—	1.07[d]	155[e]	153	—
αNd	f	—	0.86[d]	157[e]	163	—
αPm	—	—	—	159[e]	—	—
αSm	8.1 ± 1.5[g]	—	0.81[d]	162[e,f]	169	—
Eu	f	—	—	f	118	—
αGd	4.48	—	0.30	169	182	—
α′Tb	3.71	—	0.34[d]	169.6	177	—
α′Dy	4.9	—	0.32[d]	192	183	—
Ho	2.1	—	0.30[d]	175[e]	190	—
Er	8.7	—	0.33[d]	176.9	188	—
Tm	f	—	0.36[d]	179[e]	200	—
αYb	3.30	—	—	117.6	118	—
βYb	8.36	—	—	109	—	—
Lu	8.194	0.14	0.31	183.2	185	0.022[h]

Note: For additional information, see Sundström, L.J., in *Handbook on the Physics and Chemistry of Rare Earths,* Vol. 1, Gschneidner, K.A., Jr., and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1978, 379, Scott, T., in *Handbook on the Physics and Chemistry of Rare Earths,* Vol. 1, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1978, 591, Probst, C. and Wittig, J., in *Handbook on the Physics and Chemistry of Rare Earths,* Vol. 1, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1978, 749, and Tsang, T.-W.E., Gschneidner, K.A., Jr., Schmidt, F.A., and Thome, D.K., *Phys. Rev.,* B, 31, 235, 1985. Collocott, S.J., Hill, R.W. and Stewart, A.M., *J. Phys. F,* 18, L223, 1988. Hill, R.W. and Gschneidner, K.A., Jr., *J. Phys. F,* 18, 2545, 1988. Skriver, H.L. and Mertig, I., *Phys. Rev. B,* 41, 6553, 1990. Collocott, S.J. and Stewart, A.M., *J. Phys.: Condens. Matter,* 4, 6743, 1992. Pecharsky, V.K., Gschneidner, K.A., Jr. and Fort, D., *Phys. Rev. B,* 47, 5063, 1993.

[a] At 18.6 GPa.
[b] At 11 GPa.
[c] At 2.2 GPa.
[d] Calculated value.
[e] Estimated.
[f] Heat capacity results have been reported, but the resultant γ and θ_D values are unreliable because of the presence of impurities and/or there was no reliable procedure or model to correct for the magnetic contribution to the heat capacity.
[g] Based on the values reported for the purer Sm sample (IV).
[h] At 4.5 GPa.

Table 11
Room Temperature Elastic Moduli and Mechanical Properties

	Elastic moduli (GPa)				Mechanical properties (MPa)				
Rare earth metal	Young's (elastic) modulus	Shear modulus	Bulk modulus	Poisson's ratio	Yield strength 0.2% offset	Ultimate tensile strength	Uniform elongation (%)	Reduction in area (%)	Recryst. temp. (°C)
Sc	74.4	29.1	56.6	0.279	173[a]	255[a]	5.0[a]	8.0[a]	550
Y	63.5	25.6	41.2	0.243	42	129	34.0	—	550
αLa	36.6	14.3	27.9	0.280	126[a]	130	7.9[a]	—	300
βCe	—	—	—	—	86	138	—	24.0	—
γCe	33.6	13.5	21.5	0.24	28	117	22.0	30.0	325
αPr	37.3	14.8	28.8	0.281	73	147	15.4	67.0	400
αNd	41.4	16.3	31.8	0.281	71	164	25.0	72.0	400
αPm	46[b]	18[b]	33[b]	0.28[b]	—	—	—	—	400[b]
αSm	49.7	19.5	37.8	0.274	68	156	17.0	29.5	440
Eu	18.2	7.9	8.3	0.152	—	—	—	—	300
αGd	54.8	21.8	37.9	0.259	15	118	37.0	56.0	500
αTb	55.7	22.1	38.7	0.261	—	—	—	—	500
αDy	61.4	24.7	40.5	0.247	43	139	30.0	30.0	550
Ho	64.8	26.3	40.2	0.231	—	—	—	—	520
Er	69.9	28.3	44.4	0.237	60	136	11.5	11.9	520
Tm	74.0	30.5	44.5	0.213	—	—	—	—	600
βYb	23.9	9.9	30.5	0.207	7	58	43.0	92.0	300
Lu	68.6	27.2	47.6	0.261	—	—	—	—	600

Note: For additional information, see Scott, T., in *Handbook on the Physics and Chemistry of Rare Earths*, Vol. 1, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1978, 591.

[a] Value is questionable.
[b] Estimated.

Table 12
Liquid Metal Properties Near the Melting Point

Rare earth metal	Density (g/cm^3)	Surface tension (N/m)	Viscosity (centipoise)	Heat capacity (J/mol K)	Thermal conductivity (W/cm K)	Magnetic susceptibility $\chi \times 10^4$ (emu/mol)	Electrical resistivity ($\mu\Omega\cdot cm$)	$\Delta V_{L \to s}$[a] (%)	Spectral emittance at λ = 645 nm: ε (%)	Spectral emittance at λ = 645 nm: Temp. range (°C)
Sc	2.80	0.954	—	44.2[b]	—	—	—	—	—	—
Y	4.24	0.871	—	43.1	—	—	—	—	36.8	1522–1647
La	5.96	0.718	2.65	34.3	0.238	1.20	133	–0.6	25.4	920–1287
Ce	6.68	0.706	3.20	37.7	0.210	9.37	130	+1.1	32.2	877–1547
Pr	6.59	0.707	2.85	43.0	0.251	17.3	139	–0.02	28.4	931–1537
Nd	6.72	0.687	—	48.8	0.195	18.7	151	–0.9	39.4	1021–1567
Pm	6.9[b]	0.680[b]	—	50[b]	—	—	160[b]	—	—	—
Sm	7.16	0.431	—	50.2[b]	—	18.3	182	–3.6	43.7	1075
Eu	4.87	0.264	—	38.1	—	97	242	–4.8	—	—
Gd	7.4	0.664	—	37.2	0.149	67	195	–2.0	34.2	1313–1600
Tb	7.65	0.669	—	46.5	—	82	193	–3.1	—	—
Dy	8.2	0.648	—	49.9	0.187	95	210	–4.5	29.7	1412–1437
Ho	8.34	0.650	—	43.9	—	88	221	–7.4	—	—
Er	8.6	0.637	—	38.7	—	69	226	–9.0	37.2	1529–1587
Tm	9.0[b]	—	—	41.4	—	41	235[b]	–6.9	—	—
Yb	6.21	0.320	2.67	36.8	—	—	113	–5.1	—	—
Lu	9.3	0.940	—	47.9[b]	—	—	224	–3.6	—	—

Note: For additional information, see Van Zytveld, J., in *Handbook on the Physics and Chemistry of Rare Earths*, Vol. 12, Gschneidner, K.A., Jr. and Eyring, L., Eds., North-Holland Physics, Amsterdam, 1989, 357. Stretz, L.A. and Bautista, R.G., in *Temperature, Its Measurement and Control in Science and Industry*, Vol. 4, part I, H.H. Plumb, Ed., Instrument Society of America, Pittsburgh, 1972, 489. King, T.S., Baria, D.N., and Bautista, R.G., *Met. Trans. B*, 7, 411, 1976. Baria, D.N., King, T.S., and Bautista, R.G., *Met. Trans. B*, 7, 577, 1976.

[a] Volume change on freezing.
[b] Estimated.

Table 13
Ionization Potentials (Electronvolts)

Rare earth	I Neutral atom	II Singly ionized	III Doubly ionized	IV Triply ionized	V Quadruply ionized
Sc	6.56144	12.79967	24.75666	73.4894	91.65
Y	6.217	12.24	20.52	60.597	77.0
La	5.5770	11.060	19.1773	49.95	61.6
Ce	5.5387	10.85	20.198	36.758	65.55
Pr	5.464	10.55	21.624	38.98	57.53
Nd	5.5250	10.73	22.1	40.41	—
Pm	5.554	10.90	22.3	41.1	—
Sm	5.6437	11.07	23.4	41.4	—
Eu	5.6704	11.241	24.92	42.7	—
Gd	6.1500	12.09	20.63	44.0	—
Tb	5.8639	11.52	21.91	39.79	—
Dy	5.9389	11.67	22.8	41.47	—
Ho	6.0216	11.80	22.84	42.5	—
Er	6.1078	11.93	22.74	42.7	—
Tm	6.18431	12.05	23.68	42.7	—
Yb	6.25416	12.1761	25.05	43.56	—
Lu	5.42585	13.9	20.9594	45.25	66.8

Note: For references, see the table "Ionization Potentials of Atoms and Atomic Ions" in Section 10.

Table 14
Effective Ionic Radii (Å)[a]

Rare earth ion	R^{2+}		R^{3+}			R^{4+}	
	CN = 6	CN = 8	CN = 6	CN = 8	CN = 12	CN = 6	CN = 8
Sc	—	—	0.745	0.87	1.116	—	—
Y	—	—	0.900	1.015	1.220	—	—
La	—	—	1.045	1.18	1.320	—	—
Ce	—	—	1.010	1.14	1.290	0.80	0.97
Pr	—	—	0.997	1.14	1.286	0.78	0.96
Nd	—	—	0.983	1.12	1.276	—	—
Pm	—	—	0.97	1.10	1.267	—	—
Sm	1.19	1.27	0.958	1.09	1.260	—	—
Eu	1.17	1.25	0.947	1.07	1.252	—	—
Gd	—	—	0.938	1.06	1.246	—	—
Tb	—	—	0.923	1.04	1.236	0.76	0.88
Dy	—	—	0.912	1.03	1.228	—	—
Ho	—	—	0.901	1.02	1.221	—	—
Er	—	—	0.890	1.00	1.214	—	—
Tm	—	—	0.880	0.99	1.207	—	—
Yb	1.00	1.07	0.868	0.98	1.199	—	—
Lu	—	—	0.861	0.97	1.194	—	—

Note: For additional information, see Shannon, R.D. and Prewitt, C.T., *Acta Cryst.*, 25, 925, 1969 and Shannon, R.D. and Prewitt, C.T., *Acta Cryst.*, 26, 1046, 1970.

[a] Radius of O^{2-} is 1.40 Å for a coordination number (CN) of 6.

MELTING, BOILING, AND CRITICAL TEMPERATURES OF THE ELEMENTS

This table summarizes the melting point t_m, normal boiling point t_b, and critical temperature t_c (on the ITS-90 scale) for the elements for which data are available. A "tp" after a value indicates a solid-liquid-gas triple point, and "sp" indicates a sublimation point, where the vapor pressure of the solid phase reaches 101.325 kPa (1 atm). Transition temperatures between allotropic forms are included for several elements. References may be found in the tables *Physical Constants of Inorganic Compounds* and *Critical Constants*.

Name	t_m/°C	t_b/°C	t_c/°C
Actinium	1051	3198	
Aluminum	660.32	2519	
Americium	1176	2011	
Antimony	630.63	1587	
Argon	-189.35	-185.85	-122.28
Arsenic (gray)	817 tp (3.70 MPa)	603 sp	1400
Astatine	302		
Barium	727	1897	
Berkelium (α form)	1050		
Berkelium (β form)	986		
Beryllium	1287	2471	
Bismuth	271.40	1564	
Boron	2075	4000	
Bromine	-7.2	58.8	315
Cadmium	321.07	767	
Calcium	842	1484	
Californium	900		
Carbon (graphite)	4489 tp (10.3 MPa)	3825 sp	
Carbon (diamond)	4440 (12.4 GPa)		
Cerium	798	3443	
Cesium	28.5	671	1665
Chlorine	-101.5	-34.04	143.8
Chromium	1907	2671	
Cobalt	1495	2927	
Copper	1084.62	2562	
Curium	1345	≈3100	
Dysprosium	1412	2567	
Einsteinium	860		
Erbium	1529	2868	
Europium	822	1529	
Fermium	1527		
Fluorine	-219.67 tp	-188.12	-129.02
Francium	27		
Gadolinium	1313	3273	
Gallium	29.771 tp	2204	
Germanium	938.25	2833	
Gold	1064.18	2856	
Hafnium	2233	4603	
Helium		-268.93	-267.96
Holmium	1474	2700	
Hydrogen	-259.34	-252.87	-240.18
Indium	156.60	2072	
Iodine	113.7	184.4	546
Iridium	2446	4428	
Iron	1538	2861	
Krypton	-157.38 tp (73.2 kPa)	-153.22	-63.74
Lanthanum	918	3464	
Lawrencium	1627		
Lead	327.46	1749	
Lithium	180.50	1342	2950
Lutetium	1663	3402	
Magnesium	650	1090	
Manganese	1246	2061	
Mendelevium	827		
Mercury	-38.837 tp	356.73	1477
Molybdenum	2623	4639	
Neodymium	1021	3074	
Neon	-248.59	-246.08	-228.7
Neptunium	644		
Nickel	1455	2913	
Niobium	2477	4744	
Nitrogen	-210.00	-195.79	-146.94
Nobelium	827		
Osmium	3033	5012	
Oxygen	-218.79	-182.95	-118.56
Palladium	1554.9	2963	
Phosphorus (white)	44.15	280.5	721
Phosphorus (red)	590 tp	431 sp	721
Phosphorus (black)	610		
Platinum	1768.4	3825	
Plutonium	640	3228	
Polonium	254	962	
Potassium	63.5	759	1950
Praseodymium	931	3520	
Promethium	1042	3000	
Protactinium	1572		
Radium	700		
Radon	-71	-61.7	104
Rhenium	3186	5596	
Rhodium	1964	3695	
Rubidium	39.30	688	1820
Ruthenium	2334	4150	
Samarium	1074	1794	
Scandium	1541	2836	
Selenium(vitreous)	180 (trans to gray)	685	
Selenium (gray)	220.5	685	1493
Silicon	1414	3265	
Silver	961.78	2162	
Sodium	97.80	883	2300
Strontium	777	1382	
Sulfur (rhombic)	95.3 (trans to mono)	444.60	1041
Sulfur (monoclinic)	119.6	444.60	1041
Tantalum	3017	5458	
Technetium	2157	4265	
Tellurium	449.51	988	
Terbium	1356	3230	
Thallium	304	1473	
Thorium	1750	4788	
Thulium	1545	1950	
Tin (gray)	13.2 (trans to white)	2602	
Tin (white)	231.93	2602	
Titanium	1668	3287	
Tungsten	3422	5555	
Uranium	1135	4131	
Vanadium	1910	3407	
Xenon	-111.79 tp (81.6 kPa)	-108.12	16.62
Ytterbium	819	1196	
Yttrium	1522	3345	
Zinc	419.53	907	
Zirconium	1855	4409	

HEAT CAPACITY OF THE ELEMENTS AT 25°C

This table gives the specific heat capacity (c_p) in J/g K and the molar heat capacity (C_p) in J/mol K at a temperature of 25°C and a pressure of 100 kPa (1 bar or 0.987 standard atmospheres) for all the elements for which reliable data are available.

Name	c_p J/g K	C_p J/mol K
Actinium	0.120	27.2
Aluminum	0.897	24.200
Antimony	0.207	25.23
Argon	0.520	20.786
Arsenic	0.329	24.64
Barium	0.204	28.07
Beryllium	1.825	16.443
Bismuth	0.122	25.52
Boron	1.026	11.087
Bromine (Br_2)	0.226	36.057
Cadmium	0.232	26.020
Calcium	0.647	25.929
Carbon (graphite)	0.709	8.517
Cerium	0.192	26.94
Cesium	0.242	32.210
Chlorine (Cl_2)	0.479	33.949
Chromium	0.449	23.35
Cobalt	0.421	24.81
Copper	0.385	24.440
Dysprosium	0.170	27.7
Erbium	0.168	28.12
Europium	0.182	27.66
Fluorine (F_2)	0.824	31.304
Gadolinium	0.236	37.03
Gallium	0.371	25.86
Germanium	0.320	23.222
Gold	0.129	25.418
Hafnium	0.144	25.73
Helium	5.193	20.786
Holmium	0.165	27.15
Hydrogen (H_2)	14.304	28.836
Indium	0.233	26.74
Iodine (I_2)	0.145	36.888
Iridium	0.131	25.10
Iron	0.449	25.10
Krypton	0.248	20.786
Lanthanum	0.195	27.11
Lead	0.129	26.650
Lithium	3.582	24.860
Lutetium	0.154	26.86
Magnesium	1.023	24.869
Manganese	0.479	26.32
Mercury	0.140	27.983
Molybdenum	0.251	24.06
Neodymium	0.190	27.45
Neon	1.030	20.786
Nickel	0.444	26.07
Niobium	0.265	24.60
Nitrogen (N_2)	1.040	29.124
Osmium	0.130	24.7
Oxygen (O_2)	0.918	29.378
Palladium	0.246	25.98
Phosphorous (white)	0.769	23.824
Platinum	0.133	25.86
Potassium	0.757	29.600
Praseodymium	0.193	27.20
Radon	0.094	20.786
Rhenium	0.137	25.48
Rhodium	0.243	24.98
Rubidium	0.363	31.060
Ruthenium	0.238	24.06
Samarium	0.197	29.54
Scandium	0.568	25.52
Selenium	0.321	25.363
Silicon	0.705	19.789
Silver	0.235	25.350
Sodium	1.228	28.230
Strontium	0.301	26.4
Sulfur (rhombic)	0.710	22.75
Tantalum	0.140	25.36
Tellurium	0.202	25.73
Terbium	0.182	28.91
Thallium	0.129	26.32
Thorium	0.113	26.230
Thulium	0.160	27.03
Tin (white)	0.228	27.112
Titanium	0.523	25.060
Tungsten	0.132	24.27
Uranium	0.116	27.665
Vanadium	0.489	24.89
Xenon	0.158	20.786
Ytterbium	0.155	26.74
Yttrium	0.298	26.53
Zinc	0.388	25.390
Zirconium	0.278	25.36

VAPOR PRESSURE OF THE METALLIC ELEMENTS

C. B. Alcock

This table gives coefficients in an equation for the vapor pressure of 65 metallic elements in both the solid and liquid state. Vapor pressures in the range 10^{-10} to 10^{2} Pa (10^{-15} to 10^{-3} atm) are covered. The equation is:

for p in pascals: $\log (p/\mathrm{Pa}) = 5.006 + A + BT^{-1} + C\log T + DT^{-3}$

for p in atmospheres: $\log(p/\mathrm{atm}) = A + BT^{-1} + C\log T + DT^{-3}$, where T is the temperature in K

This equation reproduces the observed vapor pressures to an accuracy of ±5% or better. Reprinted with permission of the publisher, Pergamon Press.

REFERENCE

Alcock, C. B., Itkin, V. P., and Horrigan, M. K., *Canadian Metallurgical Quarterly*, 23, 309, 1984.

Element, state	*A*	*B*	*C*	*D*	Temperature range
Li sol	5.667	-8310			298-m.p.
Li liq	5.055	-8023			m.p.-1000
Na sol	5.298	-5603			298-m.p.
Na liq	4.704	-5377			m.p.-700
K sol	4.961	-4646			298-m.p.
K liq	4.402	-4453			m.p.-600
Rb sol	4.857	-4215			298-m.p.
Rb liq	4.312	-4040			m.p.-550
Cs sol	4.711	-3999			298-m.p.
Cs liq	4.165	-3830			m.p.-550
Be sol	8.042	-17020	-0.4440		298-m.p.
Be liq	5.786	-15731			m.p.-1800
Mg sol	8.489	-7813	-0.8253		298-m.p.
Ca sol	10.127	-9517	-1.4030		298-m.p.
Sr sol	9.226	-8572	-1.1926		298-m.p.
Ba sol	12.405	-9690	-2.2890		298-m.p.
Ba liq	4.007	-8163			m.p.-1200
Al sol	9.459	-17342	-0.7927		298-m.p.
Al liq	5.911	-16211			m.p.-1800
Ga sol	6.657	-14208			298-m.p.
Ga liq	6.754	-13984	-0.3413		m.p.-1600
In sol	5.991	-12548			298-m.p.
In liq	5.374	-12276			m.p.-1500
Tl sol	5.971	-9447			298-m.p.
Tl liq	5.259	-9037			m.p.-1100
Sn sol	6.036	-15710			298-m.p.
Sn liq	5.262	-15332			m.p.-1850
Pb sol	5.643	-10143			298-m.p.
Pb liq	4.911	-9701			m.p.-1200
Sc sol	6.650	-19721	0.2885	-0.3663	298-m.p.
Sc liq	5.795	-17681			m.p.-2000
Y sol	9.735	-22306	-0.8705		298-m.p.
Y liq	5.795	-20341			m.p.-2300
La sol	7.463	-22551	-0.3142		298-m.p.
La liq	5.911	-21855			m.p.-2450
Ti sol	11.925	-24991	-1.3376		298-m.p.
Ti liq	6.358	-22747			m.p.-2400
Zr sol	10.008	-31512	-0.7890		298-m.p
Zr liq	6.806	-30295			m.p.-2500
Hf sol	9.445	-32482	-0.6735		298-m.p.
V sol	9.744	-27132	-0.5501		298-m.p.

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VAPOR PRESSURE OF THE METALLIC ELEMENTS (continued)

Element, state	*A*	*B*	*C*	*D*	Temperature range
V liq	6.929	-25011			m.p.-2500
Nb sol	8.822	-37818	-0.2575		298-2500
Ta sol	16.807	-41346	-3.2152	0.7437	248-2500
Cr sol	6.800	-20733	0.4391	-0.4094	298-2000
Mo sol	11.529	-34626	-1.1331		298-2500
W sol	2.945	-44094	1.3677		298-2350
W sol	-54.527	-57687	-12.2231		2200-2500
Mn sol	12.805	-15097	-1.7896		298-m.p.
Re sol	11.543	-40726	-1.1629		298-2500
Fe sol	7.100	-21723	0.4536	-0.5846	298-m.p.
Fe liq	6.347	-19574			m.p.-2100
Ru sol	9.755	-34154	-0.4723		298-m.p.
Os sol	9.419	-41198	-0.3896		298-2500
Co sol	10.976	-22576	-1.0280		298-m.p.
Co liq	6.488	-20578			m.p.-2150
Rh sol	10.168	-29010	-0.7068		298-m.p.
Rh liq	6.802	-26792			m.p.-2500
Ir sol	10.506	-35099	-0.7500		298-2500
Ni sol	10.557	-22606	-0.8717		298-m.p.
Ni liq	6.666	-20765			m.p.-2150
Pd sol	9.502	-19813	-0.9258		298-m.p.
Pd liq	5.426	-17899			m.p.-2100
Pt sol	4.882	-29387	1.1039	-0.4527	298-m.p.
Pt liq	6.386	-26856			m.p.-2500
Cu sol	9.123	-17748	-0.7317		298-m.p.
Cu liq	5.849	-16415			m.p.-1850
Ag sol	9.127	-14999	-0.7845		298-m.p.
Ag liq	5.752	-13827			m.p.-1600
Au sol	9.152	-19343	-0.7479		298-m.p.
Au liq	5.832	-18024			m.p.-2050
Zn sol	6.102	-6776			298-m.p.
Zn liq	5.378	-6286			m.p.-750
Cd sol	5.939	-5799			298-m.p.
Cd liq	5.242	-5392			m.p.-650
Hg liq	5.116	-3190			298-400
Ce sol	6.139	-21752			298-m.p.
Ce liq	5.611	-21200			m.p.-2450
Pr sol	8.859	-18720	-0.9512		298-m.p.
Pr liq	4.772	-17315			m.p.-2200
Nd sol	8.996	-17264	-0.9519		298-m.p.
Nd liq	4.912	-15824			m.p.-2000
Sm sol	9.988	-11034	-1.3287		298-m.p.
Eu sol	9.240	-9459	-1.1661		298-m.p.
Gd sol	8.344	-20861	-0.5775		298-m.p.
Gd liq	5.557	-19389			m.p.-2250
Tb sol	9.510	-20457	-0.9247		298-m.p.
Tb liq	5.411	-18639			m.p.-2200
Dy sol	9.579	-15336	-1.1114		298-m.p.
Ho sol	9.785	-15899	-1.1753		298-m.p.
Er sol	9.916	-16642	-1.2154		298-m.p.
Er liq	4.668	-14380			m.p.-1900
Tm sol	8.882	-12270	-0.9564		298-1400
Yb sol	9.111	-8111	-1.0849		298-900
Lu sol	8.793	-22423	-0.6200		298-m.p.
Lu liq	5.648	-20302			m.p.-2350
Th sol	8.668	-31483	-0.5288		298-m.p.
Th liq	-18.453	-24569	6.6473		m.p.-2500
Pa sol	10.552	-34869	-1.0075		298-m.p.

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VAPOR PRESSURE OF THE METALLIC ELEMENTS (continued)

Element, state	***A***	***B***	***C***	***D***	**Temperature range**
Pa liq	6.177	-32874			m.p.-2500
U sol	0.770	-27729	2.6982	-1.5471	298-m.p.
U liq	20.735	-28776	-4.0962		m.p.-2500
Np sol	19.643	-24886	-3.9991		298-m.p.
Np liq	10.076	-23378	-1.3250		m.p.-2500
Pu sol	26.160	-19162	-6.6675		298-600
Pu sol	18.858	-18460	-4.4720		500-m.p.
Pu liq	3.666	-16658			m.p.-2450
Am sol	11.311	-15059	-1.3449		298-m.p.
Cm sol	8.369	-20364	-0.5770		298-m.p.
Cm liq	5.223	-18292			m.p.-2200

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DENSITY OF MOLTEN ELEMENTS AND REPRESENTATIVE SALTS

This table lists the liquid density at the melting point, ρ_m , for elements that are solid at room temperature, as well as for some representative salts of these elements. Densities at higher temperatures (up to the t_{max} given in the last column) may be estimated from the equation

$$\rho(t) = \rho_m - k(t-t_m)$$

where t_m is the melting point and k is given in the fifth column of the table. If a value of t_{max} is not given, the equation should not be used to extrapolate more than about 20°C beyond the melting point.

Data for the elements were selected from the primary literature; the assistance of Gernot Lang in compiling these data is gratefully acknowledged. The molten salt data were derived from Reference 1.

REFERENCE

1. Janz, G. J., Thermodynamic and Transport Properties of Molten Salts: Correlation Equations for Critically Evaluated Density, Surface Tension, Electrical Conductance, and Viscosity Data, *J. Phys. Chem. Ref. Data*, 17, Suppl. 2, 1988.
2. Nasch, P. M., and Steinemann, S. G., *Phys. Chem. Liq.*, 29, 43, 1995.

Formula	Name	t_m/°C	ρ_m/g cm^{-3}	k/g cm^{-3} °C^{-1}	t_{max}
Ag	Silver	961.78	9.320	0.0009	1500
AgBr	Silver(I) bromide	432	5.577	0.001035	667
AgCl	Silver(I) chloride	455	4.83	0.00094	627
AgI	Silver(I) iodide	558	5.58	0.00101	802
$AgNO_3$	Silver(I) nitrate	212	3.970	0.001098	360
Ag_2SO_4	Silver(I) sulfate	652	4.84	0.001089	770
Al	Aluminum	660.32	2.375	0.000233	1340
$AlBr_3$	Aluminum bromide	97.5	2.647	0.002435	267
$AlCl_3$	Aluminum chloride	192.6	1.302	0.002711	296
AlI_3	Aluminum iodide	188.32	3.223	0.0025	240
As	Arsenic	817	5.22	0.000544	
Au	Gold	1064.18	17.31	0.001343	1200
B	Boron	2075	2.08		
Ba	Barium	727	3.338	0.000299	1550
$BaBr_2$	Barium bromide	857	3.991	0.000924	900
$BaCl_2$	Barium chloride	962	3.174	0.000681	1081
BaF_2	Barium fluoride	1368	4.14	0.000999	1727
BaI_2	Barium iodide	711	4.26	0.000977	975
Be	Beryllium	1287	1.690	0.00011	
$BeCl_2$	Beryllium chloride	415	1.54	0.0011	473
BeF_2	Beryllium fluoride	552	1.96	0.000015	850
Bi	Bismuth	271.40	10.05	0.00135	800
$BiBr_3$	Bismuth bromide	218	4.76	0.002637	927
$BiCl_3$	Bismuth chloride	230	3.916	0.0023	350
Ca	Calcium	842	1.378	0.000230	1484
$CaBr_2$	Calcium bromide	742	3.111	0.0005	791
$CaCl_2$	Calcium chloride	775	2.085	0.000422	950
CaF_2	Calcium fluoride	1418	2.52	0.000391	2027
CaI_2	Calcium iodide	783	3.443	0.000751	1028
Cd	Cadmium	321.07	7.996	0.001218	500
$CdBr_2$	Cadmium bromide	568	4.075	0.00108	720
$CdCl_2$	Cadmium chloride	564	3.392	0.00082	807
CdI_2	Cadmium iodide	387	4.396	0.001117	700
Ce	Cerium	799	6.55	0.000710	1460
$CeCl_3$	Cerium(III) chloride	817	3.25	0.00092	950
CeF_3	Cerium(III) fluoride	1430	4.659	0.000936	1927
Co	Cobalt	1495	7.75	0.00165	1580
Cr	Chromium	1907	6.3	0.0011	2100
Cs	Cesium	28.44	1.843	0.000556	510
CsBr	Cesium bromide	636	3.133	0.001223	860
CsCl	Cesium chloride	645	2.79	0.001065	906
CsF	Cesium fluoride	703	3.649	0.001282	912
CsI	Cesium iodide	621	3.197	0.001183	907

DENSITY OF MOLTEN ELEMENTS AND REPRESENTATIVE SALTS (continued)

Formula	Name	t_m/°C	ρ_m/g cm^{-3}	k/g cm^{-3} °C^{-1}	t_{max}
$CsNO_3$	Cesium nitrate	414	2.820	0.001166	491
Cs_2SO_4	Cesium sulfate	1005	3.1	0.00095	1530
Cu	Copper	1084.62	8.02	0.000609	1630
CuCl	Copper(I) chloride	430	3.692	0.00076	585
Dy	Dysprosium	1411	8.37	0.00143	1540
$DyCl_3$	Dysprosium(III) chloride	680	3.62	0.00068	987
Er	Erbium	1529	8.86	0.00157	1700
Eu	Europium	822	5.13	0.0028	980
Fe	Iron	1538	6.98	0.000572	1680
$FeCl_2$	Iron(II) chloride	677	2.348	0.000555	877
Ga	Gallium	29.76	6.08	0.00062	400
$GaBr_3$	Gallium(III) bromide	121.5	3.116	0.00246	135
$GaCl_3$	Gallium(III) chloride	77.9	2.053	0.002083	141
GaI_3	Gallium(III) iodide	212	3.630	0.002377	252
Gd	Gadolinium	1314	7.4		
$GdCl_3$	Gadolinium(III) chloride	609	3.56	0.000671	1007
GdI_3	Gadolinium(III) iodide	925	4.12	0.000908	1032
Ge	Germanium	938.25	5.60	0.00055	1600
Hf	Hafnium	2233	12		
$HgBr_2$	Mercury(II) bromide	236	5.126	0.003233	319
$HgCl_2$	Mercury(II) chloride	276	4.368	0.002862	304
HgI_2	Mercury(II) iodide	259	5.222	0.003235	354
Ho	Holmium	1472	8.34		
In	Indium	156.60	7.02	0.000836	500
$InBr_3$	Indium(III) bromide	420	3.121	0.0015	528
$InCl_3$	Indium(III) chloride	583	2.140	0.0021	666
InI_3	Indium(III) iodide	207	3.820	0.0015	360
Ir	Iridium	2446	19		
K	Potassium	63.38	0.828	0.000232	500
KBr	Potassium bromide	734	2.127	0.000825	930
KCl	Potassium chloride	771	1.527	0.000583	939
KF	Potassium fluoride	858	1.910	0.000651	1037
KI	Potassium iodide	681	2.448	0.000956	904
KNO_3	Potassium nitrate	337	1.865	0.000723	457
La	Lanthanum	920	5.94	0.00061	1600
$LaBr_3$	Lanthanum bromide	788	4.933	0.000096	912
$LaCl_3$	Lanthanum chloride	859	3.209	0.000777	973
LaF_3	Lanthanum fluoride	1493	4.589	0.000682	2177
LaI_3	Lanthanum iodide	778	4.29	0.001110	907
Li	Lithium	180.5	0.512	0.00052	285
LiBr	Lithium bromide	552	2.528	0.000652	739
LiCl	Lithium chloride	610	1.502	0.000432	781
LiF	Lithium fluoride	848.2	1.81	0.000490	1047
LiI	Lithium iodide	469	3.109	0.000917	667
$LiNO_3$	Lithium nitrate	253	1.781	0.000546	441
Li_2SO_4	Lithium sulfate	859	2.003	0.000407	1214
Lu	Lutetium	1663	9.3		
Mg	Magnesium	650	1.584	0.000234	900
$MgBr_2$	Magnesium bromide	711	2.62	0.000478	935
$MgCl_2$	Magnesium chloride	714	1.68	0.000271	826
MgI_2	Magnesium iodide	634	3.05	0.000651	888
Mn	Manganese	1246	5.95	0.00105	1590
$MnCl_2$	Manganese(II) chloride	650	2.353	0.000437	850
Mo	Molybdenum	2623	9.33		
Na	Sodium	97.80	0.927	0.00023	600
NaBr	Sodium bromide	747	2.342	0.000816	945
Na_2CO_3	Sodium carbonate	858.1	1.972	0.000448	1004
NaCl	Sodium chloride	800.7	1.556	0.000543	1027
NaF	Sodium fluoride	996	1.948	0.000636	1097
NaI	Sodium iodide	660	2.742	0.000949	912

DENSITY OF MOLTEN ELEMENTS AND REPRESENTATIVE SALTS (continued)

Formula	Name	t_m/°C	ρ_m/g cm^{-3}	k/g cm^{-3} °C^{-1}	t_{max}
$NaNO_3$	Sodium nitrate	307	1.90	0.000715	370
Na_2SO_4	Sodium sulfate	884	2.069	0.000483	1077
Nd	Neodymium	1016	6.89	0.00076	1350
Ni	Nickel	1455	7.81	0.000726	1700
$NiCl_2$	Nickel(II) chloride	1009	2.653	0.00066	1057
Os	Osmium	3033	20		
Pb	Lead	327.46	10.66	0.00122	700
$PbBr_2$	Lead(II) bromide	371	5.73	0.00165	600
$PbCl_2$	Lead(II) chloride	501	4.951	0.0015	710
PbI_2	Lead(II) iodide	410	5.691	0.001594	697
Pd	Palladium	1554.9	10.38	0.001169	1700
Pr	Praseodymium	931	6.50	0.00093	1460
$PrCl_3$	Praseodymium chloride	786	3.23	0.00074	977
Pt	Platinum	1768.4	19.77	0.0024	2200
Pu	Plutonium	640	16.63	0.001419	950
Rb	Rubidium	39.31	1.46	0.000451	800
RbBr	Rubidium bromide	682	2.715	0.001072	907
Rb_2CO_3	Rubidium carbonate	837	2.84	0.000640	1007
RbCl	Rubidium chloride	715	2.248	0.000883	923
RbF	Rubidium fluoride	833	2.87	0.00102	1067
RbI	Rubidium iodide	642	2.904	0.001143	902
$RbNO_3$	Rubidium nitrate	305	2.519	0.001068	417
Rb_2SO_4	Rubidium sulfate	1050	2.56	0.000665	1545
Re	Rhenium	3186	18.9		
Rh	Rhodium	1964	10.7	0.000895	2200
Ru	Ruthenium	2334	10.65		
S	Sulfur	115.21	1.819	0.00080	160
Sb	Antimony	630.63	6.53	0.00067	745
$SbCl_3$	Antimony(III) chloride	73.4	2.681	0.002293	77
$SbCl_5$	Antimony(V) chloride	4	2.37	0.001869	77
SbI_3	Antimony(III) iodide	168	4.171	0.002483	322
Sc	Scandium	1541	2.80		
Se	Selenium	221	3.99		
Si	Silicon	1414	2.57	0.000936	1500
Sm	Samarium	1072	7.16		
Sn	Tin	231.93	6.99	0.000601	1200
$SnCl_2$	Tin(II) chloride	247	3.36	0.001253	480
$SnCl_4$	Tin(IV) chloride	-33	2.37	0.002687	138
Sr	Strontium	777	6.980		
$SrBr_2$	Strontium bromide	657	3.70	0.000745	1004
$SrCl_2$	Strontium chloride	874	2.727	0.000578	1037
SrF_2	Strontium fluoride	1477	3.470	0.000751	1927
SrI_2	Strontium iodide	538	4.085	0.000885	1026
Ta	Tantalum	3017	15		
$TaCl_5$	Tantalum(V) chloride	216	2.700	0.004316	457
Tb	Terbium	1359	7.65		
Te	Tellurium	449.51	5.70	0.00035	600
$ThCl_4$	Thorium chloride	770	3.363	0.0014	847
ThF_4	Thorium fluoride	1110	6.058	0.000759	1378
Ti	Titanium	1668	4.11		
$TiCl_4$	Titanium(IV) chloride	-25	1.807	0.001735	137
Tl	Thallium	304	11.22	0.00144	600
TlBr	Thallium(I) bromide	460	5.98	0.001755	647
TlCl	Thallium(I) chloride	430	5.628	0.0018	642
TlI	Thallium(I) iodide	441.8	6.15	0.001761	737
$TlNO_3$	Thallium(I) nitrate	206	4.91	0.001873	279
Tl_2SO_4	Thallium(I) sulfate	632	5.62	0.00130	927
Tm	Thulium	1545	8.56	0.00050	1675
U	Uranium	1135	17.3		
UCl_3	Uranium(III) chloride	837	4.84	0.007943	1057

DENSITY OF MOLTEN ELEMENTS AND REPRESENTATIVE SALTS (continued)

Formula	Name	t_m/°C	ρ_m/g cm^{-3}	k/g cm^{-3} °C^{-1}	t_{max}
UCl_4	Uranium(IV) chloride	590	3.572	0.001945	667
UF_4	Uranium(IV) fluoride	1036	6.485	0.000992	1341
V	Vanadium	1910	5.5		
W	Tungsten	3422	17.6		
Y	Yttrium	1526	4.24		
YCl_3	Yttrium chloride	721	2.510	0.0005	845
Yb	Ytterbium	824	6.21		
Zn	Zinc	419.53	6.57	0.0011	700
$ZnBr_2$	Zinc bromide	394	3.47	0.000959	602
$ZnCl_2$	Zinc chloride	290	2.54	0.00053	557
ZnI_2	Zinc iodide	446	3.878	0.00136	588
$ZnSO_4$	Zinc sulfate	680	3.14	0.00047	987
Zr	Zirconium	1855	5.8		
$ZrCl_4$	Zirconium chloride	437	1.643	0.007464	492

MAGNETIC SUSCEPTIBILITY OF THE ELEMENTS AND INORGANIC COMPOUNDS

When a material is placed in a magnetic field ***H***, a magnetization (magnetic moment per unit volume) ***M*** is induced in the material which is related to ***H*** by ***M*** = κ***H***, where κ is called the volume susceptibility. Since ***H*** and ***M*** have the same dimensions, κ is dimensionless. A more useful parameter is the molar susceptibility χ_m , defined by

$$\chi_m = \kappa V_m = \kappa\, M/\rho$$

where V_m is the molar volume of the substance, *M* the molar mass, and ρ the mass density. When the cgs system is used, the customary units for χ_m are $cm^3\ mol^{-1}$; the corresponding SI units are $m^3\ mol^{-1}$.

Substances that have no unpaired electron orbital or spin angular momentum generally have negative values of χ_m and are called diamagnetic. Their molar susceptibility varies only slightly with temperature. Substances with unpaired electrons, which are termed paramagnetic, have positive χ_m and show a much stronger temperature dependence, varying roughly as $1/T$. The net susceptibility of a paramagnetic substance is the sum of the paramagnetic and diamagnetic contributions, but the former almost always dominates.

This table gives values of χ_m for the elements and selected inorganic compounds. All values refer to nominal room temperature (285 to 300 K) unless otherwise indicated. When the physical state (s = solid, l = liquid, g = gas, aq = aqueous solution) is not given, the most common crystalline form is understood. An entry of "Ferro." indicates a ferromagnetic substance.

Substances are arranged in alphabetical order by the most common name, except that compounds such as hydrides, oxides, and acids are grouped with the parent element (the same ordering used in the table "Physical Constants of Inorganic Compounds").

In keeping with customary practice, the molar susceptibility is given here in units appropriate to the cgs system. These values should be multiplied by 4π to obtain values for use in SI equations (where the magnetic field strength ***H*** has units of $A\ m^{-1}$).

REFERENCES

1. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series,* II/16*, Diamagnetic Susceptibility,* Springer-Verlag, Heidelberg*,* 1986*.*
2. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series*, III/19, Subvolumes a to i2, *Magnetic Properties of Metals*, Springer-Verlag, Heidelberg, 1986-1992.
3. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series*, II/2, II/8, II/10, II/11,and II/12a, *Coordination and Organometallic Transition Metal Compounds*, Springer-Verlag, Heidelberg, 1966-1984.
4. *Tables de Constantes et Données Numérique, Volume 7, Relaxation Paramagnetique*, Masson, Paris, 1957.

Name	Formula	$\chi_m/10^{-6}\ cm^3\ mol^{-1}$
Aluminum	Al	+16.5
Aluminum trifluoride	AlF_3	-13.9
Aluminum oxide	Al_2O_3	-37
Aluminum sulfate	$Al_2(SO_4)_3$	-93
Ammonia (g)	NH_3	-16.3
Ammonia (aq)	NH_3	-18.3
Ammonium acetate	$NH_4C_2H_3O_2$	-41.1
Ammonium bromide	NH_4Br	-47
Ammonium carbonate	$(NH_4)_2CO_3$	-42.5
Ammonium chlorate	NH_4ClO_3	-42.1
Ammonium chloride	NH_4Cl	-36.7
Ammonium fluoride	NH_4F	-23
Ammonium iodate	NH_4IO_3	-62.3
Ammonium iodide	NH_4I	-66
Ammonium nitrate	NH_4NO_3	-33
Ammonium sulfate	$(NH_4)_2SO_4$	-67
Ammonium thiocyanate	NH_4SCN	-48.1
Antimony	Sb	-99
Stibine (g)	SbH_3	-34.6
Antimony(III) bromide	$SbBr_3$	-111.4
Antimony(III) chloride	$SbCl_3$	-86.7
Antimony(III) fluoride	SbF_3	-46
Antimony(III) iodide	SbI_3	-147.2
Antimony(III) oxide	Sb_2O_3	-69.4
Antimony(III) sulfide	Sb_2S_3	-86
Antimony(V) chloride	$SbCl_5$	-120.5
Argon (g)	Ar	-19.32
Arsenic (gray)	As	-5.6
Arsenic (yellow)	As	-23.2
Arsine (g)	AsH_3	-35.2
Arsenic(III) bromide	$AsBr_3$	-106
Arsenic(III) chloride	$AsCl_3$	-72.5
Arsenic(III) iodide	AsI_3	-142.2
Arsenic(III) oxide	As_2O_3	-30.34
Arsenic(III) sulfide	As_2S_3	-70
Barium	Ba	+20.6
Barium bromide	$BaBr_2$	-92
Barium bromide dihydrate	$BaBr_2\cdot 2H_2O$	-119.3
Barium carbonate	$BaCO_3$	-58.9
Barium chloride	$BaCl_2$	-72.6
Barium chloride dihydrate	$BaCl_2\cdot 2H_2O$	-100
Barium fluoride	BaF_2	-51
Barium hydroxide	$Ba(OH)_2$	-53.2
Barium iodate	$Ba(IO_3)_2$	-122.5
Barium iodide	BaI_2	-124.4
Barium iodide dihydrate	$BaI_2\cdot 2H_2O$	-163
Barium nitrate	$Ba(NO_3)_2$	-66.5
Barium oxide	BaO	-29.1
Barium peroxide	BaO_2	-40.6
Barium sulfate	$BaSO_4$	-65.8
Beryllium	Be	-9.0
Beryllium chloride	$BeCl_2$	-26.5
Beryllium hydroxide	$Be(OH)_2$	-23.1
Beryllium oxide	BeO	-11.9
Beryllium sulfate	$BeSO_4$	-37
Bismuth	Bi	-280.1

Name	Formula	$\chi_m/10^{-6}$ cm^3 mol^{-1}
Bismuth tribromide	$BiBr_3$	-147
Bismuth trichloride	$BiCl_3$	-26.5
Bismuth fluoride	BiF_3	-61.2
Bismuth hydroxide	$Bi(OH)_3$	-65.8
Bismuth triiodide	BiI_3	-200.5
Bismuth nitrate pentahydrate	$Bi(NO_3)_3 \cdot 5H_2O$	-159
Bismuth oxide	Bi_2O_3	-83
Bismuth phosphate	$BiPO_4$	-77
Bismuth sulfate	$Bi_2(SO_4)_3$	-199
Bismuth sulfide	Bi_2S_3	-123
Boron	B	-6.7
Diborane (g)	B_2H_6	-21.0
Boric acid (orthoboric acid)	H_3BO_3	-34.1
Boron trichloride	BCl_3	-59.9
Boron oxide	B_2O_3	-38.7
Bromine (l)	Br_2	-56.4
Bromine (g)	Br_2	-73.5
Bromine trifluoride	BrF_3	-33.9
Bromine pentafluoride	BrF_5	-45.1
Cadmium	Cd	-19.7
Cadmium bromide	$CdBr_2$	-87.3
Cadmium bromide tetrahydrate	$CdBr_2 \cdot 4H_2O$	-131.5
Cadmium carbonate	$CdCO_3$	-46.7
Cadmium chloride	$CdCl_2$	-68.7
Cadmium chromate	$CdCrO_4$	-16.8
Cadmium cyanide	$Cd(CN)_2$	-54
Cadmium fluoride	CdF_2	-40.6
Cadmium hydroxide	$Cd(OH)_2$	-41
Cadmium iodate	$Cd(IO_3)_2$	-108.4
Cadmium iodide	CdI_2	-117.2
Cadmium nitrate	$Cd(NO_3)_2$	-55.1
Cadmium nitrate tetrahydrate	$Cd(NO_3)_2 \cdot 4H_2O$	-140
Cadmium oxide	CdO	-30
Cadmium sulfate	$CdSO_4$	-59.2
Cadmium sulfide	CdS	-50
Calcium	Ca	+40
Calcium bromide	$CaBr_2$	-73.8
Calcium carbonate	$CaCO_3$	-38.2
Calcium chloride	$CaCl_2$	-54.7
Calcium fluoride	CaF_2	-28
Calcium hydroxide	$Ca(OH)_2$	-22
Calcium iodate	$Ca(IO_3)_2$	-101.4
Calcium iodide	CaI_2	-109
Calcium oxide	CaO	-15.0
Calcium sulfate	$CaSO_4$	-49.7
Calcium sulfate dihydrate	$CaSO_4 \cdot 2H_2O$	-74
Carbon (diamond)	C	-5.9
Carbon (graphite)	C	-6.0
Carbon monoxide (g)	CO	-9.8
Carbon dioxide (g)	CO_2	-21.0
Cerium (β)	Ce	+2500
Cerium(II) sulfide	CeS	+2110
Cerium(III) chloride	$CeCl_3$	+2490
Cerium(III) fluoride	CeF_3	+2190
Cerium(III) sulfide	Ce_2S_3	+5080
Cerium(IV) oxide	CeO_2	+26
Cerium(IV) sulfate tetrahydrate	$Ce(SO_4)_2 \cdot 4H_2O$	-97
Cesium	Cs	+29
Cesium bromate	$CsBrO_3$	-75.1
Cesium bromide	CsBr	-67.2
Cesium carbonate	Cs_2CO_3	-103.6
Cesium chlorate	$CsClO_3$	-65
Cesium chloride	CsCl	-56.7
Cesium fluoride	CsF	-44.5
Cesium iodide	CsI	-82.6
Cesium superoxide	CsO_2	+1534
Cesium sulfate	Cs_2SO_4	-116
Chlorine (l)	Cl_2	-40.4
Chlorine trifluoride (g)	ClF_3	-26.5
Chromium	Cr	+167
Chromium(II) chloride	$CrCl_2$	+7230
Chromium(III) chloride	$CrCl_3$	+6350
Chromium(III) fluoride	CrF_3	+4370
Chromium(III) oxide	Cr_2O_3	+1960
Chromium(III) sulfate	$Cr_2(SO_4)_3$	+11800
Chromium(VI) oxide	CrO_3	+40
Cobalt	Co	Ferro.
Cobalt(II) bromide	$CoBr_2$	+13000
Cobalt(II) chloride	$CoCl_2$	+12660
Cobalt(II) chloride hexahydrate	$CoCl_2 \cdot 6H_2O$	+9710
Cobalt(II) cyanide	$Co(CN)_2$	+3825
Cobalt(II) fluoride	CoF_2	+9490
Cobalt(II) iodide	CoI_2	+10760
Cobalt(II) sulfate	$CoSO_4$	+10000
Cobalt(II) sulfide	CoS	+225
Cobalt(II,III) oxide	Co_3O_4	+7380
Cobalt(III) fluoride	CoF_3	+1900
Cobalt(III) oxide	Co_2O_3	+4560
Copper	Cu	-5.46
Copper(I) bromide	CuBr	-49
Copper(I) chloride	CuCl	-40
Copper(I) cyanide	CuCN	-24
Copper(I) iodide	CuI	-63
Copper(I) oxide	Cu_2O	-20
Copper(II) bromide	$CuBr_2$	+685
Copper(II) chloride	$CuCl_2$	+1080
Copper(II) chloride dihydrate	$CuCl_2 \cdot 2H_2O$	+1420
Copper(II) fluoride	CuF_2	+1050
Copper(II) fluoride dihydrate	$CuF_2 \cdot 2H_2O$	+1600
Copper(II) hydroxide	$Cu(OH)_2$	+1170
Copper(II) nitrate trihydrate	$Cu(NO_3)_2 \cdot 3H_2O$	+1570
Copper(II) nitrate hexahydrate	$Cu(NO_3)_2 \cdot 6H_2O$	+1625
Copper(II) oxide	CuO	+238
Copper(II) sulfate	$CuSO_4$	+1330
Copper(II) sulfate pentahydrate	$CuSO_4 \cdot 5H_2O$	+1460
Copper(II) sulfide	CuS	-2.0
Dysprosium (α)	Dy	+98000
Dysprosium(III) oxide	Dy_2O_3	+89600
Dysprosium(III) sulfide	Dy_2S_3	+95200
Erbium	Er	+48000
Erbium oxide	Er_2O_3	+73920
Erbium sulfate octahydrate	$Er_2(SO_4)_3 \cdot 8H_2O$	+74600
Erbium sulfide	Er_2S_3	+77200

MAGNETIC SUSCEPTIBILITY OF THE ELEMENTS AND INORGANIC COMPOUNDS (continued)

Name	Formula	$\chi_m/10^{-6}$ cm^3 mol^{-1}
Europium	Eu	+30900
Europium(II) bromide	$EuBr_2$	+26800
Europium(II) chloride	$EuCl_2$	+26500
Europium(II) fluoride	EuF_2	+23750
Europium(II) iodide	EuI_2	+26000
Europium(II) sulfide	EuS	+23800
Europium(III) oxide	Eu_2O_3	+10100
Europium(III) sulfate	$Eu_2(SO_4)_3$	+10400
Gadolinium (350 K)	Gd	+185000
Gadolinium(III) chloride	$GdCl_3$	+27930
Gadolinium(III) oxide	Gd_2O_3	+53200
Gadolinium(III) sulfate octahydrate	$Gd_2(SO_4)_3 \cdot 8H_2O$	+53280
Gadolinium(III) sulfide	Gd_2S_3	+55500
Gallium	Ga	-21.6
Gallium suboxide	Ga_2O	-34
Gallium(II) sulfide	GaS	-23
Gallium(III) chloride	$GaCl_3$	-63
Gallium(III) sulfide	Ga_2S_3	-80
Germanium	Ge	-11.6
Germane (g)	GeH_4	-29.7
Germanium(II) oxide	GeO	-28.8
Germanium(II) sulfide	GeS	-40.9
Germanium(IV) chloride	$GeCl_4$	-72
Germanium(IV) fluoride	GeF_4	-50
Germanium(IV) iodide	GeI_4	-171
Germanium(IV) oxide	GeO_2	-34.3
Germanium(IV) sulfide	GeS_2	-53.9
Gold	Au	-28
Gold(I) bromide	AuBr	-61
Gold(I) chloride	AuCl	-67
Gold(I) iodide	AuI	-91
Gold(III) chloride	$AuCl_3$	-112
Hafnium	Hf	+71
Hafnium oxide	HfO_2	-23
Helium (g)	He	-2.02
Holmium	Ho	+72900
Holmium oxide	Ho_2O_3	+88100
Hydrazine (l)	N_2H_4	-201
Hydrogen (l, 20.3 K)	H_2	-5.44
Hydrogen (g)	H_2	-3.99
Hydrogen chloride (l)	HCl	-22.6
Hydrogen chloride (aq)	HCl	-22
Hydrogen fluoride (l)	HF	-8.6
Hydrogen fluoride (aq)	HF	-9.3
Hydrogen iodide (s, 195 K)	HI	-47.3
Hydrogen iodide (l, 233 K)	HI	-48.3
Hydrogen iodide (aq)	HI	-50.2
Hydrogen peroxide (l)	H_2O_2	-17.3
Hydrogen sulfide (g)	H_2S	-25.5
Indium	In	-10.2
Indium(I) chloride	InCl	-30
Indium(II) chloride	$InCl_2$	-56
Indium(II) sulfide	InS	-28
Indium(III) bromide	$InBr_3$	-107
Indium(III) chloride	$InCl_3$	-86
Indium(III) oxide	In_2O_3	-56
Indium(III) sulfide	In_2S_3	-98
Iodine	I_2	-90
Iodic acid	HIO_3	-48
Iodine pentoxide	I_2O_5	-79.4
Iodine chloride	ICl	-54.6
Iodine trichloride	ICl_3	-90.2
Iodine pentafluoride	IF_5	-58.1
Iridium	Ir	+25
Iridium(III) chloride	$IrCl_3$	-14.4
Iridium(IV) oxide	IrO_2	+224
Iron	Fe	Ferro.
Iron(II) bromide	$FeBr_2$	+13600
Iron(II) carbonate	$FeCO_3$	+11300
Iron(II) chloride	$FeCl_2$	+14750
Iron(II) chloride tetrahydrate	$FeCl_2 \cdot 4H_2O$	+12900
Iron(II) fluoride	FeF_2	+9500
Iron(II) iodide	FeI_2	+13600
Iron(II) oxide	FeO	+7200
Iron(II) sulfate	$FeSO_4$	+12400
Iron(II) sulfate monohydrate	$FeSO_4 \cdot H_2O$	+10500
Iron(II) sulfate heptahydrate	$FeSO_4 \cdot 7H_2O$	+11200
Iron(II) sulfide	FeS	+1074
Iron(III) chloride	$FeCl_3$	+13450
Iron(III) chloride hexahydrate	$FeCl_3 \cdot 6H_2O$	+15250
Iron(III) fluoride	FeF_3	+13760
Iron(III) fluoride trihydrate	$FeF_3 \cdot 3H_2O$	+7870
Iron(III) nitrate nonahydrate	$Fe(NO_3)_3 \cdot 9H_2O$	+15200
Krypton (g)	Kr	-29.0
Lanthanum (α)	La	+95.9
Lanthanum oxide	La_2O_3	-78
Lanthanum sulfate nonahydrate	$La_2(SO_4)_3 \cdot 9H_2O$	-262
Lanthanum sulfide	La_2S_3	-37
Lead	Pb	-23
Lead(II) acetate	$Pb(C_2H_3O_2)_2$	-89.1
Lead(II) bromide	$PbBr_2$	-90.6
Lead(II) carbonate	$PbCO_3$	-61.2
Lead(II) chloride	$PbCl_2$	-73.8
Lead(II) chromate	$PbCrO_4$	-18
Lead(II) fluoride	PbF_2	-58.1
Lead(II) iodate	$Pb(IO_3)_2$	-131
Lead(II) iodide	PbI_2	-126.5
Lead(II) nitrate	$Pb(NO_3)_2$	-74
Lead(II) oxide	PbO	-42
Lead(II) phosphate	$Pb_3(PO_4)_2$	-182
Lead(II) sulfate	$PbSO_4$	-69.7
Lead(II) sulfide	PbS	-83.6
Lithium	Li	+14.2
Lithium bromide	LiBr	-34.3
Lithium carbonate	Li_2CO_3	-27
Lithium chloride	LiCl	-24.3
Lithium fluoride	LiF	-10.1
Lithium hydride	LiH	-4.6
Lithium hydroxide (aq)	LiOH	-12.3
Lithium iodide	LiI	-50
Lithium sulfate	Li_2SO_4	-41.6
Lutetium	Lu	+182.9
Magnesium	Mg	+13.1
Magnesium bromide	$MgBr_2$	-72
Magnesium carbonate	$MgCO_3$	-32.4
Magnesium chloride	$MgCl_2$	-47.4

Name	Formula	$\chi_m/10^{-6}$ cm^3 mol^{-1}
Magnesium fluoride	MgF_2	-22.7
Magnesium hydroxide	$Mg(OH)_2$	-22.1
Magnesium iodide	MgI_2	-111
Magnesium oxide	MgO	-10.2
Magnesium sulfate	$MgSO_4$	-42
Magnesium sulfate monohydrate	$MgSO_4 \cdot H_2O$	-61
Magnesium sulfate heptahydrate	$MgSO_4 \cdot 7H_2O$	-135.7
Manganese	Mn	+511
Manganese(II) bromide	$MnBr_2$	+13900
Manganese(II) carbonate	$MnCO_3$	+11400
Manganese(II) chloride	$MnCl_2$	+14350
Manganese(II) chloride tetrahydrate	$MnCl_2 \cdot 4H_2O$	+14600
Manganese(II) fluoride	MnF_2	+10700
Manganese(II) hydroxide	$Mn(OH)_2$	+13500
Manganese(II) iodide	MnI_2	+14400
Manganese(II) oxide	MnO	+4850
Manganese(II) sulfate	$MnSO_4$	+13660
Manganese(II) sulfate monohydrate	$MnSO_4 \cdot H_2O$	+14200
Manganese(II) sulfate tetrahydrate	$MnSO_4 \cdot 4H_2O$	+14600
Manganese(II) sulfide (α form)	MnS	+5630
Manganese(II) sulfide (β form)	MnS	+3850
Manganese(II,III) oxide	Mn_3O_4	+12400
Manganese(III) fluoride	MnF_3	+10500
Manganese(III) oxide	Mn_2O_3	+14100
Manganese(IV) oxide	MnO_2	+2280
Mercury (s, 234 K)	Hg	-24.1
Mercury (l)	Hg	-33.5
Mercury(I) bromide	Hg_2Br_2	-105
Mercury(I) chloride	Hg_2Cl_2	-120
Mercury(I) fluoride	Hg_2F_2	-106
Mercury(I) iodide	Hg_2I_2	-166
Mercury(I) nitrate	$Hg_2(NO_3)_2$	-121
Mercury(I) oxide	Hg_2O	-76.3
Mercury(I) sulfate	Hg_2SO_4	-123
Mercury(II) bromide	$HgBr_2$	-94.2
Mercury(II) chloride	$HgCl_2$	-82
Mercury(II) cyanide	$Hg(CN)_2$	-67
Mercury(II) fluoride	HgF_2	-57.3
Mercury(II) iodide	HgI_2	-165
Mercury(II) nitrate	$Hg(NO_3)_2$	-74
Mercury(II) oxide	HgO	-46
Mercury(II) sulfate	$HgSO_4$	-78.1
Mercury(II) sulfide	HgS	-55.4
Mercury(II) thiocyanate	$Hg(SCN)_2$	-96.5
Molybdenum	Mo	+72
Molybdenum(III) bromide	$MoBr_3$	+525
Molybdenum(III) chloride	$MoCl_3$	+43
Molybdenum(III) oxide	Mo_2O_3	-42.0
Molybdenum(IV) bromide	$MoBr_4$	+520
Molybdenum(IV) chloride	$MoCl_4$	+1750
Molybdenum(IV) oxide	MoO_2	+41
Molybdenum(V) chloride	$MoCl_5$	+990
Molybdenum(VI) fluoride	MoF_6	-26.0
Molybdenum(VI) oxide	MoO_3	+3
Neodymium (α)	Nd	+5930
Neodymium fluoride	NdF_3	+4980
Neodymium oxide	Nd_2O_3	+10200
Neodymium sulfate	$Nd_2(SO_4)_3$	+9990
Neodymium sulfide	Nd_2S_3	+5550
Neon (g)	Ne	-6.96
Neptunium	Np	+575
Nickel	Ni	Ferro.
Nickel(II) bromide	$NiBr_2$	+5600
Nickel(II) chloride	$NiCl_2$	+6145
Nickel(II) chloride hexahydrate	$NiCl_2 \cdot 6H_2O$	+4240
Nickel(II) fluoride	NiF_2	+2410
Nickel(II) hydroxide	$Ni(OH)_2$	+4500
Nickel(II) iodide	NiI_2	+3875
Nickel(II) nitrate hexahydrate	$Ni(NO_3)_2 \cdot 6H_2O$	+4300
Nickel(II) oxide	NiO	+660
Nickel(II) sulfate	$NiSO_4$	+4005
Nickel(II) sulfide	NiS	+190
Nickel(III) sulfide	Ni_3S_2	+1030
Niobium	Nb	+208
Niobium(V) oxide	Nb_2O_5	-10
Nitrogen (g)	N_2	-12.0
Nitric acid (l)	HNO_3	-19.9
Nitrous oxide (g)	N_2O	-18.9
Nitric oxide (s, 90 K)	NO	+19.8
Nitric oxide (l, 118 K)	NO	+114.2
Nitric oxide (g)	NO	+1461
Nitrogen dioxide (g, 408 K)	NO_2	+150
Nitrogen trioxide (g)	N_2O_3	-16
Nitrogen tetroxide (g)	N_2O_4	-23.0
Osmium	Os	+11
Oxygen (s, 54 K)	O_2	+10200
Oxygen (l, 90 K)	O_2	+7699
Oxygen (g)	O_2	+3449
Ozone (l)	O_3	+6.7
Palladium	Pd	+540
Palladium(II) chloride	$PdCl_2$	-38
Phosphorus (white)	P	-26.66
Phosphorus (red)	P	-20.77
Phosphine (g)	PH_3	-26.2
Phosphoric acid (aq)	H_3PO_4	-43.8
Phosphorous acid (aq)	H_3PO_3	-42.5
Phosphorus(III) chloride (l)	PCl_3	-63.4
Platinum	Pt	+193
Platinum(II) chloride	$PtCl_2$	-54
Platinum(III) chloride	$PtCl_3$	-66.7
Platinum(IV) chloride	$PtCl_4$	-93
Platinum(IV) fluoride	PtF_4	+445
Plutonium	Pu	+525
Plutonium(IV) fluoride	PuF_4	+1760
Plutonium(IV) oxide	PuO_2	+730
Plutonium(VI) fluoride	PuF_6	+173
Potassium	K	+20.8
Potassium bromate	$KBrO_3$	-52.6
Potassium bromide	KBr	-49.1
Potassium carbonate	K_2CO_3	-59

Name	Formula	$\chi_m/10^{-6}$ cm^3 mol^{-1}
Potassium chlorate	$KClO_3$	-42.8
Potassium chloride	KCl	-38.8
Potassium chromate	K_2CrO_4	-3.9
Potassium cyanide	KCN	-37
Potassium ferricyanide	$K_3Fe(CN)_6$	+2290
Potassium ferrocyanide trihydrate	$K_4Fe(CN)_6\cdot 3H_2O$	-172.3
Potassium fluoride	KF	-23.6
Potassium hydrogen sulfate	$KHSO_4$	-49.8
Potassium hydroxide (aq)	KOH	-22
Potassium iodate	KIO_3	-63.1
Potassium iodide	KI	-63.8
Potassium nitrate	KNO_3	-33.7
Potassium nitrite	KNO_2	-23.3
Potassium permanganate	$KMnO_4$	+20
Potassium sulfate	K_2SO_4	-67
Potassium sulfide	K_2S	-60
Potassium superoxide	KO_2	+3230
Potassium thiocyanate	KSCN	-48
Praseodymium (α)	Pr	+5530
Praseodymium chloride	$PrCl_3$	+44.5
Praseodymium oxide	Pr_2O_3	+8994
Praseodymium sulfide	Pr_2S_3	+10770
Protactinium	Pa	+277
Rhenium	Re	+67
Rhenium(IV) oxide	ReO_2	+44
Rhenium(IV) sulfide	ReS_2	+38
Rhenium(V) chloride	$ReCl_5$	+1225
Rhenium(VI) oxide	ReO_3	+16
Rhenium(VII) oxide	Re_2O_7	-16
Rhodium	Rh	+102
Rhodium(III) chloride	$RhCl_3$	-7.5
Rhodium(III) oxide	Rh_2O_3	+104
Rubidium	Rb	+17
Rubidium bromide	RbBr	-56.4
Rubidium carbonate	Rb_2CO_3	-75.4
Rubidium chloride	RbCl	-46
Rubidium fluoride	RbF	-31.9
Rubidium iodide	RbI	-72.2
Rubidium nitrate	$RbNO_3$	-41
Rubidium sulfate	Rb_2SO_4	-88.4
Rubidium superoxide	RbO_2	+1527
Ruthenium	Ru	+39
Ruthenium(III) chloride	$RuCl_3$	+1998
Ruthenium(IV) oxide	RuO_2	+162
Samarium (α)	Sm	+1278
Samarium(II) bromide	$SmBr_2$	+5337
Samarium(III) bromide	$SmBr_3$	+972
Samarium(III) oxide	Sm_2O_3	+1988
Samarium(III) sulfate octahydrate	$Sm_2(SO_4)_3\cdot 8H_2O$	+1710
Samarium(III) sulfide	Sm_2S_3	+3300
Scandium (α)	Sc	+295.2
Selenium	Se	-25
Selenium dioxide	SeO_2	-27.2
Selenium bromide	Se_2Br_2	-113
Selenium chloride (l)	Se_2Cl_2	-94.8
Selenium hexafluoride (g)	SeF_6	-51
Silicon	Si	-3.12
Silane (g)	SiH_4	-20.4
Disilane (g)	Si_2H_6	-37.3
Tetramethylsilane (l)	$(CH_3)_4Si$	-74.80
Tetraethylsilane (l)	$(C_2H_5)_4Si$	-120.2
Tetrabromosilane (l)	$SiBr_4$	-126
Tetrachlorosilane (l)	$SiCl_4$	-87.5
Silicon carbide	SiC	-12.8
Silicon dioxide	SiO_2	-29.6
Silver	Ag	-19.5
Silver(I) bromide	AgBr	-61
Silver(I) carbonate	Ag_2CO_3	-80.90
Silver(I) chloride	AgCl	-49
Silver(I) chromate	Ag_2CrO_4	-40
Silver(I) cyanide	AgCN	-43.2
Silver(I) fluoride	AgF	-36.5
Silver(I) iodide	AgI	-80
Silver(I) nitrate	$AgNO_3$	-45.7
Silver(I) nitrite	$AgNO_2$	-42
Silver(I) oxide	Ag_2O	-134
Silver(I) phosphate	Ag_3PO_4	-120
Silver(I) sulfate	Ag_2SO_4	-92.90
Silver(I) thiocyanate	AgSCN	-61.8
Silver(II) oxide	AgO	-19.6
Sodium	Na	+16
Sodium acetate	$NaC_2H_3O_2$	-37.6
Sodium bromate	$NaBrO_3$	-44.2
Sodium bromide	NaBr	-41
Sodium carbonate	Na_2CO_3	-41
Sodium chlorate	$NaClO_3$	-34.7
Sodium chloride	NaCl	-30.2
Sodium dichromate	$Na_2Cr_2O_7$	+55
Sodium fluoride	NaF	-15.6
Sodium hydrogen phosphate	Na_2HPO_4	-56.6
Sodium hydroxide (aq)	NaOH	-15.8
Sodium iodate	$NaIO_3$	-53
Sodium iodide	NaI	-57
Sodium nitrate	$NaNO_3$	-25.6
Sodium nitrite	$NaNO_2$	-14.5
Sodium oxide	Na_2O	-19.8
Sodium peroxide	Na_2O_2	-28.10
Sodium sulfate	Na_2SO_4	-52
Sodium sulfate decahydrate	$Na_2SO_4\cdot 10H_2O$	-184
Sodium sulfide	Na_2S	-39
Sodium tetraborate	$Na_2B_4O_7$	-85
Strontium	Sr	+92
Strontium bromide	$SrBr_2$	-86.6
Strontium bromide hexahydrate	$SrBr_2\cdot 6H_2O$	-160
Strontium carbonate	$SrCO_3$	-47
Strontium chlorate	$Sr(ClO_3)_2$	-73
Strontium chloride	$SrCl_2$	-61.5
Strontium chloride hexahydrate	$SrCl_2\cdot 6H_2O$	-145
Strontium chromate	$SrCrO_4$	-5.1
Strontium fluoride	SrF_2	-37.2
Strontium hydroxide	$Sr(OH)_2$	-40
Strontium iodate	$Sr(IO_3)_2$	-108
Strontium iodide	SrI_2	-112
Strontium nitrate	$Sr(NO_3)_2$	-57.2

Name	Formula	$\chi_m/10^{-6}$ cm^3 mol^{-1}	Name	Formula	$\chi_m/10^{-6}$ cm^3 mol^{-1}
Strontium oxide	SrO	-35	Tungsten	W	+53
Strontium peroxide	SrO_2	-32.3	Tungsten carbide	WC	+10
Strontium sulfate	$SrSO_4$	-57.9	Tungsten(II) chloride	WCl_2	-25
Sulfur (rhombic)	S	-15.5	Tungsten(IV) oxide	WO_2	+57
Sulfur (monoclinic)	S	-14.9	Tungsten(IV) sulfide	WS_2	+5850
Sulfuric acid (l)	H_2SO_4	-39	Tungsten(V) bromide	WBr_5	+270
Sulfur dioxide (g)	SO_2	-18.2	Tungsten(V) chloride	WCl_5	+387
Sulfur trioxide (l)	SO_3	-28.54	Tungsten(VI) chloride	WCl_6	-71
Sulfur chloride (l)	$SSCl_2$	-62.2	Tungsten(VI) fluoride (g)	WF_6	-53
Sulfur dichloride (l)	SCl_2	-49.4	Tungsten(VI) oxide	WO_3	-15.8
Sulfur hexafluoride (g)	SF_6	-44	Uranium	U	+409
Thionyl chloride (l)	$SOCl_2$	-44.3	Uranium(III) bromide	UBr_3	+4740
Tantalum	Ta	+154	Uranium(III) chloride	UCl_3	+3460
Tantalum(V) chloride	$TaCl_5$	+140	Uranium(III) hydride	UH_3	+6244
Tantalum(V) oxide	Ta_2O_5	-32	Uranium(III) iodide	UI_3	+4460
Technetium	Tc	+115	Uranium(IV) bromide	UBr_4	+3530
Tellurium	Te	-38	Uranium(IV) chloride	UCl_4	+3680
Tellurium dibromide	$TeBr_2$	-106	Uranium(IV) fluoride	UF_4	+3530
Tellurium dichloride	$TeCl_2$	-94	Uranium(IV) oxide	UO_2	+2360
Tellurium hexafluoride (g)	TeF_6	-66	Uranium(VI) fluoride	UF_6	+43
Terbium (α)	Tb	+170000	Uranium(VI) oxide	UO_3	+128
Terbium oxide	Tb_2O_3	+78340	Vanadium	V	+285
Thallium	Tl	-50	Vanadium(II) bromide	VBr_2	+3230
Thallium(I) bromate	$TlBrO_3$	-75.9	Vanadium(II) chloride	VCl_2	+2410
Thallium(I) bromide	$TlBr$	-63.9	Vanadium(III) bromide	VBr_3	+2910
Thallium(I) carbonate	Tl_2CO_3	-101.6	Vanadium(III) chloride	VCl_3	+3030
Thallium(I) chlorate	$TlClO_3$	-65.5	Vanadium(III) fluoride	VF_3	+2757
Thallium(I) chloride	$TlCl$	-57.8	Vanadium(III) oxide	V_2O_3	+1976
Thallium(I) chromate	Tl_2CrO_4	-39.3	Vanadium(III) sulfide	V_2S_3	+1560
Thallium(I) cyanide	$TlCN$	-49	Vanadium(IV) chloride	VCl_4	+1215
Thallium(I) fluoride	TlF	-44.4	Vanadium(IV) oxide	VO_2	+99
Thallium(I) iodate	$TlIO_3$	-86.8	Vanadium(V) oxide	V_2O_5	+128
Thallium(I) iodide	TlI	-82.2	Water (s, 273 K)	H_2O	-12.63
Thallium(I) nitrate	$TlNO_3$	-56.5	Water (l, 293 K)	H_2O	-12.96
Thallium(I) nitrite	$TlNO_2$	-50.8	Water (l, 373 K)	H_2O	-13.09
Thallium(I) sulfate	Tl_2SO_4	-112.6	Water (g, 373 K))	H_2O	-13.1
Thallium(I) sulfide	Tl_2S	-88.8	Xenon (g)	Xe	-45.5
Thorium	Th	+97	Ytterbium (β)	Yb	+67
Thorium(IV) oxide	ThO_2	-16	Yttrium (α)	Y	+187.7
Thulium	Tm	+24700	Yttrium oxide	Y_2O_3	+44.4
Thulium oxide	Tm_2O_3	+51444	Yttrium sulfide	Y_2S_3	+100
Tin (gray)	Sn	-37.4	Zinc	Zn	-9.15
Tin(II) chloride	$SnCl_2$	-69	Zinc carbonate	$ZnCO_3$	-34
Tin(II) chloride dihydrate	$SnCl_2\cdot 2H_2O$	-91.4	Zinc chloride	$ZnCl_2$	-55.33
Tin(II) oxide	SnO	-19	Zinc cyanide	$Zn(CN)_2$	-46
Tin(IV) bromide	$SnBr_4$	-149	Zinc fluoride	ZnF_2	-34.3
Tin(IV) chloride (l)	$SnCl_4$	-115	Zinc hydroxide	$Zn(OH)_2$	-67
Tin(IV) oxide	SnO_2	-41	Zinc iodide	ZnI_2	-108
Titanium	Ti	+151	Zinc oxide	ZnO	-27.2
Titanium(II) bromide	$TiBr_2$	+720	Zinc phosphate	$Zn_3(PO_4)_2$	-141
Titanium(II) chloride	$TiCl_2$	+484	Zinc sulfate	$ZnSO_4$	-47.8
Titanium(II) iodide	TiI_2	+1790	Zinc sulfate monohydrate	$ZnSO_4\cdot H_2O$	-63
Titanium(II) sulfide	TiS	+432	Zinc sulfate heptahydrate	$ZnSO_4\cdot 7H_2O$	-138
Titanium(III) bromide	$TiBr_3$	+660	Zinc sulfide	ZnS	-25
Titanium(III) chloride	$TiCl_3$	+1110	Zirconium	Zr	+120
Titanium(III) fluoride	TiF_3	+1300	Zirconium carbide	ZrC	-26
Titanium(III) oxide	Ti_2O_3	+132	Zirconium nitrate pentahydrate	$Zr(NO_3)_4\cdot 5H_2O$	-77
Titanium(IV) chloride	$TiCl_4$	-54			
Titanium(IV) oxide	TiO_2	+5.9	Zirconium(IV) oxide	ZrO_2	-13.8

INDEX OF REFRACTION OF INORGANIC LIQUIDS

This table gives the index of refraction *n* of several inorganic substances in the liquid state at specified temperatures. The measurements refer to ambient atmospheric pressure except for substances whose normal boiling points are greater than the indicated temperature; in this case the pressure is the saturated vapor pressure of the substance. All values refer to a wavelength of 589 nm unless otherwise indicated. Entries are arranged in alphabetical order by chemical formula as normally written.

Data on the index of refraction at other temperatures and wavelengths may be found in Reference 1.

REFERENCES

1. Wohlfarth, C., and Wohlfarth, B., *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series*, III/38A, Martienssen, W., Editor, Springer-Verlag, Heidelberg, 1996.
2. Francis, A.W., *J. Chem. Eng. Data*, 5, 534, 1960.

Formula	Name	*t*/°C	*n*
Ar	Argon	-188	1.2312
$AsCl_3$	Arsenic(III) chloride	16	1.604
BBr_3	Boron tribromide	16	1.312
BrF_3	Bromine trifluoride	25	1.4536
BrF_5	Bromine pentafluoride	25	1.3529
Br_2	Bromine	15	1.659
COS	Carbon oxysulfide	25	1.3506
CO_2	Carbon dioxide	24	1.6630
CS_2	Carbon disulfide	20	1.62774
C_3O_2	Carbon suboxide	0	1.453
Cl_2	Chlorine	20	1.3834
CrO_2Cl_2	Chromyl chloride	23	1.524
$Fe(CO)_5$	Iron pentacarbonyl	14	1.523
$GeBr_4$	Germanium(IV) bromide	26	1.6269
$GeCl_4$	Germanium(IV) chloride	25	1.4614
HBr	Hydrogen bromide	10	1.325
HCN	Hydrogen cyanide	20	1.26136
HCl	Hydrogen chloride	18	1.3287 [a]
$HClO_4$	Perchloric acid	50	1.3819
HF	Hydrogen fluoride	25	1.1574
HI	Hydrogen iodide	16	1.466
HNO_3	Nitric acid	25	1.393
H_2	Hydrogen	-253	1.1096
H_2O	Water	20	1.33336
H_2O_2	Hydrogen peroxide	28	1.4061
H_2S	Hydrogen sulfide	-80	1.460
		20	1.3682
H_2SO_4	Sulfuric acid	20	1.4183
H_2S_2	Hydrogen disulfide	20	1.630
He	Helium	-269	1.02451 [c]
Kr	Krypton	-157	1.3032 [c]
NH_3	Ammonia	-77	1.3944 [b]
		20	1.3327
NO	Nitric oxide	-90	1.330
N_2	Nitrogen	-196	1.19876 [b]
N_2H_4	Hydrazine	22	1.470
N_2O	Nitrous oxide	25	1.238
O_2	Oxygen	-183	1.2243 [c]
PBr_3	Phosphorus(III) bromide	25	1.687
PCl_3	Phosphorus(III) chloride	21	1.5122
PH_3	Phosphine	17	1.317
P_2O_3	Phosphorus(III) oxide	27	1.540
S	Sulfur	125	1.9170
SCl_2	Sulfur dichloride	14	1.557
SF_6	Sulfur hexafluoride	25	1.167
$SOCl_2$	Thionyl chloride	10	1.527
SO_2	Sulfur dioxide	25	1.3396
SO_2Cl_2	Sulfuryl chloride	12	1.444

INDEX OF REFRACTION OF INORGANIC LIQUIDS (continued)

Formula	Name	*t*/°C	*n*
SO_3	Sulfur trioxide	20	1.40965
$SSCl_2$	Sulfur chloride	20	1.671
$SbCl_5$	Antimony(V) chloride	22	1.5925
$SiBr_4$	Tetrabromosilane	31	1.5685
$SiCl_4$	Tetrachlorosilane	25	1.41156
$SnBr_4$	Tin(IV) bromide	31	1.6628
$SnCl_4$	Tin(IV) chloride	25	1.5086
$TiCl_4$	Titanium(IV) chloride	18	1.6076
Xe	Xenon	-112	1.3918 [c]

[a] At 581 nm
[b] At 578 nm
[c] At 546 nm

PHYSICAL AND OPTICAL PROPERTIES OF MINERALS

The chemical formula, crystal system, density, hardness, and index of refraction of some common minerals are given in this table. Entries are arranged alphabetically by mineral name. The columns are:

- **Formula:** Chemical formula for a typical sample of the mineral. Composition often varies considerably with the origin of the sample.
- **Crystal system:** tricl = triclinic; monocl = monoclinic; orth = orthorhombic; tetr = tetragonal; hex = hexagonal; rhomb = rhombohedral; cub = cubic.
- **Density:** Typical density in g/cm^3. Individual samples may vary by a few percent.
- **Hardness:** On the Mohs' scale (range of 1 to 10, with talc = 1 and diamond = 10).
- **Index of refraction:** Values are given for the three coordinate axes in the order of least, intermediate, and greatest index. For cubic crystals there is only a single value. See Reference 1 for details on the axis systems. Variations of several percent, depending on the origin and exact composition of the sample, are common.

REFERENCES

1. Deer, W.A., Howie, R.A., and Zussman, J., *An Introduction to the Rock-Forming Minerals*, 2nd Edition, Longman Scientific & Technical, Harlow, Essex, 1992.
2. Carmichael, R.S., *Practical Handbook of Physical Properties of Rocks and Minerals*, CRC Press, Boca Raton, FL, 1989.
3. Donnay, J.D.H., and Ondik, H.M., *Crystal Data Determinative Tables, Third Edition, Volume 2, Inorganic Compounds*, Joint Committee on Powder Diffraction Standards, Swarthmore, PA, 1973.

Name	Formula	Crystal system	Density g/cm^3	Hard-ness	Index of refraction n_α	n_β	n_γ
Acanthite	Ag_2S	orth	7.2	2.3			
Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH,F)_2$	monocl	3.23	5.5	1.624	1.655	1.664
Aegirine	$NaFe(SiO_3)_2$	monocl	3.58	6	1.763	1.800	1.815
Akermanite	$Ca_2MgSi_2O_7$	tetr	2.94	5.5	1.632	1.640	
Alabandite	MnS	cub	4.0	3.8			
Albite	$NaAlSi_3O_8$	tricl	2.63	6.3	1.527	1.531	1.538
Allanite	$(Ca,Mn,Ce,La,Y,Th)_2(Fe,Ti)(Al,Fe)$ $O{\cdot}OH(Si_2O_7)(SiO_4)$	monocl	3.8	5.8	1.75	1.78	1.80
Allemontite	SbAs	hex	6.0	3.5			
Almandine	$Fe_3Al_2Si_3O_{12}$	cub	4.32	6.8	1.830		
Altaite	PbTe	cub	8.16	3			
Aluminite	$Al_2(SO_4)(OH)_4{\cdot}7H_2O$	monocl	1.74	1.5	1.459	1.464	1.470
Alunite	$(K,Na)Al_3(SO_4)_2(OH)_6$	rhomb	2.8	3.8	1.572	1.592	
Alunogen	$Al_2(SO_4)_3{\cdot}18H_2O$	monocl	1.69	1.8	1.467	1.47	1.478
Amblygonite	$(Li,Na)Al(PO_4)(F,OH)$	tricl	3.1	5.8	1.591	1.604	1.613
Analcite	$NaAlSi_2O_6{\cdot}H_20$	cub	2.27	5.5	1.486		
Anatase	TiO_2	tetr	4.23	5.8	2.488	2.561	
Andalusite	Al_2OSiO_4	orth	3.15	7.5	1.635	1.639	1.644
Andesine	$NaAlSi_3O_8{\cdot}CaAl_2Si_2O_8$	tricl	2.67	6.3	1.550	1.553	1.557
Andorite	$PbAgSb_3S_6$	rhomb	5.35	3.3			
Andradite	$Ca_3(Fe,Ti)_2Si_3O_{12}$	cub	3.86	6.8	1.887		
Anglesite	$PbSO_4$	orth	6.29	2.8	1.877	1.883	1.894
Anhydrite	$CaSO_4$	orth	2.96	3.5	1.570	1.575	1.614
Ankerite	$Ca(Fe,Mg,Mn)(CO_3)_2$	rhomb	3.0	3.8	1.529	1.720	
Anorthite	$CaAl_2Si_2O_8$	tricl	2.76	6.3	1.577	1.585	1.590
Anorthoclase	$(Na,K)AlSi_3O_8$	tricl	2.58	6	1.523	1.528	1.529
Anthophyllite	$(Mg,Fe)_7Si_8O_{22}(OH,F)_2$	rhomb	3.21	5.8	1.645	1.658	1.668
Apatite	$Ca_5(PO_4)_3(OH,F,Cl)$	hex	3.2	5	1.645	1.648	
Apophyllite	$KFCa_4Si_8O_{20}{\cdot}8H_2O$	tetr	2.35	4.8	1.535	1.536	
Aragonite	$CaCO_3$	orth	2.83	3.5	1.531	1.680	1.686
Arcanite	K_2SO_4	orth	2.66		1.494	1.494	1.497
Argentite	Ag_2S	orth	7.2	2.3			
Arsenolite	As_2O_3	cub	3.86	1.5	1.755		
Arsenopyrite	FeAsS	monocl	6.1	5.8			
Atacamite	$Cu_2(OH)_3Cl$	rhomb	3.76	3.3	1.831	1.861	1.880
Augelite	$Al_2(PO_4)(OH)_3$	monocl	2.70	4.8	1.574	1.576	1.588
Augite	$(Ca,Mg,Fe,Ti,Al)_2(Si,Al)_2O_6$	monocl	3.38	6	1.703	1.707	1.738
Autunite	$Ca(UO_{22})(PO_4)_2{\cdot}10H20$	tetr	3.2	2.3	1.553	1.577	
Axinite	$(Ca,Mn,Fe)_3Al_2BO_3Si_4O_{12}(OH)$	tricl	3.31	6.8	1.684	1.691	1.694

Name	Formula	Crystal system	Density g/cm³	Hard-ness	Index of refraction n_α	n_β	n_γ
Azurite	$Cu_3(OH)_2(CO_3)_2$	monocl	3.77	3.8	1.730	1.758	1.838
Baddeleyite	ZrO_2	monocl	5.7	6.5	2.13	2.19	2.20
Barite	$BaSO_4$	orth	4.49	3.3	1.636	1.637	1.648
Benitoite	$BaTi(SiO_3)_3$	rhomb	3.65	6.3	1.757	1.804	
Bertrandite	$Be_4Si_2O_7(OH)_2$	rhomb	2.6	6	1.589	1.602	1.613
Beryl	$Be_3Al_2(SiO_3)_6$	hex	2.64	7.8	1.582	1.589	
Beryllonite	$NaBe(PO)_4$	monocl	2.81	5.8	1.552	1.558	1.561
Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH,F)_2$	monocl	3.0	2.8	1.595	1.651	1.651
Bismuthinite	Bi_2S_3	orth	6.78	2			
Bixbyite	$(Mn,Fe)_2O_3$	cub	4.95	6.3			
Bloedite	$Na_2Mg(SO_4)_2{\cdot}4H_2O$	monocl	2.25	2.8	1.483	1.486	1.487
Boehmite	$AlO(OH)$	orth	3.44	3.8	1.64	1.65	1.66
Boracite	$Mg_3B_7O_{13}Cl$	rhomb	2.94	7.3	1.66	1.66	1.67
Borax	$Na_2B_4O_7{\cdot}10H_2O$	monocl	1.73	2.3	1.447	1.469	1.472
Bornite	Cu_5FeS_4	cub	5.07	3			
Boulangerite	$Pb_5Sb_4S_{11}$	monocl	6.1	2.8			
Bournonite	$PbCuSbS_3$	rhomb	5.83	2.8			
Braggite	PtS	tetr	10.2				
Braunite	$(Mn,Si)_2O_3$	tetr	4.78	6.3			
Bravoite	$(Ni,Fe)S_2$	cub	4.62	5.8			
Breithauptite	$NiSb$	hex	≈8.7	5.5			
Brochantite	$Cu_4(SO_4)(OH)_6$	monocl	3.79	3.8	1.728	1.771	1.800
Bromyrite	$AgBr$	cub	6.47	2.5	2.253		
Brookite	TiO_2	orth	4.23	5.8	2.583	2.584	2.700
Brucite	$Mg(OH)_2$	hex	2.37	2.5	1.575	1.59	
Bunsenite	NiO	cub	6.72	5.5			
Cacoxenite	$Fe_4(PO_4)_3(OH)_3{\cdot}12H_20$	hex	2.3	3.5	1.580	1.646	
Calcite	$CaCO_3$	hex	2.71	3	1.486	1.658	
Caledonite	$Cu_2Pb_5(SO_4)_3(CO_3)(OH)_6$	rhomb	5.76	2.8	1.818	1.866	1.909
Calomel	Hg_2Cl_2	tetr	7.16	1.5	1.973	2.656	
Cancrinite	$(Na,Ca,K)_7[Al_6Si_6O_{24}]$ $(CO_3,SO_4,Cl,OH)_2{\cdot}H_20$	hex	2.42	5.5	1.495	1.509	
Carnalite	$KMgCl_3{\cdot}6H_20$	rhomb	1.60	2.5	1.466	1.475	1.494
Carnotite	$K_2(UO_2)_2(VO_4)_2{\cdot}3H_2O$	rhomb		1.5	1.75	1.92	1.95
Cassiterite	SnO_2	tetr	6.85	6.5	2.006	2.097	
Celestite	$SrSO_4$	orth	3.96	3.3	1.622	1.624	1.631
Celsian	$BaAl_2Si_2O_8$	monocl	3.25	6.3	1.583	1.588	1.594
Cerargyrite	$AgCl$	cub	5.56	2.5	2.071		
Cerussite	$PbCO_3$	orth	6.6	3.3	1.804	2.076	2.079
Cervantite	Sb_2O_4	orth	6.64	4.5			
Chabazite	$Ca[Al_2Si_4O_{12}]{\cdot}6H_2O$	trig	2.08	4.5	1.482		
Chalcanthite	$CuSO_4{\cdot}5H_2O$	tricl	2.29	2.5	1.514	1.537	1.543
Chalcocite	Cu_2S	orth	5.6	2.8			
Chalcopyrite	$CuFeS_2$	tetr	4.2	3.8			
Chiolite	$Na_5Al_3F_{14}$	tetr	3.00	3.8	1.342	1.349	
Chlorite	$(Mg,Al,Fe)_{12}(Si,Al)_8O_{20}(OH)_{16}$	monocl	3.0	2.5	1.61	1.62	1.62
Chloritoid	$FeAl_4O_2(SiO_4)_2(OH)_4$	monocl	3.66	6.5	1.717	1.721	1.726
Chondrodite	$Mg(OH,F)_2{\cdot}2Mg_2SiO_4$	monocl	3.21	6.5	1.604	1.615	1.634
Chromite	$FeCr_2O_4$	cub	5.0	5.5	2.16		
Chrysoberyl	$BeAl_2O_4$	orth	3.65	8.5	1.746	1.748	1.756
Chrysocolla	$CuSiO_3{\cdot}2H_2O$	rhomb	2.4	2	1.575	1.597	1.598
Cinnabar	HgS	hex	8.17	2.3	2.814	3.143	
Claudetite	As_2O_3	monocl	3.74	2.5	1.87	1.92	2.01
Clinohumite	$Mg(OH,F)_2{\cdot}4Mg_2SiO_4$	monocl	3.21	6	1.633	1.647	1.668
Clinozoisite	$Ca_2Al_3Si_3O_{12}(OH)$	monocl	3.30	6.5	1.693	1.700	1.712
Cobaltite	$CoAsS$	cub	≈6.1	5.5			
Colemanite	$Ca_2B_6O_{11}{\cdot}5H_2O$	monocl	2.42	4.5	1.586	1.592	1.614
Columbite	$(Fe,Mn)(Nb,Ta)_2O_6$	rhomb	5.20	6			
Connellite	$Cu_{19}(SO_4)Cl_4(OH)_{32}{\cdot}3H_2O$	hex	3.36	3	1.731	1.752	

Name	Formula	Crystal system	Density g/cm³	Hard-ness	Index of refraction n_α	n_β	n_γ
Copiapite	$(Fe,Mg)Fe_4(SO_4)_6(OH)_2·20H_2O$	tricl	2.13	2.8	1.52	1.54	1.59
Coquimbite	$Fe_2(SO_4)_3·9H_2O$	hex	2.1	2.5	1.54	1.56	
Cordierite	$Al_3(Mg,Fe)_2Si_5AlO_{18}$	rhomb	2.66	7	1.540	1.549	1.553
Corundum	Al_2O_3	hex	3.97	9	1.761	1.769	
Cotunnite	$PbCl_2$	orth	5.98	2.5	2.199	2.217	2.260
Covellite	CuS	hex	4.8	1.8			
Cristobalite	SiO_2	hex	2.33	6.5	1.484	1.487	
Crocoite	$PbCrO_4$	monocl	6.12	2.8	2.29	2.36	2.66
Cryolite	Na_3AlF_6	monocl	2.97	2.5	1.338	1.338	1.339
Cryolithionite	$Na_3Li_3Al_2F_{12}$	cub	2.77	2.8	1.340		
Cubanite	$CuFe_2S_3$	rhomb	4.11	3.5			
Cummingtonite	$(Mg,Fe)_7Si_8O_{22}(OH)_2$	monocl	3.4	5.5	1.650	1.660	1.676
Cuprite	Cu_2O	cub	6.0	3.8			
Danburite	$CaSi_2B_2O_8$	rhomb	3.0	7	1.63	1.63	1.63
Datolite	$CaBSiO_4(OH)$	monocl	2.98	5.3	1.624	1.652	1.668
Daubreelite	Cr_2FeS_4	cub	3.81				
Derbylite	$Fe_6Ti_6Sb_2O_{23}$	rhomb	4.53	5	2.45	2.45	2.51
Diamond	C	cub	3.51	10	2.418		
Diaspore	AlO(OH)	orth	3.4	6.8	1.694	1.715	1.741
Digenite	$Cu_{2-x}S$	cub	5.55	2.8			
Diopside	$CaMgSi_2O_6$	monocl	3.30	6	1.680	1.687	1.708
Dioptase	$CuSiO_2(OH)_2$	rhomb	3.5	5	1.65	1.70	
Dolomite	$CaMg(CO_3)_2$	rhomb	2.86	3.5	1.500	1.679	
Douglasite	$K_2FeCl_4·2H_2O$	orth	2.16		1.488	1.500	
Dyscrasite	Ag_3Sb	rhomb	9.74	3.8			
Eddingtonite	$BaAl_2Si_3O_{10}·4H_2O$	rhomb	2.8		1.541	1.553	1.557
Eglestonite	Hg_4OCl_2	cub	8.4	2.5	2.49		
Emplectite	$CuBiS_2$	rhomb	6.38	2			
Enargite	Cu_3AsS_4	rhomb	4.5	3			
Enstatite	$MgSiO_3$	monocl	3.19	5.5	1.656	1.662	1.669
Epidote	$Ca_2Al_2(Al,Fe)OH(SiO_4)_3$	monocl	3.44	6	1.733	1.755	1.765
Epsomite	$MgSO_4·7H_2O$	orth	1.67	2.3	1.433	1.455	1.461
Erythrite	$(Co,Ni)_3(AsO_4)_2·8H_2O$	monocl	3.06	2	1.626	1.661	1.699
Eucairite	CuAgSe	orth	7.7	2.5			
Euclasite	$BeAlSiO_4(OH)$	monocl	3.1	7.5	1.651	1.655	1.671
Eudialite	$(Na,Ca,Ce)_5(Fe,Mn)(Zr,Ti)(Si_3O_9)_2$ (OH,Cl)	hex	3.0	5.5	1.623	1.600	1.615
Eulytite	$Bi_4Si_3O_{12}$	cub	6.6	4.5	2.05		
Euxenite	$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$	rhomb	5.5	6	2.2		
Fayalite	Fe_2SiO_4	orth	4.30	6.5	1.827	1.869	1.879
Ferberite	$FeWO_4$	monocl	7.51	4.3			
Fergussonite	$(Y,Er,Ce,Fe)(Nb,Ta,Ti)O_4$	tetr	5.7	6	2.1		
Fluorite	CaF_2	cub	3.18	4	1.434		
Forsterite	Mg_2SiO_4	orth	3.21	7	1.635	1.651	1.670
Franklinite	$ZnFe_2O_4$	cub	5.21	6	2.36		
Gahnite	$ZnAl_2O_4$	cub	4.62	7.8	1.805		
Galaxite	$MnAl_2O_4$	cub	4.04	7.8	1.92		
Galena	PbS	cub	7.60	2.5	3.91		
Galenabismuthite	$PbBi_2S_4$	rhomb	7.04	3			
Ganomalite	$(Ca,Pb)_{10}(OH,Cl)_2(Si_2O_7)_3$	hex	5.6	3.5	1.910	1.945	
Gaylussite	$Na_2Ca(CO_3)_2·5H_2O$	monocl	1.99	2.8	1.444	1.516	1.523
Gehlenite	$Ca_2Al_2SiO_7$	tetr	3.04	5.5	1.658	1.669	
Geikielite	$MgTiO_3$	hex	3.85	5.5	1.95	2.31	
Gibbsite	$Al(OH)_3$	monocl	2.42	3	1.57	1.57	1.59
Glauberite	$Na_2Ca(SO_4)_2$	monocl	2.80	2.8	1.515	1.535	1.536
Glauconite	$(K,Na,Ca)_{1.6}(Fe,Al,Mg)_{4.0}Si_{7.3}Al_{0.7}$ $O_{20}(OH)_4$	monocl	2.7	2	1.60	1.63	1.63
Glaucophane	$Na_2Mg_3Al_2Si_8O_{22}(OH)_2$	monocl	3.19	6	1.634	1.645	1.648
Gmelinite	$(Ca,Na_2)[Al_2Si_4O_{12}]·6H_2O$	hex	2.10	4.5	1.477	1.485	

Name	Formula	Crystal system	Density g/cm^3	Hard-ness	Index of refraction n_α	n_β	n_γ
Goethite	$FeO(OH)$	orth	4.3	5.3	2.268	2.401	2.457
Goslarite	$ZnSO_4 \cdot 7H_2O$	orth	1.97	2.3	1.457	1.480	1.484
Greenockite	CdS	cub	4.8	3.3	2.506	2.529	
Grossularite	$Ca_3Al_2Si_3O_{12}$	cub	3.59	6.8	1.734		
Gummite	$UO_3 \cdot H_2O$	orth	7.05	3.8			
Gypsum	$CaSO_4 \cdot 2H_2O$	monocl	2.32	2	1.520	1.525	1.530
Halite	$NaCl$	cub	2.17	2	1.544		
Hambergite	$Be_2(OH)(BO_3)$	rhomb	2.36	7.5	1.56	1.59	1.63
Hanksite	$Na_{22}K(SO_4)_9(CO_3)_2Cl$	hex	2.56	3.3	1.461	1.481	
Harmotome	$Ba[Al_2Si_6O_{16}] \cdot 6H_2O$	monocl	2.44	4.5	1.506	1.507	1.511
Hausmannite	Mn_3O_4	tetr	4.84	5.5	2.15	2.46	
Haüyne	$(Na,Ca)_{4\text{-}8}Al_6Si_6O_{24}(SO_4,S)_{1\text{-}2}$	cub	2.47	5.8	1.502		
Hedenbergite	$CaFeSi_2O_6$	monocl	3.53	6	1.721	1.727	1.746
Helvite	$Mn_4Be_3Si_3O_{12}S$	cub	3.32	6	1.739		
Hematite	Fe_2O_3	hex	5.25	6	2.91	3.19	
Hemimorphite	$Zn_4Si_2O_7(OH)_2 \cdot H_2O$	rhomb	3.45	5	1.614	1.617	1.636
Hercynite	$Fe(AlO_2)_2$	cub	4.3	7.8	1.835		
Herderite	$CaBe(PO_4)(Fe,OH)$	monocl	2.98	5.3	1.592	1.612	1.621
Hessite	Ag_2Te	orth	8.4	2.5			
Heulandite	$(Ca,Na_2,K_2)[Al_2Si_7O_{18}] \cdot 6H_2O$	monocl	2.2	3.8	1.498	1.498	1.506
Hopeite	$Zn_3(PO_4)_2 \cdot 4H_2O$	orth	3.0	3.2	1.58	1.59	1.59
Hornblende	$Ca_2(Mg,Fe)_4Al(Si_7AlO_{22})(OH)_2$	monocl	3.24	5.5	1.67	1.67	1.69
Huebnerite	$MnWO_4$	monocl	7.2	4.3	2.17	2.22	2.32
Humite	$Mg(OH,F)_2 \cdot 3Mg_2SiO_4$	orth	3.3	6	1.625	1.636	1.657
Huntite	$Mg_3Ca(CO_3)_4$	trig	2.70				
Hydrogrossularite	$Ca_3Al_2Si_2O_8(SiO_4)_{1\text{-}m}(OH)_{4m}$	cub	3.4	6.8	1.70		
Hydromagnesite	$3MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O$	monocl	2.24	3.5	1.523	1.527	1.545
Illite	$KAl_4[Si_7AlO_{20}](OH)_4$	monocl	2.8	1.5	1.56	1.59	1.59
Ilmenite	$FeTiO_3$	rhomb	4.72	5.5			
Iodyrite	AgI	hex	5.68	1.5	2.21	2.22	
Jacobsite	$MnFe_2O_4$	cub	4.87	7.8	2.3		
Jadeite	$NaAlSi_2O_6$	monocl	3.34	6	1.649	1.654	1.663
Jamesonite	$Pb_4FeSb_6S_{14}$	monocl	5.63	2.5			
Jarosite	$KFe_3(SO_4)_2(OH)_6$	rhomb	3.09	3	1.715	1.820	
Kainite	$KMg(SO_4)Cl \cdot 3H_2O$	monocl	2.15	2.8	1.494	1.505	1.516
Kaliophylite	$KAlSiO_4$	hex	2.61	6	1.532	1.537	
Kaolinite	$Al_4Si_4O_{10}(OH)_8$	tricl	2.65	2.3	1.549	1.564	1.565
Kernite	$Na_2B_4O_7 \cdot 4H_2O$	monocl	1.95	2.5	1.454	1.472	1.488
Kieserite	$MgSO_4 \cdot H_2O$	monocl	2.57	3.5	1.520	1.533	1.584
Kyanite	Al_2OSiO_4	tricl	3.59	6.3	1.715	1.722	1.731
Lanarkite	$Pb_2(SO_4)O$	monocl	6.92	2.3	1.928	2.007	2.036
Lanthanite	$(La,Ce)_2(CO_3)_3 \cdot 8H_2O$	rhomb	2.72	2.8	1.52	1.587	1.613
Laumontite	$Ca_4[Al_8Si_{16}O_{48}] \cdot 16H_2O$	monocl	2.3	3.3	1.508	1.517	1.519
Laurionite	$Pb(OH)Cl$	rhomb	6.24	3.3	2.08	2.12	2.16
Lawsonite	$CaAl_2(OH)_2Si_2O_7 \cdot H_2O$	rhomb	3.08	6	1.655	1.675	1.685
Lazulite	$(Mg,Fe)Al_2(PO_4)_2(OH)_2$	monocl	3.23	5.8	1.615	1.64	1.650
Lazurite	$Na_4SSi_3Al_3O_{12}$	cub	2.42	5.3	1.500		
Leadhillite	$Pb_4(SO_4)(CO_3)_2(OH)_2$	monocl	6.55	2.8	1.87	2.00	2.01
Lepidocrocite	$FeO(OH)$	orth	4.26	5	1.94	2.20	2.51
Lepidolite	$K_2(Li,Al)_{5\text{-}6}[Si_{6\text{-}7}Al_{2\text{-}1}O_{20}](OH,F)_4$	monocl	2.85	3.3	1.536	1.565	1.566
Leucite	$KAlSi_2O_6$	tetr	2.49	5.8	1.510		
Levyne	$(Ca,Na_2)Al_2Si_4O_{12} \cdot 6H_2O$	rhomb	2.10	4.5	1.496	1.501	
Litharge	PbO	tetr	9.35	2	2.535	2.665	
Loellingite	$FeAs_2$	rhomb	7.40	5.3			
Maghemite	Fe_2O_3	cub	4.88	7.8	2.63		
Magnesite	$MgCO_3$	hex	3.05	4	1.536	1.741	
Magnetite	Fe_3O_4	cub	5.17	6	2.42		
Malachite	$Cu_2(OH)_2(CO_3)$	monocl	4.05	3.8	1.655	1.875	1.909
Manganite	$MnO(OH)$	monocl	≈4.3	4	2.25	2.25	2.53

Name	Formula	Crystal system	Density g/cm³	Hard-ness	Index of refraction n_α	n_β	n_γ
Manganosite	MnO	cub	5.37	5.5			
Marcasite	FeS_2	cub	5.02	6.3			
Marialite	$Na_4Al_3Si_9O_{24}Cl$	tetr	2.56	5.5	1.541	1.548	
Marshite	CuI	cub	5.67	2.5	2.346		
Mascagnite	$(NH_4)_2SO_4$	orth	1.77	2.3	1.520	1.523	1.533
Matlockite	$PbClF$	tetr	7.05	2.8	2.006	2.145	
Meionite	$Ca_4Al_6Si_6O_{24}CO_3$	tetr	2.78	5.5	1.559	1.595	
Melanterite	$FeSO_4{\cdot}7H_2O$	monocl	1.89	2	1.47	1.48	1.49
Melilite	$(Ca,Na)_2(Mg,Fe,Al,Si)_3O_7$	tetr	3.00	5.5	1.639	1.645	
Mellite	$Al_2C_{12}O_{12}{\cdot}18H_2O$	tetr	1.64	2.3	1.511	1.539	
Mendipite	$Pb_3O_2Cl_2$	rhomb	7.24	2.5	2.24	2.27	2.31
Mesolite	$Na_2Ca_2(Al_2Si_3O_{10})_3{\cdot}8H_2O$	orth	2.26	5	1.506		
Metacinnabar	HgS	cub	7.70	3			
Microcline	$KAlSi_3O_8$	monocl	2.56	6.3	1.522	1.526	1.530
Miersite	AgI	hex	5.68	2.5	2.20		
Millerite	NiS	hex	5.5	3.3			
Mimetite	$Pb_5(AsO_4,PO_4)_3Cl$	hex	7.24	3.8	2.128	2.147	
Minium	Pb_3O_4	tetr	8.9	2.5			
Mirabilite	$Na_2SO_4{\cdot}10H_2O$	monocl	1.46	1.8	1.394	1.396	1.398
Moissanite	SiC	hex	3.16	9.5	2.648	2.691	
Molybdenite	MoS_2	hex	5.06	1.3			
Monazite	$(Ce,La,Th)PO_4$	monocl	5.2	5	1.787	1.789	1.840
Monetite	$CaHPO_4$	tricl	2.92	3.5	1.587	1.61	1.640
Monticellite	$Ca(Mg,Fe)SiO_4$	orth	3.18	5.5	1.647	1.655	1.664
Montmorillonite	$(0.5Ca,Na)_{0.7}(Al,Mg,Fe)_4$ $[(Si,Al)_8O_{20}](OH)_4{\cdot}nH_2O$	monocl	2.5	1.5	1.55	1.57	1.57
Montroydite	HgO	orth	11.14	2.5	2.37	2.50	2.65
Mordenite	$(Na,K,Ca)[Al_2Si_{10}O_{24}]{\cdot}7H_2O$	orth	2.13	3.5	1.478	1.480	1.482
Muscovite	$KAl_2Si_3AlO_{10}(OH,F)_2$	monocl	2.83	2.8	1.563	1.596	1.602
Nantokite	$CuCl$	cub	4.14	2.5	1.930		
Natrolite	$Na_2Al_2Si_3O_{10}{\cdot}2H_2O$	orth	2.23	5	1.478	1.481	1.491
Nepheline	$Na_3KAl_4Si_4O_{16}$	hex	2.61	5.8	1.534	1.538	
Newberyite	$MgHPO_4{\cdot}3H_2O$	orth	2.13	3.3	1.514	1.517	1.533
Niccolite	$NiAs$	hex	7.77	5.3			
Norbergite	$Mg(OH,F)_2{\cdot}Mg_2SiO_4$	orth	3.21	6.5	1.565	1.573	1.592
Nosean	$Na_8Al_6Si_6O_{24}SO_4$	cub	2.35	5.5	1.495		
Oldhamite	CaS	cub	2.59	4	2.137		
Oligoclase	$([NaSi]_{0.9\text{-}0.7}[CaAl]_{0.1\text{-}0.3})AlSi_2O_8$	tricl	2.64	6.3	1.539	1.543	1.547
Olivenite	$Cu_2(AsO_4)(OH)$	rhomb	4.2	3	1.77	1.80	1.85
Olivine	$(Mg,Fe)SiO_4$	rhomb	3.81	6.8	1.73	1.76	1.78
Opal	$SiO_2{\cdot}nH_2O$	amorp	1.9	5	1.44		
Orpiment	As_2S_3	monocl	3.46	1.8	2.40	2.81	3.02
Orthoclase	$KAlSi_3O_8$	monocl	2.56	6	1.523	1.527	1.531
Orthopyroxene	$(Mg,Fe)SiO_3$	rhomb	3.6	5.5	1.709	1.712	1.723
Paragonite	$NaAl_2Si_3AlO_{10}(OH)_2$	monocl	2.85	2.5	1.572	1.602	1.605
Parisite	$(Ce,La,Na)FCO_3{\cdot}CaCO_3$	hex	4.42	4.5	1.672	1.771	
Pectolite	$Ca_2NaH(SiO_3)_3$	tricl	2.88	4.8	1.603	1.610	1.639
Penfieldite	$Pb_4Cl_6(OH)_2$	hex	6.6		2.13	2.21	
Pentlandite	$(Fe,Ni)_9S_8$	cub	4.8	3.8			
Percylite	$PbCuCl_2(OH)_2$	cub		2.5	2.05		
Periclase	MgO	cub	3.6	5.5	1.735		
Perovskite	$CaTiO_3$	cub	3.98	5.5	2.34		
Petalite	$LiAlSi_4O_{10}$	monocl	2.42	6.5	1.506	1.511	1.519
Pharmacosiderite	$Fe_3(AsO_4)_2(OH)_3{\cdot}5H_2O$	cub	2.80	2.5	1.690		
Phenakite	Be_2SiO_4	rhomb	2.98	7.5	1.654	1.670	
Phillipsite	$K(Ca_{0.5},Na)_2[Al_3Si_5O_{16}]{\cdot}6H_2O$	monocl	2.2	4.3	1.494	1.497	1.505
Phlogopite	$KMg_3AlSi_3O_{10}(OH,F)_2$	monocl	2.83	2.3	1.560	1.597	1.598
Phosgenite	$Pb_2(CO_3)Cl_2$	tetr	6.13	2.5	2.118	2.145	
Piemontite	$Ca_2(Mn,Fe,Al)_3O(Si_2O_7)(SiO_4)(OH)$	monocl	3.49	6	1.762	1.773	1.796

Name	Formula	Crystal system	Density g/cm^3	Hard-ness	Index of refraction n_α	n_β	n_γ
Pigeonite	$(Mg,Fe,Ca)(Mg,Fe)Si_2O_6$	monocl	3.38	6	1.702	1.703	1.728
Pollucite	$CsAlSi_2O_6$	tetr	2.9	6.5	1.517		
Polybasite	$(Ag,Cu)_{16}Sb_2S_{11}$	monocl	6.1	2.5			
Powellite	$Ca(Mo,W)O_4$	tetr	4.35	3.8	1.971	1.980	
Prehnite	$Ca_2Al_2Si_3O_{10}(OH)_2$	rhomb	2.93	6.3	1.622	1.628	1.648
Proustite	Ag_3AsS_3	rhomb	5.57	2.3	2.792	3.088	
Pseudobrookite	Fe_2TiO_5	rhomb	4.36	6	2.38	2.39	2.42
Psilomelane	$BaMn_9O_{16}(OH)_4$	rhomb	4.71	5.5			
Pumpellyite	$Ca_2Al_2(Al,Fe,Mg)[Si_2(O,OH)_7]$ $(SiO_4)(OH,O)_3$	monocl	3.21	5.5	1.688	1.695	1.705
Pyrargyrite	Ag_3SbS_3	rhomb	5.85	2.5	2.88	3.08	
Pyrite	FeS_2	cub	5.02	6.3			
Pyrochlore	$NaCaNb_2O_6F$	cub	5.3	5.3			
Pyrochroite	$Mn(OH)_2$	hex	3.26	2.5	1.68	1.72	
Pyrolusite	MnO_2	tetr	5.08	6.3			
Pyromorphite	$Pb_5(PO_4,AsO_4)_3Cl$	hex	7.04	3.8	2.048	2.058	
Pyrope	$Mg_3Al_2Si_3O_{12}$	cub	3.58	6.8	1.714		
Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$	monocl	2.78	1.5	1.545	1.579	1.599
Pyrrhotite	Fe_7S_8	hex	4.62	4			
Quartz	SiO_2	hex	2.65	7	1.544	1.553	
Rammelsbergite	$NiAs_2$	orth	7.1	5.8			
Raspite	$PbWO_4$	monocl	8.46	2.8	1.27	1.27	1.30
Realgar	As_4S_4	monocl	3.5	1.8	2.538	2.684	2.704
Rhodochrosite	$MnCO_3$	hex	3.70	3.8	1.597	1.816	
Rhodonite	$(Mn,Fe,Ca)SiO_3$	orth	3.48	6	1.725	1.729	1.737
Riebeckite	$Na_2Fe_5(Si_8O_{22})(OH)_2$	monocl	3.3	5	1.675	1.683	1.694
Rutile	TiO_2	tetr	4.23	6.2	2.609	2.900	
Safflorite	$(Co,Fe)As_2$	rhomb	7.3	4.8			
Samarskite	(Y,Er,Ce,U,Ca,Fe,Pb,Th) $(Nb,Ta,Ti,Sn)_2O_6$	rhomb	5.69	5.5	2.200		
Sapphirine	$(Mg,Fe)_2Al_4O_6SiO_4$	monocl	3.49	7.5	1.709	1.712	1.715
Scapolite	$(Na,Ca)_4Al_3(Al,Si)_3Si_6O_{24}$ (Cl,F,OH,CO_3,SO_4)	tetr	2.64	5.5	1.551	1.573	
Scheelite	$CaWO_4$	tetr	6.06	4.8	1.920	1.936	
Scolecite	$CaAl_2Si_3O_{10}\cdot 3H_2O$	monocl	2.27	5	1.510	1.518	1.519
Scorodite	$Fe(AsO_4)\cdot 2H_2O$	rhomb	3.28	3.8	1.784	1.795	1.814
Sellaite	MgF_2	tetr	3.15	5	1.378	1.390	
Senarmontite	Sb_2O_3	cub	5.58	2.3	2.087		
Serpentine	$Mg_3Si_2O_5(OH)_4$	monocl	2.55	3	1.55	1.56	1.56
Siderite	$FeCO_3$	hex	3.9	4.3	1.635	1.875	
Sillimanite	Al_2OSiO_4	rhomb	3.25	7	1.658	1.660	1.660
Skutterudite	$(Co,Ni)As_3$	cub	6.8	5.8			
Smithsonite	$ZnCO_3$	rhomb	4.4	4.3	1.621	1.848	
Sodalite	$Na_8Al_6Si_6O_{24}Cl_2$	cub	2.30	5.8	1.485		
Sperrylite	$PtAs_2$	cub	10.58	6.5			
Spessartite	$Mn_3Al_2Si_3O_{12}$	cub	4.19	6.8	1.800		
Sphalerite	ZnS	cub	4.0	3.8	2.369		
Sphene	$CaTiSiO_4(O,OH,F)$	monocl	3.50	5	1.90	1.95	2.03
Spinel	$MgAl_2O_4$	cub	3.55	7.8	1.719		
Spodumene	$LiAlSi_2O_6$	monocl	3.13	6.8	1.656	1.662	1.671
Stannite	Cu_2FeSn_4	tetr	4.4	4			
Staurolite	$(Fe,Mg,Zn)_2(Al,Fe,Ti)_9O_6$ $[(Si,Al)O_4]_4(O,OH)_2$	monocl	3.79	7.5	1.743	1.747	1.755
Stercorite	$Na(NH_4)H(PO_4)\cdot 4H_2O$	tricl	1.62	2	1.439	1.442	1.469
Stibiotantalite	$Sb(Ta,Nb)O_4$	rhomb	6.6	5.5	2.38	2.41	2.46
Stibnite	Sb_2S_3	orth	4.56	2			
Stilbite	$NaCa_2[Al_5Si_{13}O_{36}]\cdot 14H_2O$	monocl	2.2	3.8	1.492	1.499	1.503

PHYSICAL AND OPTICAL PROPERTIES OF MINERALS (continued)

Name	Formula	Crystal system	Density g/cm³	Hardness	Index of refraction		
					n_α	n_β	n_γ
Stilpnomelane	$(K,Na,Ca)_{0.6}(Fe,Mg)_6Si_8Al(O,OH)_{27}\cdot 2H_2O$	monocl	2.8	3.5	1.585	1.665	1.665
Stolzite	$PbWO_4$	tetr	8.2	2.8	2.19	2.27	
Strengite	$FePO_4\cdot 2H_2O$	orth	2.87	4	1.707	1.719	1.741
Strontianite	$SrCO_3$	orth	3.5	3.5	1.518	1.666	1.668
Struvite	$Mg(NH_4)(PO_4)\cdot 6H_2O$	rhomb	1.71	2	1.495	1.496	1.504
Sulfur	S	orth	2.07	2	1.958	2.038	2.245
Sylvanite	$(Ag,Au)Te_2$	monocl	8.16	1.8			
Sylvite	KCl	cub	1.99	2	1.490		
Talc	$Mg_3Si_4O_{10}(OH)_2$	monocl	2.71	1	1.545	1.592	1.595
Tantalite	$(Fe,Mn)(Ta,Nb)_2O_6$	rhomb	7.95	6.5	2.26	2.32	2.43
Tapiolite	$FeTa_2O_6$	tetr	7.9	6.3	2.27	2.42	
Tellurobismuthite	Bi_2Te_3	hex	7.74	1.8			
Terlinguaite	Hg_2OCl	monocl	8.73	2.5	2.35	2.64	2.66
Tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$	cub	4.9	3.8			
Thenardite	Na_2SO_4	orth	2.7	2.8	1.468	1.475	1.483
Thermonatrite	$Na_2CO_3\cdot H_2O$	orth	2.25	1.3	1.420	1.506	1.524
Thomsenolite	$NaCaAlF_6\cdot H_2O$	monocl	2.98	2	1.407	1.414	1.415
Thorianite	ThO_2	cub	10.0	6.5	2.200		
Thorite	$ThSiO_4$	tetr	6.7	4.8	1.8		
Topaz	$Al_2SiO_3(OH,F)_2$	rhomb	3.53	8	1.618	1.620	1.627
Torbernite	$Cu(UO_2)_2(PO_4)_2\cdot 8H_2O$	tetr	3.22	2.3	1.582	1.592	
Tourmaline	$Na(Mg,Fe,Mn,Li,Al)_3Al_6Si_6O_{18}(BO_3)_3$	rhomb	3.14	7	1.62	1.65	
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH,F)_2$	monocl	3.0	5.5	1.599	1.612	1.622
Trevorite	$NiFe_2O_4$	cub	5.33	7.8	2.3		
Tridymite	SiO_2	hex	2.27	7	1.475	1.476	1.479
Triphyllite-Lithiophyllite	$Li(Fe,Mn)PO_4$	rhomb	3.46	4.5	1.68	1.68	1.69
Troegerite	$(UO_2)_3(AsO_4)_2\cdot 12H_2O$	tetr		2.5	1.59	1.630	
Troilite	FeS	hex	4.7	4			
Trona	$Na_3H(CO_3)_2\cdot 2H_2O$	monocl	2.14	2.8	1.412	1.492	1.540
Turquois	$Cu(Al,Fe)_6(PO_4)_4(OH)_8\cdot 4H_2O$	tricl	2.9	5.3	1.70	1.73	1.75
Ullmannite	NiSbS	cub	6.65	5.3			
Uraninite	UO_2	cub	11.0	5.5			
Uvarovite	$Ca_3Cr_2Si_3O_{12}$	cub	3.83	6.8	1.865		
Valentinite	Sb_2O_3	orth	5.7	2.8	2.18	2.35	2.35
Vanadinite	$Pb_5(VO_4)_3Cl$	hex	6.8	2.9	2.350	2.416	
Variseite-Strengite	$(Al,Fe)(PO_4)\cdot 2H_2O$	rhomb	2.72	4	1.635	1.654	1.668
Vaterite	$CaCO_3$	hex	2.71		1.550	1.645	
Vermiculite	$(Mg,Ca)_{0.7}(Mg,Fe,Al)_6[(Al,Si)_8O_{20}](OH)_4\cdot 8H_2O$	monocl	2.3	1.5	1.542	1.556	1.556
Vesuvianite	$Ca_{10}(Mg,Fe)_2Al_4(Si_2O_7)_2(SiO_4)_5(OH,F)_4$	tetr	3.33	6.5	1.72	1.73	
Villiaumite	NaF	cub	2.78	2.3	1.327		
Vivianite	$Fe_3(PO_4)_2\cdot 8H_2O$	monocl	2.58	1.8	1.598	1.629	1.652
Wagnerite	$Mg_2(PO_4)F$	monocl	3.15	5.3	1.568	1.572	1.582
Wavellite	$Al_3(OH)_3(PO_4)_2\cdot 5H_2O$	rhomb	2.36	3.6	1.527	1.535	1.553
Whewellite	$CaC_2O_4\cdot H_2O$	cub	2.2	2.8	1.491	1.554	1.650
Willemite	Zn_2SiO_4	hex	4.1	5.5	1.691	1.719	
Witherite	$BaCO_3$	orth	4.29	3.5	1.529	1.676	1.677
Wolframite	$(Fe,Mn)WO_4$	monocl	7.3	4.3	2.26	2.32	2.42
Wollastonite	$CaSiO_3$	monocl	2.92	4.8	1.628	1.639	1.642
Wulfenite	$PbMoO_4$	tetr	6.7	2.9	2.283	2.403	
Wurtzite	ZnS	hex	4.09	3.8	2.356	2.378	
Xenotime	YPO_4	tetr	4.8	4.5	1.721	1.816	
Zeunerite	$Cu(UO_2)_2(AsO_4)_2\cdot 10H_2O$	tetr			1.606		
Zincite	ZnO	hex	5.6	4	2.013	2.029	
Zircon	$ZrSiO_4$	tetr	4.6	7.5	1.94	1.99	
Zoisite	$Ca_2Al_3Si_3O_{12}(OH)$	rhomb	3.26	6	1.695	1.699	1.711

CRYSTALLOGRAPHIC DATA ON MINERALS

This table contains x-ray crystallographic data on about 400 common minerals, as well as selected crystalline elements. Entries are arranged alphabetically by mineral name. The columns are:

Name: Common name of the mineral.
Formula: Chemical formula for a typical sample of the mineral. Composition often varies considerably with the origin of the sample.
Crystal system: tricl = triclinic; monocl = monoclinic; orth = orthorhombic; tetr = tetragonal; hex = hexagonal; rhomb = rhombohedral; cubic = cubic.
Structure type: Prototype for the structural arrangement of the crystallographic cell.
Z: Number of formula units per the unit cell.
a, *b*, *c*: Lengths of the cell edges in Å (1Å = 10^{-8} cm).
α, β, γ : Angles between cell axes.

REFERENCES

1. Robie, R.A., Bethke, P.M., and Beardsley, K.M., *U. S. Geological Survey Bulletin 1248*, U. S. Government Printing Office, Washington, D.C.
2. Donnay, J.D.H., and Ondik, H.M., *Crystal Data Determinative Tables, Third Edition, Volume 2, Inorganic Compounds*, Joint Committee on Powder Diffraction Standards, Swarthmore, PA, 1973.
3. Deer, W.A., Howie, R.A., and Zussman, J., *An Introduction to the Rock-Forming Minerals, 2nd Edition*, Longman Scientific & Technical, Harlow, Essex, 1992.

Name	Formula	Crystal system	Structure type	*Z*	*a*/Å	*b*/Å	*c*/Å	α	β	γ
Acanthite	Ag_2S	monocl		4	4.228	6.928	7.862		99.58°	
Acmite (Aegirine)	$NaFe(SiO_3)_2$	monocl	diopside	4	9.658	8.795	5.294		107.42°	
Akermanite	$Ca_2MgSi_2O_7$	tetr	melilite	2	7.8435		5.010			
Alabandite	MnS	cubic	rock salt	4	5.223					
Almandine (Almandite)	$Fe_3Al_2Si_3O_{12}$	cubic	garnet	8	11.526					
Altaite	PbTe	cubic	rock salt	4	6.4606					
Aluminum	Al	cubic	copper	4	4.049					
Alunite	$KAl_3(SO_4)_2(OH)_6$	rhomb		3	6.982		17.32			
Analcite	$NaAlSi_2O_6 \cdot H_20$	cubic		16	13.733					
Anatase	TiO_2	tetr		4	3.785		9.514			
Andalusite	Al_2OSiO_4	orth		4	7.7959	7.8983	5.5583			
Andradite	$Ca_3Fe_2Si_3O_{12}$	cubic	garnet	8	12.048					
Anglesite	$PbSO_4$	orth	barite	4	8.480	5.398	6.958			
Anhydrite	$CaSO_4$	orth	anhydrite	4	6.991	6.996	6.238			
Annite	$KFe_3[AlSi_3O_{10}](OH)_2$	monocl	1M mica	2	10.29	9.33	5.39		105.1°	
Anorthite	$CaAl_2Si_2O_8$	tricl	primitive cell	8	8.177	12.877	14.169	93.17°	115.85°	91.22°
Anthophyllite	$Mg_7Si_8O_{22}(OH)_2$	orth		4	18.61	18.01	5.24			
Antimony	Sb	rhomb	arsenic	6	4.2996		11.2516			
Aragonite	$CaCO_3$	orth	aragonite	4	5.741	7.968	4.959			
Arcanite	K_2SO_4	orth	arcanite	4	5.772	10.072	7.483			
Argentite	Ag_2S	cubic		2	4.870					
Argentopyrite	$AgFe_2S_3$	orth		4	6.64	11.47	6.45			
Arsenic	As	rhomb	arsenic	6	3.760		10.555			
Arsenolite	As_2O_3	cubic	diamond	16	11.074					
Arsenopyrite	FeAsS	tricl		4	5.760	5.690	5.785	90.00°	112.23°	90.00°
Azurite	$Cu_3(OH)_2(CO_3)_2$	monocl		2	5.008	5.844	10.336		92.45°	
Baddeleyite	ZrO_2	monocl	baddeleyite	4	5.1454	5.2075	5.3107		99.23°	
Banalsite	$BaNa_2Al_4Si_4O_{16}$	orth		4	8.50	9.97	16.72			
Barite	$BaSO_4$	orth	barite	4	8.878	5.450	7.152			
Berlinite	$AlPO_4$	hex	α-quartz	3	4.942		10.97			
Beryl	$Be_3Al_2(SiO_3)_6$	hex	beryl	2	9.215		9.192			
Berzelianite	Cu_2Se	cubic		4	5.85					
Bismite	Bi_2O_3	monocl	pseudo-orth	4	7.48	8.14	5.83		112.9°	
Bismuth	Bi	rhomb	arsenic	6	4.5367		11.8383			
Bismuthinite	Bi_2S_3	orth	stibnite	4	11.150	11.300	3.981			
Bixbyite	Mn_2O_3	cubic	thallium trioxide	16	9.411					
Boehmite	AlO(OH)	orth	lepidocrocite	4	2.868	12.227	3.700			
Borax	$Na_2B_4O_7 \cdot 10H_2O$	monocl		4	11.858	10.674	12.197		106.68°	
Bornite (metastable)	Cu_5FeS_4	cubic		8	10.94					
Breithauptite	NiSb	hex	niccolite	2	3.942		5.155			
Brochantite	$Cu_4SO_4(OH)_6$	monocl		4	13.066	9.85	6.022		103.27°	
Bromargyrite	AgBr	cubic	rock salt	4	5.7745					
Bromellite	BeO	hex	zincite	2	2.6979		4.3772			
Brookite	TiO_2	orth		8	5.456	9.182	5.143			
Brucite	$Mg(OH)_2$	hex	cadmium iodide	1	3.147		4.769			

Name	Formula	Crystal system	Structure type	*Z*	***a***/Å	***b***/Å	***c***/Å	α	β	γ
Bunsenite	NiO	cubic	rock salt	4	4.177					
Bustamite	$CaMn(SiO_3)_2$	tricl		6	7.736	7.157	13.824	90.52°	94.58°	103.87°
Cadmium telluride	$CdTe$	cubic	sphalerite	4	6.4805					
Cadmoselite	$CdSe$	hex	zincite	2	4.2977		7.0021			
Calcite	$CaCO_3$	rhomb	calcite	6	4.9899		17.064			
Calomel	Hg_2Cl_2	tetr		4	4.478		10.910			
Carbonate-apatite	$Ca_{10}(PO_4)_6CO_3{\cdot}H_2O$	hex	apatite	1	9.436		6.883			
Cassiterite	SnO_2	tetr	rutile	2	4.738		3.188			
Cattierite	CoS_2	cubic	pyrite	4	5.5345					
Celestite	$SrSO_4$	orth	barite	4	8.359	5.352	6.866			
Celsian	$BaAl_2Si_2O_8$	monocl		8	8.627	13.045	14.408		115.20°	
Cerianite	CeO_2	cubic	fluorite	4	5.4110					
Cerussite	$PbCO_3$	orth	aragonite	4	6.152	8.436	5.195			
Cervantite	Sb_2O_4	orth		4	5.424	11.76	4.804			
Chalcanthite	$CuSO_4{\cdot}5H_2O$	tricl		2	6.1045	10.72	5.949	97.57°	107.28°	77.43°
Chalcocite	Cu_2S	orth		96	11.881	27.323	13.491			
Chalcopyrite	$CuFeS_2$	tetr		4	5.2988		10.434			
Chlorapatite	$Ca_5(PO_4)_3Cl$	hex	apatite	2	9.629		6.777			
Chlorargyrite	$AgCl$	cubic	rock salt	4	5.5491					
Chloritoid	$FeAl_4O_2(SiO_4)_2(OH)_4$	monocl		8	9.48	5.48	18.18		101.77°	
Chloromagnesite	$MgCl_2$	rhomb		3	3.632		17.795			
Chondrodite	$2Mg_2SiO_4{\cdot}MgF_2$	monocl		2	7.89	4.743	10.29		109.03°	
Chrysoberyl	$BeAl_2O_4$	orth	olivine	4	5.4756	9.4041	4.4267			
Cinnabar	HgS	hex	cinnabar	3	4.149		9.495			
Claudetite	As_2O_3	monocl		4	5.339	12.984	4.5405		94.27°	
Clausthalite	$PbSe$	cubic	rock salt	4	6.1255					
Clinoenstatite	$MgSiO_3$	monocl		8	9.620	8.825	5.188		108.33°	
Clinoferrosilite	$FeSiO_3$	monocl		8	9.7085	9.0872	5.2284		108.43°	
Clinohumite	$4Mg_2SiO_4{\cdot}MgF_2$	monocl		2	13.68	4.75	10.27		100.83°	
Clinozoisite	$Ca_2Al_3(SiO_4)_3OH$	monocl		2	8.887	5.581	10.14		115.93°	
Cobalt olivine	Co_2SiO_4	orth	olivine	4	4.782	10.301	6.003			
Cobalt oxide	CoO	cubic	rock salt	4	4.260					
Cobalt sulfide	CoS	cubic	sphalerite	4	5.339					
Cobalt titanate	$CoTiO_3$	rhomb	ilmenite	6	5.066		13.918			
Cobalticalcite	$CoCO_3$	rhomb	calcite	6	4.6581		14.958			
Cobaltite	$CoAsS$	cubic	NiSbS	4	5.60					
Coesite	SiO_2	monocl		16	7.152	12.379	7.152		120.00°	
Coffinite	$USiO_4$	tetr	zircon	4	6.995		6.263			
Colemanite	$Ca_2B_6O_{11}{\cdot}5H_2O$	monocl		4	8.743	11.264	6.102		110.12°	
Coloradoite	$HgTe$	cubic	sphalerite	4	6.4600					
Cooperite	PtS	tetr		2	3.4699		6.1098			
Copper	Cu	cubic	face-centered cubic	4	3.6150					
Corundum	Al_2O_3	rhomb	corundum	6	4.7591		12.9894			
Cotunnite	$PbCl_2$	orth		4	4.535	7.62	9.05			
Covellite	CuS	hex		6	3.792		16.34			

Name	Formula	Crystal system	Structure type	*Z*	*a*/Å	*b*/Å	*c*/Å	α	β	γ
Cristobalite (α)	SiO_2	tetr		4	4.971		6.918			
Cristobalite (β)	SiO_2	cubic		8	7.1382					
Cryolite	Na_3AlF_6	monocl		2	5.40	5.60	7.776		90.18°	
Cubanite	$CuFe_2S_3$	orth		4	6.46	11.12	6.23			
Cummingtonite	$(Mg,Fe,Mn)_7(Si_4O_{11})_2(OH)_2$	monocl	tremolite	2	9.522	18.223	5.332		101.92°	
Cuprite	Cu_2O	cubic		2	4.2696					
Danburite	$CaB_2Si_2O_8$	orth		4	8.04	8.77	7.74			
Datolite	$CaBSiO_4(OH)$	monocl		4	9.62	7.60	4.84		90.15°	
Daubreeite	$FeCr_2S_4$	cubic	spinel	8	9.966					
Diamond	C	cubic	diamond	8	3.5670					
Diaspore	AlO(OH)	orth		4	4.401	9.421	2.845			
Dickite	$Al_2Si_2O_5(OH)_4$	monocl		4	5.150	8.940	14.736		103.58°	
Digenite	$Cu_{1.79}S$	cubic	deformed fluorite	4	5.5695					
Diopside	$CaMg(SiO_3)_2$	monocl	diopside	4	9.743	8.923	5.251		105.93°	
Dioptase	$CuSiO_2(OH)_2$	rhomb	phenacite	18	14.61		7.80			
Dolerophanite	$Cu_2O(SO_4)$	monocl		4	8.334	6.312	7.628		108.4°	
Dolomite	$CaMg(CO_3)_2$	rhomb	calcite	3	4.8079		16.010			
Dravite	$NaMg_3Al_6B_3Si_6O_{27}(OH)_4$	rhomb	tourmaline	3	15.942		7.224			
Elbaite	$NaLiAl_{7.67}B_3Si_6O_{27}(OH)_4$	rhomb	tourmaline	3	15.842		7.009			
Enargite	Cu_3AsS_4	orth		2	6.426	7.422	6.144			
Enstatite	$MgSiO_3$	orth		16	8.829	18.22	5.192			
Epidote	$Ca_2Al_2(Al,Fe)OH(SiO_4)_3$	monocl		2	8.89	5.63	10.19		115.40°	
Epsomite	$MgSO_4{\cdot}7H_2O$	orth		4	11.86	11.99	6.858			
Eskolaite	Cr_2O_3	rhomb	corundum	6	4.9607		13.599			
Eucairite	AgCuSe	orth		10	4.105	20.35	6.31			
Euclase	$AlBeSiO_4(OH)$	monocl		4	4.763	14.29	4.618		100.25°	
Famatimite	Cu_3SbS_4	tetr		2	5.384		10.770			
Fayalite	Fe_2SiO_4	orth	olivine	4	4.817	10.477	6.105			
Fe-Cordierite	$Fe_2Al_3(AlSi_5O_{18})$	orth	cordierite	4	9.726	17.065	9.287			
Fe-Gehlenite	$Ca_2Fe_2SiO_7$	tetr	melilite	2	7.54		4.855			
Fe-Indialite	$Fe_2Al_3(AlSi_5O_{18})$	hex	beryl	2	9.860		9.285			
Fe-Leucite	$KFeSi_2O_6$	tetr		16	13.205		13.970			
Fe-Microcline	$KFeSi_3O_8$	tricl		4	8.68	13.10	7.340	90.75°	116.05°	86.23°
Fe-Sanidine	$KFeSi_3O_8$	monocl		4	8.689	13.12	7.319		116.10°	
Fe-Skutterudite	$FeAs_{2.95}$	cubic		8	8.1814					
Ferberite	$FeWO_4$	monocl	wolframite	2	4.732	5.708	4.965		90.00°	
Ferriannite	$KFe_3[FeSi_3O_{10}](OH)_2$	monocl		2	5.430	9.404	10.341		100.07°	
Ferroselite	$FeSe_2$	orth	marcasite	2	4.801	5.778	3.587			
Ferrotremolite	$Ca_2Fe_5[Si_8O_{22}](OH)_2$	monocl	tremolite	2	9.97	18.34	5.30		104.50°	
Fluor-edenite	$NaCa_2Mg_5[AlSi_7O_{22}]F_2$	monocl	tremolite	2	9.847	18.00	5.282		104.83°	
Fluor-humite	$3Mg_2SiO_4{\cdot}MgF_2$	orth		4	10.243	20.72	4.735			
Fluor-norbergite	$Mg_2SiO_4{\cdot}MgF_2$	orth		4	8.727	10.271	4.709			
Fluor-phlogopite	$KMg_3[AlSi_3O_{10}]F_2$	monocl	1M mica	2	5.299	9.188	10.135		99.92°	
Fluor-richterite	$Na_2CaMg_5[Si_8O_{22}]F_2$	monocl	tremolite	2	9.823	17.96	5.268		104.33°	
Fluor-tremolite	$Ca_2Mg_5[Si_8O_{22}]F_2$	monocl	tremolite	2	9.781	18.01	5.267		104.52°	

Name	Formula	Crystal system	Structure type	*Z*	*a*/Å	*b*/Å	*c*/Å	α	β	γ
Fluorapatite	$Ca_5(PO_4)_3F$	hex	apatite	2	9.3684		6.8841			
Fluorite	CaF_2	cubic	fluorite	4	5.4638					
Forsterite	Mg_2SiO_4	orth	olivine	4	4.758	10.214	5.984			
Frohbergite	$FeTe_2$	orth	marcasite	2	5.265	6.265	3.869			
Gahnite	$ZnAl_2O_4$	cubic	spinel	8	8.0848					
Galaxite	$MnAl_2O_4$	cubic	spinel	8	8.258					
Galena	PbS	cubic	rock salt	4	5.9360					
Gallium oxide	Ga_2O_3	rhomb	corundum	6	4.9793		13.429			
Gehlenite	$Ca_2Al_2SiO_7$	tetr	melilite	2	7.690		5.0675			
Geikielite	$MgTiO_3$	rhomb	ilmenite	6	5.054		13.898			
Gerhardite	$Cu_2(NO_3)(OH)_3$	orth		4	6.075	13.812	5.592			
Gersdorfite	NiAsS	cubic		4	5.693					
Gibbsite	$Al(OH)_3$	monocl		8	9.719	5.0705	8.6412		94.57°	
Glauchroite	$CaMnSiO_4$	orth	olivine	4	4.944	11.19	6.529			
Glaucodot	(Co,Fe)AsS	orth		24	6.64	28.39	5.64			
Glaucophane I	$Na_2Mg_3Al_2[Si_8O_{22}](OH)_2$	monocl	tremolite	2	9.748	17.915	5.273		102.78°	
Glaucophane II	$Na_2Mg_3Al_2[Si_8O_{22}](OH)_2$	monocl	tremolite	2	9.663	17.696	5.277		103.67°	
Goethite	FeO(OH)	orth		4	4.596	9.957	3.021			
Gold	Au	cubic	face-centered cubic	4	4.0786					
Goldmanite	$Ca_3V_2Si_3O_{12}$	cubic	garnet	8	12.070					
Goslarite	$ZnSO_4·7H_2O$	orth	epsomite	4	11.779	12.050	6.822			
Graphite	C	hex	graphite	4	2.4612		6.7079			
Greenockite	CdS	hex	zincite	2	4.1354		6.7120			
Greigite	Fe_3S_4	cubic	spinel	8	9.876					
Grossularite	$Ca_3Al_2Si_3O_{12}$	cubic	garnet	8	11.851					
Grunerite	$Fe_7[Si_8O_{22}](OH)_2$	monocl	tremolite	2	9.572	18.44	5.342		101.77°	
Gudmundite	FeSbS	monocl		8	10.00	5.93	6.73		90.00°	
Gypsum	$CaSO_4·2H_2O$	monocl		4	5.68	15.18	6.29		113.83°	
Hafnia	HfO_2	monocl	baddeleyite	4	5.1156	5.1722	5.2948		99.18°	
Halite	NaCl	cubic	rock salt	4	5.6402					
Hambergite	$Be_2(OH,F)BO_3$	orth		8	9.755	12.201	4.426			
Hardystonite	$Ca_2ZnSi_2O_7$	tetr	melilite	2	7.87		5.01			
Hauerite	MnS_2	cubic	pyrite	4	6.1014					
Hausmannite	Mn_3O_4	tetr		8	8.136		9.422			
Hawleyite	CdS	cubic	sphalerite	4	5.833					
Heazelwoodite	Ni_3S_2	rhomb		3	5.746		7.134			
Hedenbergite	$CaFe(SiO_3)_2$	monocl	diopside	4	9.854	9.024	5.263		104.23°	
Hematite	Fe_2O_3	rhomb	corundum	6	5.0329				13.749	
Hemimorphite	$Zn_4(OH)_2Si_2O_7·H_2O$	orth		2	8.370	10.719	5.120			
Hercynite	$Fe(AlO_2)_2$	cubic	spinel	8	8.150					
Herzenbergite	SnS	orth	germanium sulfide	4	4.328	11.190	3.978			
Hessite	Ag_2Te	monocl		4	8.13	4.48	8.09		111.9°	
Hexahydrite	$MgSO_4·6H_2O$	monocl		8	10.110	7.212	24.41		98.30°	
High albite (Analbite)	$NaAlSi_3O_8$	tricl		4	8.160	12.870	7.106	93.54°	116.36°	90.19°
High argentite	Ag_2S	cubic		4	6.269					

Name	Formula	Crystal system	Structure type	*Z*	***a***/Å	***b***/Å	***c***/Å	α	β	γ
High bornite	Cu_5FeS_4	cubic		1	5.50					
High carnegeite	$NaAlSiO_4$	cubic		4	7.325					
High chalcocite	Cu_2S	hex		2	3.961		6.722			
High clinoenstatite	$MgSiO_3$	tricl		8	10.000	8.934	5.170	88.27°	70.03°	91.01°
High digenite	Cu_2S	cubic		4	5.725					
High germania	GeO_2	hex	α–quartz	3	4.987		5.652			
High leucite	$KAlSi_2O_6$	cubic		16	13.43					
High naumanite	Ag_2Se	cubic		2	4.993					
High sanidine	$KAlSi_3O_8$	monocl		4	8.615	13.031	7.177		115.98°	
Huebnerite	$MnWO_4$	monocl	wolframite	2	4.834	5.758	4.999		91.18°	
Huntite	$Mg_3Ca(CO_3)_4$	rhomb	calcite	3	9.498		7.816			
Hydroxylapatite	$Ca_5(PO_4)_3OH$	hex	apatite	2	9.418		6.883			
Ice	H_2O	hex		4	4.5212		7.3666			
Ilmenite	$FeTiO_3$	rhomb	ilmenite	6	5.093		14.055			
Indialite (Cordierite)	$Mg_2Al_3(AlSi_5O_{18})$	hex	beryl	2	9.7698		9.3517			
Iodargyrite	AgI	hex	zincite	2	4.5955		7.5005			
Iron (α)	Fe	cubic	body-centered cubic	2	2.8664					
Jacobsite	$MnFe_2O_4$	cubic	spinel	8	8.499					
Jadeite	$NaAl(SiO_3)_2$	monocl	diopside	4	9.409	8.564	5.220		107.50°	
Jalpaite	$Ag_{1.55}Cu_{0.45}S$	tetr		16	8.673		11.756			
Johannsenite	$CaMn(SiO_3)_2$	monocl	diopside	4	9.83	9.04	5.27		105.00°	
Kaliophilite	$KAlSiO_4$	hex		54	26.930		8.522			
Kalsilite	$KAlSiO_4$	hex		2	5.1597		8.7032			
Kaolinite	$Al_2Si_2O_5(OH)_4$	tricl		2	5.155	8.959	7.407	91.68°	104.87°	89.93°
Karelianite	V_2O_3	rhomb	corundum	6	4.952		14.002			
Keatite	SiO_2	tetr		12	7.456		8.604			
Kernite	$Na_2B_4O_7 \cdot 4H_2O$	monocl		4	7.022	9.151	15.676		108.83°	
Kerschsteinite	$CaFeSiO_4$	orth	olivine	4	4.886	11.146	6.434			
Klockmannite	CuSe	hex	deformed covellite	78	14.206		17.25			
Knebelite	$MnFeSiO_4$	orth	olivine	4	4.854	10.602	6.162			
Kyanite	Al_2OSiO_4	tricl		4	7.123	7.848	5.564	89.92°	101.25°	105.97°
Larnite	Ca_2SiO_4	monocl		4	5.48	6.76	9.28		94.55°	
Laurite	RuS_2	cubic	pyrite	4	5.60					
Lawrencite	$FeCl_2$	rhomb		3	3.593		17.58			
Lawsonite	$CaAl_2Si_2O_7(OH)_2 \cdot H_2O$	orth		4	8.787	5.836	13.123			
Lead	Pb	cubic	face-centered cubic	4	4.9505					
Leonhardtite	$MgSO_4 \cdot 4H_2O$	monocl		4	5.922	13.604	7.905		90.85°	
Lepidocrocite	FeO(OH)	orth		4	3.868	12.525	3.066			
Lepidolite	$K_2Al_3Li_2AlSi_7O_{20}(OH)_4$	monocl	2M2 mica	2	9.2	5.3	20.0		98.00°	
Leucite	$KAlSi_2O_6$	tetr		16	13.074		13.738			
Lime	CaO	cubic	rock salt	4	4.8108					
Lime olivine	Ca_2SiO_4	orth	olivine	4	5.091	11.371	6.782			
Linnaeite	Co_3S_4	cubic	spinel	8	9.401					
Litharge	PbO	tetr		2	3.9759		5.023			
Loellingite	$FeAs_2$	orth	marcasite	2	5.300	5.981	2.882			

Name	Formula	Crystal system	Structure type	*Z*	*a*/Å	*b*/Å	*c*/Å	α	β	γ
Low albite	$NaAlSi_3O_8$	tricl		4	8.139	12.788	7.160	94.27°	116.57°	87.68°
Low bornite	Cu_5FeS_4	tetr		16	10.94		21.88			
Low cordierite	$Mg_2Al_3(AlSi_5O_{18})$	orth		4	9.721	17.062	9.339			
Low germania	GeO_2	tetr	rutile	2	4.3963		2.8626			
Low nepheline	$NaAlSiO_4$	hex		8	9.986		8.330			
Luzonite	Cu_3AsS_4	tetr		2	5.289		10.440			
Mackinawite	FeS	tetr		2	3.675		5.030			
Magnesioriebeckite	$Na_2Mg_3Fe_2[Si_8O_{22}](OH)_2$	monocl	tremolite	2	9.733	17.946	5.299		103.30°	
Magnesite	$MgCO_3$	rhomb	calcite	6	4.6330		15.016			
Magnetite	Fe_3O_4	cubic	spinel	8	8.3940					
Malachite	$Cu_2(OH)_2CO_3$	monocl		4	9.502	11.974	3.240		98.75°	
Maldonite	Au_2Bi	cubic		8	7.958					
Manganese sulfide (γ)	MnS	hex	zincite	2	3.976		6.432			
Manganese sulfide (β)	MnS	cubic	sphalerite	4	5.611					
Manganosite	MnO	cubic	rock salt	4	4.4448					
Marcasite	FeS_2	orth	marcasite	2	4.443	5.423	3.3876			
Margarite	$CaAl_2[AlSi_2O_{10}](OH)_2$	monocl	2M mica	4	5.13	8.92	19.50		95.00°	
Marialite	$Na_4Al_3Si_9O_{24}Cl$	tetr		2	12.064		7.514			
Marshite	CuI	cubic	sphalerite	4	6.0507					
Mascagnite	$(NH_4)_2SO_4$	orth	arcanite	4	7.782	5.993	10.636			
Massicot	PbO	orth		4	5.489	4.755	5.891			
Matlockite	PbClF	tetr		2	4.106		7.23			
Maucherite	$Ni_{11}As_8$	tetr		4	6.870		21.81			
Meionite	$Ca_4Al_6Si_6O_{24}CO_3$	tetr		2	12.174		7.652			
Melanophlogite	SiO_2	cubic	clathrate type	46	13.402					
Melanterite	$FeSO_4{\cdot}7H_2O$	monocl		4	14.072	6.503	11.041		105.57°	
Melonite	$NiTe_2$	hex	cadmium iodide	1	3.869		5.308			
Metacinnabar	HgS	cubic	sphalerite	4	5.8517					
Miargyrite	$AgSbS_2$	monocl		8	12.862	4.111	13.220		98.63°	
Microcline	$KAlSi_3O_8$	tricl		4	8.582	12.964	7.222	90.62°	115.92°	87.68°
Miersite	AgI	cubic	sphalerite	4	6.4963					
Millerite	NiS	rhomb		9	9.616		3.152			
Minium	Pb_3O_4	tetr		4	8.815		6.565			
Minnesotaite	$Fe_3Si_4O_{10}(OH)_2$	monocl		4	5.4	9.42	19.4		100.00°	
Mirabilite	$Na_2SO_4{\cdot}10H_2O$	monocl		4	11.51	10.38	12.83		107.75°	
Mn-Indialite	$Mn_2Al_3(AlSi_5O_{18})$	hex	beryl	2	9.925		9.297			
Molybdenite	MoS_2	hex	molybdenite	2	3.1604		12.295			
Molybdenum	Mo	cubic		2	3.1653					
Molybdite	MoO_3	orth		4	3.962	13.858	3.697			
Monteponite	CdO	cubic	rock salt	4	4.6953					
Monticellite	$CaMgSiO_4$	orth	olivine	4	4.827	11.084	6.376			
Montroydite	HgO	orth		4	6.608	5.518	3.519			
Mullite (2:1)	$2Al_2O_3{\cdot}SiO_2$	orth		6	7.5788	7.6909	2.8883			
Mullite (3:2)	$3Al_2O_3{\cdot}2SiO_2$	orth		3	7.557	7.6876	2.8842			
Muscovite	$KAl_2AlSi_3O_{10}(OH)_2$	monocl	2M2 mica	4	5.203	8.995	20.030		94.47°	

Name	Formula	Crystal system	Structure type	*Z*	***a***/Å	***b***/Å	***c***/Å	α	β	γ
Nacrite	$Al_2Si_2O_5(OH)_4$	monocl		4	8.909	5.146	15.697		113.70°	
Nantokite	CuCl	cubic	sphalerite	4	5.416					
Natroalunite	$NaAl_3(SO_4)_2(OH)_6$	rhomb		3	6.974		16.69			
Natrolite	$Na_2Al_2Si_3O_{10}\cdot 2H_2O$	orth		8	18.30	18.63	6.60			
Neighborite	$NaMgF_3$	orth	perovskite	4	5.363	7.676	5.503			
Ni-Skutterudite	$NiAs_{2.95}$	cubic		8	8.3300					
Niccolite	NiAs	hex	niccolite	2	3.618		5.034			
Nickel	Ni	cubic	face-centered cubic	4	3.5238					
Nickel carbonate	$NiCO_3$	rhomb	calcite	6	4.5975		14.723			
Nickel olivine	Ni_2SiO_4	orth	olivine	4	4.727	10.121	5.915			
Nickel selenide	$NiSe_2$	cubic	pyrite	4	5.9604					
Niter	KNO_3	orth	aragonite	4	6.431	9.164	5.414			
Norsethite	$BaMg(CO_3)_2$	rhomb	calcite	3	5.020		16.75			
Oldhamite	CaS	cubic	rock salt	4	5.689					
Orpiment	As_2S_3	monocl		4	11.49	9.59	4.25		90.45°	
Orthoclase	$KAlSi_3O_8$	monocl		4	8.562	12.996	7.193		116.02°	
Orthoferrosilite	$FeSiO_3$	orth	enstatite	16	9.080	18.431	5.238			
Otavite	$CdCO_3$	rhomb	calcite	6	4.9204		16.298			
Paracelsian	$BaAl_2Si_2O_8$	monocl		4	8.58	9.583	9.08		90.00°	
Paragonite	$NaAl_2AlSi_3O_{10}(OH)_2$	monocl	2M1 mica	4	5.13	8.89	19.32		95.17°	
Pararammelsbergite	$NiAs_2$	orth		8	5.75	5.82	11.428			
Paratellurite	TeO_2	tetr		4	4.810		7.613			
Parawollastonite	$CaSiO_3$	monocl		12	15.417	7.321	7.066		95.40°	
Pectolite	$Ca_2NaH(SiO_3)_3$	tricl		2	7.99	7.04	7.02	90.05°	95.27°	102.47°
Pentlandite	$Fe_{5.25}Ni_{3.75}S_8$	cubic		4	10.196					
Pentlandite	$Fe_{4.75}Ni_{5.25}S_8$	cubic		4	10.095					
Periclase	MgO	cubic	rock salt	4	4.2117					
Perovskite	$CaTiO_3$	orth	perovskite	4	5.3670	7.6438	5.4439			
Petalite	$LiAlSi_4O_{10}$	monocl		2	11.32	5.14	7.62		105.90°	
Petzite	Ag_3AuTe_2	cubic		8	10.38					
Phenacite	Be_2SiO_4	rhomb	phenacite	18	12.472		8.252			
Phlogopite	$KMg_3AlSi_3O_{10}(OH)_2$	monocl	1M mica	2	5.326	9.210	10.311		100.17°	
Picrochromite	$MgCr_2O_4$	cubic	spinel	8	8.333					
Piemontite	$Ca_2Al_{1.5}Mn_{1.5}(SiO_4)_3OH$	monocl		2	8.95	5.70	9.41		115.70°	
Platinum	Pt	cubic	face-centered cubic	4	3.9231					
Polymidite	Ni_3S_4	cubic	spinel	8	9.480					
Portlandite	$Ca(OH)_2$	hex	cadmium iodide	1	3.5933		4.9086			
Powellite	$CaMoO_4$	tetr	scheelite	4	5.226		11.43			
Protoenstatite	$MgSiO_3$	orth		8	9.25	8.74	5.32			
Proustite	Ag_3AsS_3	rhomb		6	10.816		8.6948			
Pseudowollastonite	$CaSiO_3$	tricl		24	6.90	11.78	19.65	90.00°	90.80°	90.00°
Pyrargyrite	Ag_3SbS_3	rhomb		6	11.052		8.7177			
Pyrite	FeS_2	cubic	pyrite	4	5.4175					
Pyrolusite	MnO_2	tetr	rutile	2	4.388		2.865			
Pyrope	$Mg_3Al_2Si_3O_{12}$	cubic	garnet	8	11.459					

Name	Formula	Crystal system	Structure type	*Z*	*a*/Å	*b*/Å	*c*/Å	α	β	γ
Pyrophanite	$MnTiO_3$	rhomb	ilmenite	6	5.155		14.18			
Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$	monocl	2M1 mica	4	5.14	8.90	18.55		99.92°	
Pyroxmangite	$MnFe(SiO_3)_2$	tricl		7	7.56	17.45	6.67	84.00°	94.30°	113.70°
Pyrrhotite	$Fe_{0.980}S$	hex	defect niccolite	2	3.446		5.848			
Pyrrhotite	$Fe_{0.885}S$	hex	defect niccolite	2	3.440		5.709			
Quartz (α)	SiO_2	hex		3	4.9136		5.4051			
Quartz (β)	SiO_2	hex		3	4.999		5.4592			
Rammelsbergite	$NiAs_2$	orth	marcasite	2	4.757	5.797	3.542			
Realgar	AsS	monocl		16	9.29	13.53	6.57		106.55°	
Retgersite	$NiSO_4·4H_2O$	tetr		4	6.782		18.28			
Rhodochrosite	$MnCO_3$	rhomb	calcite	6	4.7771		15.664			
Rhodonite	$MnSiO_3$	tricl		10	7.682	11.818	6.707	92.36°	93.95°	105.66°
Riebeckite	$Na_2Fe_5FSi_8O_{22}(OH)_2$	monocl	tremolite	2	9.729	18.065	5.334		103.31°	
Rutile	TiO_2	tetr		2	4.5937		2.9618			
Safflorite	$Co_{0.5}Fe_{0.5}As_2$	orth	marcasite	2	5.231	5.953	2.962			
Sanmartinite	$ZnWO_4$	monocl	wolframite	2	4.691	5.720	4.925		89.36°	
Sapphirine	$Mg_2Al_4O_6SiO_4$	monocl		8	9.96	28.60	9.85		110.5°	
Scacchite	$MnCl_2$	rhomb		3	3.711		17.59			
Scheelite	$CaWO_4$	tetr	scheelite	4	5.242		11.372			
Schorl	$NaFe_3Al_6B_3Si_6O_{27}(OH)_4$	rhomb	tourmaline	3	16.032		7.149			
Selenium	Se	hex		3	4.3642		4.9588			
Selenolite	SeO_2	tetr		8	8.35		5.05			
Sellaite	MgF_2	tetr	rutile	2	4.621		3.050			
Senarmontite	Sb_2O_3	cubic	arsenic trioxide	16	11.152					
Shandite	$Ni_3Pb_2S_2$	rhomb		3	5.576		13.658			
Shortite	$Na_2Ca_2(CO_3)_3$	orth		2	4.961	11.03	7.12			
Siderite	$FeCO_3$	rhomb	calcite	6	4.6887		15.373			
Silicon	Si	cubic	diamond	8	5.4305					
Sillimanite	Al_2OSiO_4	orth		4	7.4843	7.6730	5.7711			
Silver	Ag	cubic	face-centered cubic	4	4.0862					
Silver telluride I	Ag_2Te	cubic		2	5.29					
Silver telluride II	Ag_2Te	cubic		4	6.585					
Smithsonite	$ZnCO_3$	rhomb	calcite	6	4.6528		15.025			
Soda niter	$NaNO_3$	rhomb	calcite	6	5.0696		16.829			
Sodium melilite	$NaCaAlSi_2O_7$	tetr	melilite	2	8.511		4.809			
Sperrylite	$PtAs_2$	cubic	pyrite	4	5.968					
Spessartite	$Mn_3Al_2Si_3O_{12}$	cubic	garnet	8	11.621					
Sphalerite	ZnS	cubic	sphalerite	4	5.4093					
Sphene	$CaTiSiO_5$	monocl		4	7.07	8.72	6.56		113.95°	
Spinel	$MgAl_2O_4$	cubic	spinel	8	8.080					
Spodumene	$LiAl(SiO_3)_2$	monocl	diopside	4	9.451	8.387	5.208		110.07°	
Spodumene (β)	$LiAl(SiO_3)_2$	tetr		4	7.5332		9.1540			
Staurolite	$Fe_2Al_9Si_4O_{22}(OH)_2$	monocl		2	7.90	16.65	5.63		90.00°	
Sternbergite	$AgFe_2S_3$	orth		8	11.60	12.675	6.63			
Stibnite	Sb_2S_3	orth	stibnite	4	11.229	11.310	3.8389			

Name	Formula	Crystal system	Structure type	*Z*	***a***/Å	***b***/Å	***c***/Å	α	β	γ
Stilleite	$ZnSe$	cubic	sphalerite	4	5.6685					
Stishovite	SiO_2	tetr	rutile	2	4.1790		2.6649			
Stolzite	$PbWO_4$	tetr	scheelite	4	5.4616		12.046			
Stromeyerite	$Ag_{0.93}Cu_{1.07}S$	orth		4	4.066	6.628	7.972			
Strontianite	$SrCO_3$	orth	aragonite	4	6.029	8.414	5.107			
Sulfur (monoclinic)	S	monocl	S8 ring molecules	48	11.04	10.98	10.92		96.73°	
Sulfur (orthorhombic)	S	orth	S8 ring molecules	128	10.4646	12.8660	24.4860			
Sulfur (rhombohedral)	S	rhomb	S6 ring molecules	18	10.818		4.280			
Sylvite	KCl	cubic	rock salt	4	6.2931					
Syngenite	$K_2Ca(SO_4)_2 \cdot H_2O$	monocl		2	9.775	7.156	6.251		104.00°	
Synthetic anorthite	$CaAl_2Si_2O_8$	hex		2	5.10		14.72			
Synthetic anorthite	$CaAl_2Si_2O_8$	orth		2	8.22	8.60	4.83			
Talc	$Mg_3Si_4O_{10}(OH)_2$	monocl	2M1 mica	4	5.287	9.158	18.95		99.50°	
Tantalum	Ta	cubic	tungsten	2	3.3058					
Teallite	$PbSnS_2$	orth	germanium sulfide	2	4.266	11.419	4.090			
Tellurite	TeO_2	orth	tellurite	8	5.607	12.034	5.463			
Tellurium	Te	hex	selenium	3	4.4570		5.9290			
Tellurobismuthite	Bi_2Te_3	rhomb		3	4.3835		30.487			
Tennantite	$Cu_{12}As_4S_{13}$	cubic	tetrahedrite	2	10.190					
Tenorite	CuO	monocl		4	4.684	3.425	5.129		99.47°	
Tephroite	Mn_2SiO_4	orth	olivine	4	4.871	10.636	6.232			
Tetrahedrite	$Cu_{12}Sb_4S_{13}$	cubic	tetrahedrite	2	10.327					
Thenardite	Na_2SO_4	orth	thenardite	8	5.863	12.304	9.821			
Thorianite	ThO_2	cubic	fluorite	4	5.5952					
Thorite	$ThSiO_4$	tetr	zircon	4	7.143		6.327			
Tiemannite	$HgSe$	cubic	sphalerite	4	6.0853					
Tin	Sn	tetr		4	5.8315		3.1813			
Titanium	Ti	hex		2	2.953		4.729			
Titanium(III) oxide	Ti_2O_3	rhomb	corundum	6	5.149		13.642			
Topaz	$Al_2(SiO_4)(OH)$	orth		4	8.394	8.792	4.649			
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$	monocl	tremolite	2	9.840	18.052	5.275		104.70°	
Trevorite	$NiFe_2O_4$	cubic	spinel	8	8.339					
Tridymite (β)	SiO_2	hex		4	5.0463		8.2563			
Trogtalite	$CoSe_2$	cubic	pyrite	4	5.8588					
Troilite	FeS	hex	niccolite	2	3.446		5.877			
Tschermakite	$CaAl_2SiO_6$	monocl	diopside	4	9.615	8.661	5.272		106.12°	
Tungsten	W	cubic		2	3.1653					
Tungstenite	WS_2	hex	molybdenite	2	3.154		12.362			
Turquois	$CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$	tricl		1	7.424	7.629	9.910	68.61°	69.71°	65.08°
Umangite	Cu_3Se_2	tetr		2	6.402		4.276			
Uraninite	UO_2	cubic	fluorite	4	5.4682					
Ureyite	$NaCr(SiO_3)_2$	monocl	diopside	4	9.550	8.712	5.273		107.44°	
Uvarovite	$Ca_3Cr_2Si_3O_{12}$	cubic	garnet	8	11.999					
Uvite	$CaMg_4Al_5B_3Si_6O_{27}(OH)_4$	rhomb	tourmaline	3	15.86		7.19			
Vaesite	NiS_2	cubic	pyrite	4	5.6873					

Name	Formula	Crystal system	Structure type	*Z*	*a*/Å	*b*/Å	*c*/Å	α	β	γ
Valentinite	Sb_2O_3	orth	antimony trioxide	4	4.914	12.468	5.421			
Vanthoffite	$MgSO_4 \cdot 3Na_2SO_4$	monocl		2	9.797	9.217	8.199		113.50°	
Vaterite	$CaCO_3$	hex		6	7.135		8.524			
Villiaumite	NaF	cubic	rock salt	4	4.6342					
Violarite	$FeNi_2S_4$	cubic	spinel	8	9.464					
Willemite	Zn_2SiO_4	rhomb	phenacite	18	13.94		9.309			
Witherite	$BaCO_3$	orth	aragonite	4	6.430	8.904	5.314			
Wolframite	$Fe_{0.5}Mn_{0.5}WO_4$	monocl	wolframite	2	4.782	5.731	4.982		90.57°	
Wollastonite	$CaSiO_3$	tricl		6	7.94	7.32	7.07	90.03°	95.37°	103.43°
Wulfenite	$PbMoO_4$	tetr	scheelite	4	5.435		12.110			
Wurtzite	ZnS	hex	zincite	2	3.8230		6.2565			
Wustite	$Fe_{0.953}O$	cubic	defect rock salt	4	4.3088					
Xenotime	YPO_4	tetr	zircon	4	6.885		5.982			
Zinc	Zn	hex	hexagonal close pack	2	2.665		4.947			
Zinc telluride	ZnTe	cubic	sphalerite	4	6.1020					
Zincite	ZnO	hex	zincite	2	3.2495		5.2069			
Zinkosite	$ZnSO_4$	orth	barite	4	8.588	6.740	4.770			
Zircon	$ZrSiO_4$	tetr	zircon	4	6.604		5.979			
Zoisite	$Ca_2Al_3(SiO_4)_3OH$	orth		4	16.15	5.581	10.06			

CODATA KEY VALUES FOR THERMODYNAMICS

The Committee on Data for Science and Technology (CODATA) has conducted a project to establish internationally agreed values for the thermodynamic properties of key chemical substances. This table presents the final results of the project. Use of these recommended, internally consistent values is encouraged in the analysis of thermodynamic measurements, data reduction, and preparation of other thermodynamic tables.

The table includes the standard enthalpy of formation at 298.15 K, the entropy at 298.15 K, and the quantity $H°$ (298.15 K)–$H°$ (0). A value of 0 in the $\Delta_f H°$ column for an element indicates the reference state for that element. The standard state pressure is 100000 Pa (1 bar). See the reference for information on the dependence of gas-phase entropy on the choice of standard state pressure.

Substances are listed in alphabetical order of their chemical formulas when written in the most common form.

The table is reprinted with permission of CODATA.

REFERENCE

Cox, J. D., Wagman, D. D., and Medvedev, V. A., *CODATA Key Values for Thermodynamics*, Hemisphere Publishing Corp., New York, 1989.

Substance	State	$\Delta_f H°$ (298.15 K) kJ·mol^{-1}	$S°$ (298.15 K) J·K^{-1}·mol^{-1}	$H°$ (298.15 K)–$H°$ (0) kJ·mol^{-1}
Ag	cr	0	42.55 ± 0.20	5.745 ± 0.020
Ag	g	284.9 ± 0.8	172.997 ± 0.004	6.197 ± 0.001
Ag^{+}	aq	105.79 ± 0.08	73.45 ± 0.40	
AgCl	cr	-127.01 ± 0.05	96.25 ± 0.20	12.033 ± 0.020
Al	cr	0	28.30 ± 0.10	4.540 ± 0.020
Al	g	330.0 ± 4.0	164.554 ± 0.004	6.919 ± 0.001
Al^{+3}	aq	-538.4 ± 1.5	-325 ± 10	
AlF_3	cr	-1510.4 ± 1.3	66.5 ± 0.5	11.62 ± 0.04
Al_2O_3	cr, corundum	-1675.7 ± 1.3	50.92 ± 0.10	10.016 ± 0.020
Ar	g	0	154.846 ± 0.003	6.197 ± 0.001
B	cr, rhombic	0	5.90 ± 0.08	1.222 ± 0.008
B	g	565 ± 5	153.436 ± 0.015	6.316 ± 0.002
BF_3	g	-1136.0 ± 0.8	254.42 ± 0.20	11.650 ± 0.020
B_2O_3	cr	-1273.5 ± 1.4	53.97 ± 0.30	9.301 ± 0.040
Be	cr	0	9.50 ± 0.08	1.950 ± 0.020
Be	g	324 ± 5	136.275 ± 0.003	6.197 ± 0.001
BeO	cr	-609.4 ± 2.5	13.77 ± 0.04	2.837 ± 0.008
Br	g	111.87 ± 0.12	175.018 ± 0.004	6.197 ± 0.001
Br^{-}	aq	-121.41 ± 0.15	82.55 ± 0.20	
Br_2	l	0	152.21 ± 0.30	24.52 ± 0.01
Br_2	g	30.91 ± 0.11	245.468 ± 0.005	9.725 ± 0.001
C	cr, graphite	0	5.74 ± 0.10	1.050 ± 0.020
C	g	716.68 ± 0.45	158.100 ± 0.003	6.536 ± 0.001
CO	g	-110.53 ± 0.17	197.660 ± 0.004	8.671 ± 0.001
CO_2	g	-393.51 ± 0.13	213.785 ± 0.010	9.365 ± 0.003
CO_2	aq, undissoc.	-413.26 ± 0.20	119.36 ± 0.60	
CO_3^{-2}	aq	-675.23 ± 0.25	-50.0 ± 1.0	
Ca	cr	0	41.59 ± 0.40	5.736 ± 0.040
Ca	g	177.8 ± 0.8	154.887 ± 0.004	6.197 ± 0.001
Ca^{+2}	aq	-543.0 ± 1.0	-56.2 ± 1.0	
CaO	cr	-634.92 ± 0.90	38.1 ± 0.4	6.75 ± 0.06
Cd	cr	0	51.80 ± 0.15	6.247 ± 0.015
Cd	g	111.80 ± 0.20	167.749 ± 0.004	6.197 ± 0.001
Cd^{+2}	aq	-75.92 ± 0.60	-72.8 ± 1.5	
CdO	cr	-258.35 ± 0.40	54.8 ± 1.5	8.41 ± 0.08
$CdSO_4{\cdot}8/3H_2O$	cr	-1729.30 ± 0.80	229.65 ± 0.40	35.56 ± 0.04
Cl	g	121.301 ± 0.008	165.190 ± 0.004	6.272 ± 0.001
Cl^{-}	aq	-167.080 ± 0.10	56.60 ± 0.20	
ClO_4^{-}	aq	-128.10 ± 0.40	184.0 ± 1.5	
Cl_2	g	0	223.081 ± 0.010	9.181 ± 0.001
Cs	cr	0	85.23 ± 0.40	7.711 ± 0.020
Cs	g	76.5 ± 1.0	175.601 ± 0.003	6.197 ± 0.001
Cs^{+}	aq	-258.00 ± 0.50	132.1 ± 0.5	

Substance	State	$\Delta_f H°$ (298.15 K) kJ·mol^{-1}	$S°$ (298.15 K) J·K^{-1}·mol^{-1}	$H°$ (298.15 K)–$H°$ (0) kJ·mol^{-1}
Cu	cr	0	33.15 ± 0.08	5.004 ± 0.008
Cu	g	337.4 ± 1.2	166.398 ± 0.004	6.197 ± 0.001
Cu^{+2}	aq	64.9 ± 1.0	-98 ± 4	
$CuSO_4$	cr	-771.4 ± 1.2	109.2 ± 0.4	16.86 ± 0.08
F	g	79.38 ± 0.30	158.751 ± 0.004	6.518 ± 0.001
F^-	aq	-335.35 ± 0.65	-13.8 ± 0.8	
F_2	g	0	202.791 ± 0.005	8.825 ± 0.001
Ge	cr	0	31.09 ± 0.15	4.636 ± 0.020
Ge	g	372 ± 3	167.904 ± 0.005	7.398 ± 0.001
GeF_4	g	-1190.20 ± 0.50	301.9 ± 1.0	17.29 ± 0.10
GeO_2	cr, tetragonal	-580.0 ± 1.0	39.71 ± 0.15	7.230 ± 0.020
H	g	217.998 ± 0.006	114.717 ± 0.002	6.197 ± 0.001
H^+	aq	0	0	
HBr	g	-36.29 ± 0.16	198.700 ± 0.004	8.648 ± 0.001
HCO_3^-	aq	-689.93 ± 0.20	98.4 ± 0.5	
HCl	g	-92.31 ± 0.10	186.902 ± 0.005	8.640 ± 0.001
HF	g	-273.30 ± 0.70	173.779 ± 0.003	8.599 ± 0.001
HI	g	26.50 ± 0.10	206.590 ± 0.004	8.657 ± 0.001
HPO_4^{-2}	aq	-1299.0 ± 1.5	-33.5 ± 1.5	
HS^-	aq	-16.3 ± 1.5	67 ± 5	
HSO_4^-	aq	-886.9 ± 1.0	131.7 ± 3.0	
H_2	g	0	130.680 ± 0.003	8.468 ± 0.001
H_2O	l	-285.830 ± 0.040	69.95 ± 0.03	13.273 ± 0.020
H_2O	g	-241.826 ± 0.040	188.835 ± 0.010	9.905 ± 0.005
$H_2PO_4^-$	aq	-1302.6 ± 1.5	92.5 ± 1.5	
H_2S	g	-20.6 ± 0.5	205.81 ± 0.05	9.957 ± 0.010
H_2S	aq, undissoc.	-38.6 ± 1.5	126 ± 5	
H_3BO_3	cr	-1094.8 ± 0.8	89.95 ± 0.60	13.52 ± 0.04
H_3BO_3	aq, undissoc.	-1072.8 ± 0.8	162.4 ± 0.6	
He	g	0	126.153 ± 0.002	6.197 ± 0.001
Hg	l	0	75.90 ± 0.12	9.342 ± 0.008
Hg	g	61.38 ± 0.04	174.971 ± 0.005	6.197 ± 0.001
Hg^{+2}	aq	170.21 ± 0.20	-36.19 ± 0.80	
HgO	cr, red	-90.79 ± 0.12	70.25 ± 0.30	9.117 ± 0.025
Hg_2^{+2}	aq	166.87 ± 0.50	65.74 ± 0.80	
Hg_2Cl_2	cr	-265.37 ± 0.40	191.6 ± 0.8	23.35 ± 0.20
Hg_2SO_4	cr	-743.09 ± 0.40	200.70 ± 0.20	26.070 ± 0.030
I	g	106.76 ± 0.04	180.787 ± 0.004	6.197 ± 0.001
I^-	aq	-56.78 ± 0.05	106.45 ± 0.30	
I_2	cr	0	116.14 ± 0.30	13.196 ± 0.040
I_2	g	62.42 ± 0.08	260.687 ± 0.005	10.116 ± 0.001
K	cr	0	64.68 ± 0.20	7.088 ± 0.020
K	g	89.0 ± 0.8	160.341 ± 0.003	6.197 ± 0.001
K^+	aq	-252.14 ± 0.08	101.20 ± 0.20	
Kr	g	0	164.085 ± 0.003	6.197 ± 0.001
Li	cr	0	29.12 ± 0.20	4.632 ± 0.040
Li	g	159.3 ± 1.0	138.782 ± 0.010	6.197 ± 0.001
Li^+	aq	-278.47 ± 0.08	12.24 ± 0.15	
Mg	cr	0	32.67 ± 0.10	4.998 ± 0.030
Mg	g	147.1 ± 0.8	148.648 ± 0.003	6.197 ± 0.001
Mg^{+2}	aq	-467.0 ± 0.6	-137 ± 4	
MgF_2	cr	-1124.2 ± 1.2	57.2 ± 0.5	9.91 ± 0.06
MgO	cr	-601.60 ± 0.30	26.95 ± 0.15	5.160 ± 0.020
N	g	472.68 ± 0.40	153.301 ± 0.003	6.197 ± 0.001
NH_3	g	-45.94 ± 0.35	192.77 ± 0.05	10.043 ± 0.010
NH_4^+	aq	-133.26 ± 0.25	111.17 ± 0.40	
NO_3^-	aq	-206.85 ± 0.40	146.70 ± 0.40	

CODATA KEY VALUES FOR THERMODYNAMICS (continued)

Substance	State	$\Delta_f H°$ (298.15 K) kJ·mol^{-1}	$S°$ (298.15 K) J·K^{-1}·mol^{-1}	$H°$ (298.15 K)–$H°$ (0) kJ·mol^{-1}
N_2	g	0	191.609 ± 0.004	8.670 ± 0.001
Na	cr	0	51.30 ± 0.20	6.460 ± 0.020
Na	g	107.5 ± 0.7	153.718 ± 0.003	6.197 ± 0.001
Na^+	aq	-240.34 ± 0.06	58.45 ± 0.15	
Ne	g	0	146.328 ± 0.003	6.197 ± 0.001
O	g	249.18 ± 0.10	161.059 ± 0.003	6.725 ± 0.001
OH^-	aq	-230.015 ± 0.040	-10.90 ± 0.20	
O_2	g	0	205.152 ± 0.005	8.680 ± 0.002
P	cr, white	0	41.09 ± 0.25	5.360 ± 0.015
P	g	316.5 ± 1.0	163.199 ± 0.003	6.197 ± 0.001
P_2	g	144.0 ± 2.0	218.123 ± 0.004	8.904 ± 0.001
P_4	g	58.9 ± 0.3	280.01 ± 0.50	14.10 ± 0.20
Pb	cr	0	64.80 ± 0.30	6.870 ± 0.030
Pb	g	195.2 ± 0.8	175.375 ± 0.005	6.197 ± 0.001
Pb^{+2}	aq	0.92 ± 0.25	18.5 ± 1.0	
$PbSO_4$	cr	-919.97 ± 0.40	148.50 ± 0.60	20.050 ± 0.040
Rb	cr	0	76.78 ± 0.30	7.489 ± 0.020
Rb	g	80.9 ± 0.8	170.094 ± 0.003	6.197 ± 0.001
Rb^+	aq	-251.12 ± 0.10	121.75 ± 0.25	
S	cr, rhombic	0	32.054 ± 0.050	4.412 ± 0.006
S	g	277.17 ± 0.15	167.829 ± 0.006	6.657 ± 0.001
SO_2	g	-296.81 ± 0.20	248.223 ± 0.050	10.549 ± 0.010
SO_4^{-2}	aq	-909.34 ± 0.40	18.50 ± 0.40	
S_2	g	128.60 ± 0.30	228.167 ± 0.010	9.132 ± 0.002
Si	cr	0	18.81 ± 0.08	3.217 ± 0.008
Si	g	450 ± 8	167.981 ± 0.004	7.550 ± 0.001
SiF_4	g	-1615.0 ± 0.8	282.76 ± 0.50	15.36 ± 0.05
SiO_2	cr, alpha quartz	-910.7 ± 1.0	41.46 ± 0.20	6.916 ± 0.020
Sn	cr, white	0	51.18 ± 0.08	6.323 ± 0.008
Sn	g	301.2 ± 1.5	168.492 ± 0.004	6.215 ± 0.001
Sn^{+2}	aq	-8.9 ± 1.0	-16.7 ± 4.0	
SnO	cr, tetragonal	-280.71 ± 0.20	57.17 ± 0.30	8.736 ± 0.020
SnO_2	cr, tetragonal	-577.63 ± 0.20	49.04 ± 0.10	8.384 ± 0.020
Th	cr	0	51.8 ± 0.5	6.35 ± 0.05
Th	g	602 ± 6	190.17 ± 0.05	6.197 ± 0.003
ThO_2	cr	-1226.4 ± 3.5	65.23 ± 0.20	10.560 ± 0.020
Ti	cr	0	30.72 ± 0.10	4.824 ± 0.015
Ti	g	473 ± 3	180.298 ± 0.010	7.539 ± 0.002
$TiCl_4$	g	-763.2 ± 3.0	353.2 ± 4.0	21.5 ± 0.5
TiO_2	cr, rutile	-944.0 ± 0.8	50.62 ± 0.30	8.68 ± 0.05
U	cr	0	50.20 ± 0.20	6.364 ± 0.020
U	g	533 ± 8	199.79 ± 0.10	6.499 ± 0.020
UO_2	cr	-1085.0 ± 1.0	77.03 ± 0.20	11.280 ± 0.020
UO_2^{+2}	aq	-1019.0 ± 1.5	-98.2 ± 3.0	
UO_3	cr, gamma	-1223.8 ± 1.2	96.11 ± 0.40	14.585 ± 0.050
U_3O_8	cr	-3574.8 ± 2.5	282.55 ± 0.50	42.74 ± 0.10
Xe	g	0	169.685 ± 0.003	6.197 ± 0.001
Zn	cr	0	41.63 ± 0.15	5.657 ± 0.020
Zn	g	130.40 ± 0.40	160.990 ± 0.004	6.197 ± 0.001
Zn^{+2}	aq	-153.39 ± 0.20	-109.8 ± 0.5	
ZnO	cr	-350.46 ± 0.27	43.65 ± 0.40	6.933 ± 0.040

STANDARD THERMODYNAMIC PROPERTIES OF CHEMICAL SUBSTANCES

This table gives the standard state chemical thermodynamic properties of about 2400 individual substances in the crystalline, liquid, and gaseous states. Substances are listed by molecular formula in a modified Hill order; all compounds not containing carbon appear first, followed by those that contain carbon. The properties tabulated are:

$\Delta_f H°$ Standard molar enthalpy (heat) of formation at 298.15 K in kJ/mol
$\Delta_f G°$ Standard molar Gibbs energy of formation at 298.15 K in kJ/mol
$S°$ Standard molar entropy at 298.15 K in J/mol K
C_p Molar heat capacity at constant pressure at 298.15 K in J/mol K

The standard state pressure is 100 kPa (1 bar). The standard states are defined for different phases by:

- The standard state of a pure gaseous substance is that of the substance as a (hypothetical) ideal gas at the standard state pressure.
- The standard state of a pure liquid substance is that of the liquid under the standard state pressure.
- The standard state of a pure crystalline substance is that of the crystalline substance under the standard state pressure.

An entry of 0.0 for $\Delta_f H°$ for an element indicates the reference state of that element. See References 1 and 2 for further information on reference states. A blank means no value is available.

We are indebted to M.V. Korobov for providing data on fullerene compounds.

REFERENCES

1. Cox, J.D., Wagman, D.D., and Medvedev, V.A., *CODATA Key Values for Thermodynamics*, Hemisphere Publishing Corp., New York, 1989.
2. Wagman, D.D., Evans, W.H., Parker, V.B., Schumm, R.H., Halow, I., Bailey, S.M., Churney, K.L., and Nuttall, R.L., *The NBS Tables of Chemical of Chemical Thermodynamic Properties, J. Phys. Chem. Ref. Data*, Vol. 11, Suppl. 2, 1982.
3. Chase M.W., Davies, C.A., Downey, J.R., Frurip, D.J., McDonald, R.A., and Syverud, A.N., *JANAF Thermochemical Tables, Third Edition, J. Phys. Chem. Ref. Data*, Vol. 14, Suppl. 1, 1985.
4. Daubert, T.E., Danner, R.P., Sibul, H.M., and Stebbins, C.C., *Physical and Thermodynamic Properties of Pure Compounds: Data Compilation*, extant 1994 (core with 4 supplements), Taylor & Francis, Bristol, PA.
5. Pedley, J.B., Naylor, R.D., and Kirby, S.P., *Thermochemical Data of Organic Compounds, Second Edition*, Chapman & Hall, London, 1986.
6. Pedley, J.B., *Thermochemical Data and Structures of Organic Compounds*, Thermodynamic Research Center, Texas A & M University, College Station, TX, 1994.
7. Dolmalski, E.S., Evans, W.H., Hearing E.D., *Heat Capacities and Entropies of Organic Compounds in the Condensed Phase, J. Phys. Chem. Ref. Data*, Vol. 13, Suppl. 1, 1984; Vol. 19, No. 4, 881—1047, 1990.
8. Gurvich, L.V., Veyts, I.V., and Alcock, C.B., *Thermodynamic Properties of Individual Substances, Fourth Edition*, Vol. 1, Hermisphere Publishing Corp., New York, 1989.
9. Gurvich, L.V., Veyts, I.V., and Alcock, C.B., *Thermodynamic Properties of Individual Substances, Fourth Edition*, Vol. 3, CRC Press, Boca Raton, FL, 1994.

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
Ac	Actinium	0.0		406.0			366.0	56.5		188.1	27.2		20.8
Ag	Silver	0.0		284.9			246.0	42.6		173.0	25.4		20.8
AgBr	Silver(I) bromide	-100.4			-96.9			107.1			52.4		
$AgBrO_3$	Silver(I) bromate	-10.5			71.3			151.9					
AgCl	Silver(I) chloride	-127.0			-109.8			96.3			50.8		
$AgClO_3$	Silver(I) chlorate	-30.3			64.5			142.0					
$AgClO_4$	Silver(I) perchlorate	-31.1											
AgF	Silver(I) fluoride	-204.6											
AgF_2	Silver(II) fluoride	-360.0											
AgI	Silver(I) iodide	-61.8			-66.2			115.5			56.8		
$AgIO_3$	Silver(I) iodate	-171.1			-93.7			149.4			102.9		
$AgNO_3$	Silver(I) nitrate	-124.4			-33.4			140.9			93.1		
Ag_2	Disilver			410.0			358.8			257.1			37.0
Ag_2CrO_4	Silver(I) chromate	-731.7			-641.8			217.6			142.3		
Ag_2O	Silver(I) oxide	-31.1			-11.2			121.3			65.9		
Ag_2O_2	Silver(II) oxide	-24.3			27.6			117.0			88.0		
Ag_2O_3	Silver(III) oxide	33.9			121.4			100.0					
Ag_2O_4S	Silver(I) sulfate	-715.9			-618.4			200.4			131.4		
Ag_2S	Silver(I) sulfide (argentite)	-32.6			-40.7			144.0			76.5		
Al	Aluminum	0.0		330.0			289.4	28.3		164.6	24.4		21.4
AlB_3H_{12}	Aluminum borohydride		-16.3	13.0		145.0	147.0		289.1	379.2		194.6	
AlBr	Aluminum monobromide			-4.0			-42.0			239.5			35.6
$AlBr_3$	Aluminum tribromide	-527.2		-425.1				180.2			100.6		
AlCl	Aluminum monochloride			-47.7			-74.1			228.1			35.0
$AlCl_2$	Aluminum dichloride			-331.0									
$AlCl_3$	Aluminum trichloride	-704.2		-583.2	-628.8			109.3			91.1		
AlF	Aluminum monofluoride			-258.2			-283.7			215.0			31.9
AlF_3	Aluminum trifluoride	-1510.4		-1204.6	-1431.1		-1188.2	66.5		277.1	75.1		62.6
AlF_4Na	Sodium tetrafluoroaluminate			-1869.0			-1827.5			345.7			105.9
AlH	Aluminum hydride			259.2			231.2			187.9			29.4
AlH_3	Aluminum hydride	-46.0						30.0			40.2		
AlH_4K	Potassium aluminum hydride	-183.7											
AlH_4Li	Lithium aluminum hydride	-116.3			-44.7			78.7			83.2		
AlH_4Na	Sodium aluminum hydride	-15.5											
AlI	Aluminum monoiodide			65.5									36.0
AlI_3	Aluminum triiodide	-313.8		-207.5	-300.8			159.0			98.7		
AlN	Aluminum nitride	-318.0			-287.0			20.2			30.1		
AlO	Aluminum monoxide			91.2			65.3			218.4			30.9
AlO_4P	Aluminum phosphate	-1733.8			-1617.9			90.8			93.2		
AlP	Aluminum phosphide	-166.5											
AlS	Aluminum monosulfide			200.9			150.1			230.6			33.4
Al_2	Dialuminum			485.9			433.3			233.2			36.4
Al_2Br_6	Aluminum hexabromide			-970.7									
Al_2Cl_6	Aluminum hexachloride			-1290.8			-1220.4			490.0			

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
Al_2F_6	Aluminum hexafluoride			-2628.0									
Al_2I_6	Aluminum hexaiodide			-516.7									
Al_2O	Aluminum oxide (Al_2O)			-130.0			-159.0			259.4			45.7
Al_2O_3	Aluminum oxide (corundum)	-1675.7			-1582.3			50.9			79.0		
Al_2S_3	Aluminum sulfide	-724.0						116.9			105.1		
Am	Americium	0.0											
Ar	Argon			0.0						154.8			20.8
As	Arsenic (gray)	0.0		302.5			261.0	35.1		174.2	24.6		20.8
As	Arsenic (yellow)	14.6											
$AsBr_3$	Arsenic(III) bromide	-197.5		-130.0			-159.0			363.9			79.2
$AsCl_3$	Arsenic(III) chloride		-305.0	-261.5		-259.4	-248.9		216.3	327.2			75.7
AsF_3	Arsenic(III) fluoride		-821.3	-785.8		-774.2	-770.8		181.2	289.1		126.6	65.6
AsGa	Gallium arsenide	-71.0			-67.8			64.2			46.2		
AsH_3	Arsine			66.4			68.9			222.8			38.1
AsH_3O_4	Arsenic acid	-906.3											
AsI_3	Arsenic(III) iodide	-58.2			-59.4			213.1		388.3	105.8		80.6
AsIn	Indium arsenide	-58.6			-53.6			75.7			47.8		
AsO	Arsenic monoxide			70.0									
As_2	Diarsenic			222.2			171.9			239.4			35.0
As_2O_5	Arsenic(V) oxide	-924.9			-782.3			105.4			116.5		
As_2S_3	Arsenic(III) sulfide	-169.0			-168.6			163.6			116.3		
At	Astatine	0.0											
Au	Gold	0.0		366.1			326.3	47.4		180.5	25.4		20.8
AuBr	Gold(I) bromide	-14.0											
$AuBr_3$	Gold(III) bromide	-53.3											
AuCl	Gold(I) chloride	-34.7											
$AuCl_3$	Gold(III) chloride	-117.6											
AuF_3	Gold(III) fluoride	-363.6											
AuH	Gold hydride			295.0			265.7			211.2			29.2
AuI	Gold(I) iodide	0.0											
Au_2	Digold			515.1									36.9
B	Boron (rhombic)	0.0		565.0			521.0	5.9		153.4	11.1		20.8
BBr	Bromoborane			238.1			195.4			225.0			32.9
BBr_3	Boron tribromide		-239.7	-205.6		-238.5	-232.5		229.7	324.2			67.8
BCl	Chloroborane			149.5			120.9			213.2			31.7
BClO	Chloroxyborane			-314.0									
BCl_3	Boron trichloride		-427.2	-403.8		-387.4	-388.7		206.3	290.1		106.7	62.7
$BCsO_2$	Cesium metaborate	-972.0			-915.0			104.4			80.6		
BF	Fluoroborane			-122.2			-149.8			200.5			29.6
BFO	Fluorooxyborane			-607.0									
BF_3	Boron trifluoride			-1136.0			-1119.4			254.4			
BF_3H_3N	Aminetrifluoroboron	-1353.9											
BF_3H_3P	Trihydro(phosphorus trifluoride)boron			-854.0									
BF_4Na	Sodium tetrafluoroborate	-1844.7			-1750.1			145.3			120.3		

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
BH	Boron monohydride			442.7			419.6			171.9			29.2
BHO_2	Metaboric acid (monoclinic)	-794.3		-561.9	-723.4		-551.0	38.0		240.1			42.2
BH_3	Borane (3)			89.2						188.2			36.0
BH_3O_3	Boric acid (orthoboric acid)	-1094.3		-994.1	-968.9			90.0			86.1		
BH_4K	Potassium borohydride	-227.4			-160.3			106.3			96.1		
BH_4Li	Lithium borohydride	-190.8			-125.0			75.9			82.6		
BH_4Na	Sodium borohydride	-188.6			-123.9			101.3			86.8		
BI_3	Boron triiodide			71.1			20.7			349.2			70.8
BKO_2	Potassium metaborate	-981.6			-923.4			80.0			66.7		
$BLiO_2$	Lithium metaborate	-1032.2			-976.1			51.5			59.8		
BN	Boron nitride	-254.4		647.5	-228.4		614.5	14.8		212.3	19.7		29.5
$BNaO_2$	Sodium metaborate	-977.0			-920.7			73.5			65.9		
BO	Boron monoxide			25.0			-4.0			203.5			29.2
BO_2	Boron dioxide			-300.4			-305.9			229.6			43.0
BO_2Rb	Rubidium metaborate	-971.0			-913.0			94.3			74.1		
BS	Boron monosulfide			342.0			288.8			216.2			30.0
B_2	Diboron			830.5			774.0			201.9			30.5
B_2Cl_4	Tetrachlorodiborane		-523.0	-490.4		-464.8	-460.6		262.3	357.4		137.7	95.4
B_2F_4	Tetrafluorodiborane			-1440.1			-1410.4			317.3			79.1
B_2H_6	Diborane			36.4			86.7			232.1			56.7
B_2O_2	Diboron dioxide			-454.8			-462.3			242.5			57.3
B_2O_3	Boron oxide	-1273.5		-843.8	-1194.3		-832.0	54.0		279.8	62.8		66.9
B_2S_3	Boron sulfide	-240.6		67.0				100.0			111.7		
$B_3H_6N_3$	Borazine		-541.0			-392.7			199.6				
B_4H_{10}	Tetraborane (10)			66.1						280.3			93.2
$B_4Na_2O_7$	Sodium tetraborate	-3291.1			-3096.0			189.5			186.8		
B_5H_9	Pentaborane(9)		42.7	73.2		171.8	175.0		184.2	280.6		151.1	99.6
B_5H_{11}	Pentaborane (11)		73.2	103.3						321.0			130.3
B_6H_{10}	Hexaborane (10)		56.3	94.6						296.8			125.7
Ba	Barium	0.0		180.0			146.0	62.5		170.2	28.1		20.8
$BaBr_2$	Barium bromide	-757.3			-736.8			146.0					
$BaCl_2$	Barium chloride	-855.0			-806.7			123.7			75.1		
$BaCl_2H_4O_2$	Barium chloride dihydrate	-1456.9			-1293.2			203.0					
BaF_2	Barium fluoride	-1207.1			-1156.8			96.4			71.2		
BaH_2	Barium hydride	-177.0			-138.2			63.0			46.0		
BaH_2O_2	Barium hydroxide	-944.7											
BaI_2	Barium iodide	-602.1											
BaN_2O_4	Barium nitrite	-768.2											
BaN_2O_6	Barium nitrate	-988.0			-792.6			214.0			151.4		
BaO	Barium oxide	-548.0			-520.3			72.1			47.3		
BaO_4S	Barium sulfate	-1473.2			-1362.2			132.2			101.8		
BaS	Barium sulfide	-460.0			-456.0			78.2			49.4		
Be	Beryllium	0.0		324.0			286.6	9.5		136.3	16.4		20.8
$BeBr_2$	Beryllium bromide	-353.5						108.0			69.4		
$BeCl_2$	Beryllium chloride	-490.4			-445.6			75.8			62.4		

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
BeF_2	Beryllium fluoride	-1026.8			-979.4			53.4			51.8		
BeH_2O_2	Beryllium hydroxide	-902.5			-815.0			45.5			62.1		
BeI_2	Beryllium iodide	-192.5						121.0			71.1		
BeO	Beryllium oxide	-609.4			-580.1			13.8			25.6		
BeO_4S	Beryllium sulfate	-1205.2			-1093.8			77.9			85.7		
BeS	Beryllium sulfide	-234.3						34.0			34.0		
Bi	Bismuth	0.0		207.1			168.2	56.7		187.0	25.5		20.8
BiClO	Bismuth oxychloride	-366.9			-322.1			120.5					
$BiCl_3$	Bismuth trichloride	-379.1		-265.7	-315.0		-256.0	177.0		358.9	105.0		79.7
BiH_3O_3	Bismuth hydroxide	-711.3											
BiI_3	Bismuth triiodide				-175.3								
Bi_2	Dibismuth			219.7									36.9
Bi_2O_3	Bismuth oxide	-573.9			-493.7			151.5			113.5		
$Bi_2O_{12}S_3$	Bismuth sulfate	-2544.3											
Bi_2S_3	Bismuth sulfide	-143.1			-140.6			200.4			122.2		
Bk	Berkelium	0.0											
Br	Bromine (atomic)			111.9			82.4			175.0			20.8
BrCl	Bromine chloride			14.6			-1.0			240.1			35.0
$BrCl_3Si$	Bromotrichlorosilane									350.1			90.9
BrCs	Cesium bromide	-405.8			-391.4			113.1			52.9		
BrCu	Copper(I) bromide	-104.6			-100.8			96.1			54.7		
BrF	Bromine fluoride			-93.8			-109.2			229.0			33.0
BrF_3	Bromine trifluoride		-300.8	-255.6		-240.5	-229.4		178.2	292.5		124.6	66.6
BrF_5	Bromine pentafluoride		-458.6	-428.9		-351.8	-350.6		225.1	320.2			99.6
BrGe	Germanium monobromide			235.6									37.1
$BrGeH_3$	Bromogermane									274.8			56.4
BrH	Hydrogen bromide			-36.3			-53.4			198.7			29.1
BrHSi	Bromosilylene			-464.4									
BrH_3Si	Bromosilane									262.4			52.8
BrH_4N	Ammonium bromide	-270.8			-175.2			113.0			96.0		
BrI	Iodine bromide			40.8			3.7			258.8			36.4
BrIn	Indium(I) bromide	-175.3		-56.9	-169.0		-94.3	113.0		259.5			36.7
BrK	Potassium bromide	-393.8			-380.7			95.9			52.3		
$BrKO_3$	Potassium bromate	-360.2			-271.2			149.2			105.2		
$BrKO_4$	Potassium perbromate	-287.9			-174.4			170.1			120.2		
BrLi	Lithium bromide	-351.2			-342.0			74.3					
BrNO	Nitrosyl bromide			82.2			82.4			273.7			45.5
BrNa	Sodium bromide	-361.1		-143.1	-349.0		-177.1	86.8		241.2	51.4		36.3
$BrNaO_3$	Sodium bromate	-334.1			-242.6			128.9					
BrO	Bromine monoxide			125.8			108.2			237.6			32.1
BrO_2	Bromine dioxide	48.5											
BrRb	Rubidium bromide	-394.6			-381.8			110.0			52.8		
BrSi	Bromosilyldyne			209.0									38.6
BrTl	Thallium(I) bromide	-173.2		-37.7	-167.4			120.5					
Br_2	Bromine		0.0	30.9			3.1		152.2	245.5		75.7	36.0

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
Br_2Ca	Calcium bromide	-682.8			-663.6			130.0					
Br_2Cd	Cadmium bromide	-316.2			-296.3			137.2			76.7		
Br_2Co	Cobalt(II) bromide	-220.9									79.5		
Br_2Cr	Chromium(II) bromide	-302.1											
Br_2Cu	Copper(II) bromide	-141.8											
Br_2Fe	Iron(II) bromide	-249.8			-238.1			140.6					
Br_2H_2Si	Dibromosilane									309.7			65.5
Br_2Hg	Mercury(II) bromide	-170.7			-153.1			172.0					
Br_2Hg_2	Mercury(I) bromide	-206.9			-181.1			218.0					
Br_2Mg	Magnesium bromide	-524.3			-503.8			117.2					
Br_2Mn	Manganese(II) bromide	-384.9											
Br_2Ni	Nickel(II) bromide	-212.1											
Br_2Pb	Lead(II) bromide	-278.7			-261.9			161.5			80.1		
Br_2Pt	Platinum(II) bromide	-82.0											
Br_2S_2	Sulfur bromide		-13.0										
Br_2Se	Selenium bromide			-21.0									
Br_2Sn	Tin(II) bromide	-243.5											
Br_2Sr	Strontium bromide	-717.6			-697.1			135.1			75.3		
Br_2Ti	Titanium(II) bromide	-402.0											
Br_2Zn	Zinc bromide	-328.7			-312.1			138.5					
Br_3ClSi	Tribromochlorosilane									377.1			95.3
Br_3Fe	Iron(III) bromide	-268.2											
Br_3Ga	Gallium(III) bromide	-386.6			-359.8			180.0					
Br_3HSi	Tribromosilane		-355.6	-317.6		-336.4	-328.5		248.1	348.6			80.8
Br_3In	Indium(III) bromide	-428.9		-282.0									
Br_3OP	Phosphorus(V) oxybromide	-458.6								359.8			89.9
Br_3P	Phosphorus(III) bromide		-184.5	-139.3		-175.7	-162.8		240.2	348.1			76.0
Br_3Pt	Platinum(III) bromide	-120.9											
Br_3Re	Rhenium(III) bromide	-167.0											
Br_3Ru	Ruthenium(III) bromide	-138.0											
Br_3Sb	Antimony(III) bromide	-259.4		-194.6	-239.3		-223.9	207.1		372.9			80.2
Br_3Sc	Scandium bromide	-743.1											
Br_3Ti	Titanium(III) bromide	-548.5			-523.8			176.6			101.7		
Br_4Ge	Germanium(IV) bromide		-347.7	-300.0		-331.4	-318.0		280.7	396.2			101.8
Br_4Pa	Protactinium(IV) bromide	-824.0			-787.8			234.0					
Br_4Pt	Platinum(IV) bromide	-156.5											
Br_4Si	Tetrabromosilane		-457.3	-415.5		-443.9	-431.8		277.8	377.9			97.1
Br_4Sn	Tin(IV) bromide	-377.4		-314.6	-350.2		-331.4	264.4		411.9			103.4
Br_4Te	Tellurium tetrabromide	-190.4											
Br_4Ti	Titanium(IV) bromide	-616.7		-549.4	-589.5		-568.2	243.5		398.4	131.5		100.8
Br_4V	Vanadium(IV) bromide			-336.8									
Br_4Zr	Zirconium(IV) bromide	-760.7											
Br_5P	Phosphorus(V) bromide	-269.9											
Br_5Ta	Tantalum(V) bromide	-598.3											
Br_6W	Tungsten(VI) bromide	-348.5											

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
Ca	Calcium	0.0		177.8			144.0	41.6		154.9	25.9		20.8
$CaCl_2$	Calcium chloride	-795.4			-748.8			108.4			72.9		
CaF_2	Calcium fluoride	-1228.0			-1175.6			68.5			67.0		
CaH_2	Calcium hydride	-181.5			-142.5			41.4			41.0		
CaH_2O_2	Calcium hydroxide	-985.2			-897.5			83.4			87.5		
CaI_2	Calcium iodide	-533.5			-528.9			142.0					
CaN_2O_6	Calcium nitrate	-938.2			-742.8			193.2			149.4		
CaO	Calcium oxide	-634.9			-603.3			38.1			42.0		
CaO_4S	Calcium sulfate	-1434.5			-1322.0			106.5			99.7		
CaS	Calcium sulfide	-482.4			-477.4			56.5			47.4		
$Ca_3O_8P_2$	Calcium phosphate	-4120.8			-3884.7			236.0			227.8		
Cd	Cadmium	0.0		111.8				51.8		167.7	26.0		20.8
$CdCl_2$	Cadmium chloride	-391.5			-343.9			115.3			74.7		
CdF_2	Cadmium fluoride	-700.4			-647.7			77.4					
CdH_2O_2	Cadmium hydroxide	-560.7			-473.6			96.0					
CdI_2	Cadmium iodide	-203.3			-201.4			161.1			80.0		
CdO	Cadmium oxide	-258.4			-228.7			54.8			43.4		
CdO_4S	Cadmium sulfate	-933.3			-822.7			123.0			99.6		
CdS	Cadmium sulfide	-161.9			-156.5			64.9					
CdTe	Cadmium telluride	-92.5			-92.0			100.0					
Ce	Cerium (γ, fcc)	0.0		423.0			385.0	72.0		191.8	26.9		23.1
$CeCl_3$	Cerium(III) chloride	-1060.5			-984.8			151.0			87.4		
CeI_3	Cerium(III) iodide	-669.3											
CeO_2	Cerium(IV) oxide	-1088.7			-1024.6			62.3			61.6		
CeS	Cerium(II) sulfide	-459.4			-451.5			78.2			50.0		
Ce_2O_3	Cerium(III) oxide	-1796.2			-1706.2			150.6			114.6		
Cf	Californium	0.0											
Cl	Chlorine (atomic)			121.3			105.3			165.2			21.8
ClCs	Cesium chloride	-443.0			-414.5			101.2			52.5		
$ClCsO_4$	Cesium perchlorate	-443.1			-314.3			175.1			108.3		
ClCu	Copper(I) chloride	-137.2			-119.9			86.2			48.5		
ClF	Chlorine fluoride			-50.3			-51.8			217.9			32.1
$ClFO_3$	Perchloryl fluoride			-23.8			48.2			279.0			64.9
ClF_3	Chlorine trifluoride		-189.5	-163.2			-123.0			281.6			63.9
ClF_5S	Sulfur chloride pentafluoride		-1065.7										
ClGe	Germanium monochloride			155.2			124.2			247.0			36.9
$ClGeH_3$	Chlorogermane									263.7			54.7
ClH	Hydrogen chloride			-92.3			-95.3			186.9			29.1
ClHO	Hypochlorous acid			-78.7			-66.1			236.7			37.2
$ClHO_4$	Perchloric acid		-40.6										
ClH_3Si	Chlorosilane									250.7			51.0
ClH_4N	Ammonium chloride	-314.4			-202.9			94.6			84.1		
ClH_4NO_4	Ammonium perchlorate	-295.3			-88.8			186.2					
ClH_4P	Phosphonium chloride	-145.2											
ClI	Iodine chloride		-23.9	17.8		-13.6	-5.5		135.1	247.6			35.6

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
ClIn	Indium(I) chloride	-186.2		-75.0									
ClK	Potassium chloride	-436.5		-214.6	-408.5		-233.3	82.6		239.1	51.3		36.5
$ClKO_3$	Potassium chlorate	-397.7			-296.3			143.1			100.3		
$ClKO_4$	Potassium perchlorate	-432.8			-303.1			151.0			112.4		
ClLi	Lithium chloride	-408.6			-384.4			59.3			48.0		
$ClLiO_4$	Lithium perchlorate	-381.0											
ClNO	Nitrosyl chloride			51.7			66.1			261.7			44.7
$ClNO_2$	Nitryl chloride			12.6			54.4			272.2			53.2
ClNa	Sodium chloride	-411.2			-384.1			72.1			50.5		
$ClNaO_2$	Sodium chlorite	-307.0											
$ClNaO_3$	Sodium chlorate	-365.8			-262.3			123.4					
$ClNaO_4$	Sodium perchlorate	-383.3			-254.9			142.3					
ClO	Chlorine monoxide			101.8			98.1			226.6			31.5
ClOV	Vanadyl chloride	-607.0			-556.0			75.0					
ClO_2	Chlorine dioxide			102.5			120.5			256.8			42.0
ClO_2	Chlorine superoxide (ClOO)			89.1			105.0			263.7			46.0
ClO_4Rb	Rubidium perchlorate	-437.2			-306.9			161.1					
ClRb	Rubidium chloride	-435.4			-407.8			95.9			52.4		
ClSi	Chlorosilylidyne			189.9									36.9
ClTl	Thallium(I) chloride	-204.1		-67.8	-184.9			111.3			50.9		
Cl_2	Chlorine			0.0						223.1			33.9
Cl_2Co	Cobalt(II) chloride	-312.5			-269.8			109.2			78.5		
Cl_2Cr	Chromium(II) chloride	-395.4			-356.0			115.3			71.2		
Cl_2CrO_2	Chromyl chloride		-579.5	-538.1		-510.8	-501.6		221.8	329.8			84.5
Cl_2Cu	Copper(II) chloride	-220.1			-175.7			108.1			71.9		
Cl_2Fe	Iron(II) chloride	-341.8			-302.3			118.0			76.7		
Cl_2H_2Si	Dichlorosilane									285.7			60.5
Cl_2Hg	Mercury(II) chloride	-224.3			-178.6			146.0					
Cl_2Hg_2	Mercury(I) chloride	-265.4			-210.7			191.6					
Cl_2Mg	Magnesium chloride	-641.3			-591.8			89.6			71.4		
Cl_2Mn	Manganese(II) chloride	-481.3			-440.5			118.2			72.9		
Cl_2Ni	Nickel(II) chloride	-305.3			-259.0			97.7			71.7		
Cl_2O	Chlorine oxide			80.3			97.9			266.2			45.4
Cl_2OS	Thionyl chloride		-245.6	-212.5			-198.3			309.8		121.0	66.5
Cl_2O_2S	Sulfuryl chloride		-394.1	-364.0			-320.0			311.9		134.0	77.0
Cl_2O_2U	Uranyl chloride	-1243.9			-1146.4			150.5			107.9		
Cl_2Pb	Lead(II) chloride	-359.4			-314.1			136.0					
Cl_2Pt	Platinum(II) chloride	-123.4											
Cl_2S	Sulfur dichloride		-50.0										
Cl_2S_2	Sulfur chloride		-59.4										
Cl_2Sn	Tin(II) chloride	-325.1											
Cl_2Sr	Strontium chloride	-828.9			-781.1			114.9			75.6		
Cl_2Ti	Titanium(II) chloride	-513.8			-464.4			87.4			69.8		
Cl_2Zn	Zinc chloride	-415.1		-266.1	-369.4			111.5			71.3		
Cl_2Zr	Zirconium(II) chloride	-502.0											

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
Cl_3Cr	Chromium(III) chloride	-556.5			-486.1			123.0			91.8		
Cl_3Dy	Dysprosium(III) chloride	-1000.0											
Cl_3Er	Erbium chloride	-998.7									100.0		
Cl_3Eu	Europium(III) chloride	-936.0											
Cl_3Fe	Iron(III) chloride	-399.5			-334.0			142.3			96.7		
Cl_3Ga	Gallium(III) chloride	-524.7			-454.8			142.0					
Cl_3Gd	Gadolinium(III) chloride	-1008.0									88.0		
Cl_3HSi	Trichlorosilane		-539.3	-513.0		-482.5	-482.0		227.6	313.9			75.8
Cl_3Ho	Holmium chloride	-1005.4									88.0		
Cl_3In	Indium(III) chloride	-537.2		-374.0									
Cl_3Ir	Iridium(III) chloride	-245.6											
Cl_3La	Lanthanum chloride	-1072.2									108.8		
Cl_3Lu	Lutetium chloride	-945.6		-649.0									
Cl_3N	Nitrogen trichloride		230.0										
Cl_3Nd	Neodymium chloride	-1041.0									113.0		
Cl_3OP	Phosphorus(V) oxychloride		-597.1	-558.5		-520.8	-512.9		222.5	325.5		138.8	84.9
Cl_3OV	Vanadyl trichloride		-734.7	-695.6		-668.5	-659.3		244.3	344.3			89.9
Cl_3Os	Osmium(III) chloride	-190.4											
Cl_3P	Phosphorus(III) chloride		-319.7	-287.0		-272.3	-267.8		217.1	311.8			71.8
Cl_3Pr	Praseodymium chloride	-1056.9									100.0		
Cl_3Pt	Platinum(III) chloride	-182.0											
Cl_3Re	Rhenium(III) chloride	-264.0			-188.0			123.8			92.4		
Cl_3Rh	Rhodium(III) chloride	-299.2											
Cl_3Ru	Ruthenium(III) chloride	-205.0											
Cl_3Sb	Antimony(III) chloride	-382.2			-323.7			184.1			107.9		
Cl_3Sc	Scandium chloride	-925.1											
Cl_3Sm	Samarium(III) chloride	-1025.9											
Cl_3Tb	Terbium chloride	-997.0											
Cl_3Ti	Titanium(III) chloride	-720.9			-653.5			139.7			97.2		
Cl_3Tl	Thallium(III) chloride	-315.1											
Cl_3Tm	Thulium chloride	-986.6											
Cl_3U	Uranium(III) chloride	-866.5			-799.1			159.0			102.5		
Cl_3V	Vanadium(III) chloride	-580.7			-511.2			131.0			93.2		
Cl_3Y	Yttrium chloride	-1000.0		-750.2									75.0
Cl_3Yb	Ytterbium(III) chloride	-959.8											
Cl_4Ge	Germanium(IV) chloride		-531.8	-495.8		-462.7	-457.3		245.6	347.7			96.1
Cl_4Hf	Hafnium(IV) chloride	-990.4		-884.5	-901.3			190.8			120.5		
Cl_4Pa	Protactinium(IV) chloride	-1043.0			-953.0			192.0					
Cl_4Pb	Lead(IV) chloride		-329.3										
Cl_4Pt	Platinum(IV) chloride	-231.8											
Cl_4Si	Tetrachlorosilane		-687.0	-657.0		-619.8	-617.0		239.7	330.7		145.3	90.3
Cl_4Sn	Tin(IV) chloride		-511.3	-471.5		-440.1	-432.2		258.6	365.8		165.3	98.3
Cl_4Te	Tellurium tetrachloride	-326.4									138.5		
Cl_4Th	Thorium(IV) chloride	-1186.2		-964.4	-1094.1		-932.0	190.4		390.7	120.3		107.5
Cl_4Ti	Titanium(IV) chloride		-804.2	-763.2		-737.2	-726.3		252.3	353.2		145.2	95.4

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
Cl_4U	Uranium(IV) chloride	-1019.2		-809.6	-930.0		-786.6	197.1		419.0	122.0		
Cl_4V	Vanadium(IV) chloride		-569.4	-525.5		-503.7	-492.0		255.0	362.4			96.2
Cl_4Zr	Zirconium(IV) chloride	-980.5			-889.9			181.6			119.8		
Cl_5Nb	Niobium(V) chloride	-797.5		-703.7	-683.2		-646.0	210.5		400.6	148.1		120.8
Cl_5P	Phosphorus(V) chloride	-443.5		-374.9			-305.0			364.6			112.8
Cl_5Pa	Protactinium(V) chloride	-1145.0			-1034.0			238.0					
Cl_5Ta	Tantalum(V) chloride	-859.0											
Cl_6U	Uranium(VI) chloride	-1092.0		-1013.0	-962.0		-928.0	285.8		431.0	175.7		
Cl_6W	Tungsten(VI) chloride	-602.5		-513.8									
Cm	Curium	0.0											
Co	Cobalt	0.0		424.7			380.3	30.0		179.5	24.8		23.0
CoF_2	Cobalt(II) fluoride	-692.0			-647.2			82.0			68.8		
CoH_2O_2	Cobalt(II) hydroxide	-539.7			-454.3			79.0					
CoI_2	Cobalt(II) iodide	-88.7											
CoN_2O_6	Cobalt(II) nitrate	-420.5											
CoO	Cobalt(II) oxide	-237.9			-214.2			53.0			55.2		
CoO_4S	Cobalt(II) sulfate	-888.3			-782.3			118.0					
CoS	Cobalt(II) sulfide	-82.8											
Co_2S_3	Cobalt(III) sulfide	-147.3											
Co_3O_4	Cobalt(II,III) oxide	-891.0			-774.0			102.5			123.4		
Cr	Chromium	0.0		396.6			351.8	23.8		174.5	23.4		20.8
CrF_2	Chromium(II) fluoride	-778.0											
CrF_3	Chromium(III) fluoride	-1159.0			-1088.0			93.9			78.7		
CrI_2	Chromium(II) iodide	-156.9											
CrI_3	Chromium(III) iodide	-205.0											
CrO_2	Chromium(IV) oxide	-598.0											
CrO_4Pb	Lead(II) chromate	-930.9											
Cr_2FeO_4	Chromium iron oxide	-1444.7			-1343.8			146.0			133.6		
Cr_2O_3	Chromium(III) oxide	-1139.7			-1058.1			81.2			118.7		
Cr_3O_4	Chromium(II,III) oxide	-1531.0											
Cs	Cesium	0.0		76.5			49.6	85.2		175.6	32.2		20.8
CsF	Cesium fluoride	-553.5			-525.5			92.8			51.1		
CsF_2H	Cesium hydrogen fluoride	-923.8			-858.9			135.2			87.3		
CsH	Cesium hydride	-54.2											
CsHO	Cesium hydroxide	-417.2											
$CsHO_4S$	Cesium hydrogen sulfate	-1158.1											
CsH_2N	Cesium amide	-118.4											
CsI	Cesium iodide	-346.6			-340.6			123.1			52.8		
$CsNO_3$	Cesium nitrate	-506.0			-406.5			155.2					
CsO_2	Cesium superoxide	-286.2											
Cs_2O	Cesium oxide	-345.8			-308.1			146.9			76.0		
Cs_2O_3S	Cesium sulfite	-1134.7											
Cs_2O_4S	Cesium sulfate	-1443.0			-1323.6			211.9			134.9		
Cs_2S	Cesium sulfide	-359.8											
Cu	Copper	0.0		337.4			297.7	33.2		166.4	24.4		20.8

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
CuF_2	Copper(II) fluoride	-542.7											
CuH_2O_2	Copper(II) hydroxide	-449.8											
CuI	Copper(I) iodide	-67.8			-69.5			96.7			54.1		
CuN_2O_6	Copper(II) nitrate	-302.9											
CuO	Copper(II) oxide	-157.3			-129.7			42.6			42.3		
CuO_4S	Copper(II) sulfate	-771.4			-662.2			109.2					
CuO_4W	Copper(II) tungstate	-1105.0											
CuS	Copper(II) sulfide	-53.1			-53.6			66.5			47.8		
CuSe	Copper(II) selenide	-39.5											
Cu_2	Dicopper			484.2			431.9			241.6			36.6
Cu_2O	Copper(I) oxide	-168.6			-146.0			93.1			63.6		
Cu_2S	Copper(I) sulfide	-79.5			-86.2			120.9			76.3		
Dy	Dysprosium	0.0		290.4			254.4	75.6		196.6	27.7		20.8
Dy_2O_3	Dysprosium(III) oxide	-1863.1			-1771.5			149.8			116.3		
Er	Erbium	0.0		317.1			280.7	73.2		195.6	28.1		20.8
ErF_3	Erbium fluoride	-1711.0											
Er_2O_3	Erbium oxide	-1897.9			-1808.7			155.6			108.5		
Es	Einsteinium	0.0											
Eu	Europium	0.0		175.3			142.2	77.8		188.8	27.7		20.8
Eu_2O_3	Europium(III) oxide	-1651.4			-1556.8			146.0			122.2		
Eu_3O_4	Europium(II,III) oxide	-2272.0			-2142.0			205.0					
F	Fluorine (atomic)			79.4			62.3			158.8			22.7
FGa	Gallium monofluoride			-251.9									33.3
FGe	Germanium monofluoride			-33.4									34.7
$FGeH_3$	Fluorogermane									252.8			51.6
FH	Hydrogen fluoride		-299.8	-273.3			-275.4			173.8			
FH_3Si	Fluorosilane									238.4			47.4
FH_4N	Ammonium fluoride	-464.0			-348.7			72.0			65.3		
FI	Iodine fluoride			-95.7			-118.5			236.2			33.4
FIn	Indium monofluoride			-203.4									
FK	Potassium fluoride	-567.3			-537.8			66.6			49.0		
FLi	Lithium fluoride	-616.0			-587.7			35.7			41.6		
FNO	Nitrosyl fluoride			-66.5			-51.0			248.1			41.3
FNO_2	Nitryl fluoride									260.4			49.8
FNS	Thionitrosyl fluoride (NSF)									259.8			44.1
FNa	Sodium fluoride	-576.6			-546.3			51.1			46.9		
FO	Fluorine monoxide			109.0			105.0			216.8			30.5
FRb	Rubidium fluoride	-557.7											
FSi	Fluorosilylidyne			7.1			-24.3			225.8			32.6
FTl	Thallium(I) fluoride	-324.7		-182.4									
F_2	Fluorine			0.0						202.8			31.3
F_2Fe	Iron(II) fluoride	-711.3			-668.6			87.0			68.1		
F_2HK	Potassium hydrogen fluoride	-927.7			-859.7			104.3			76.9		
F_2HN	Difluoramine									252.8			43.4
F_2HNa	Sodium hydrogen fluoride	-920.3			-852.2			90.9			75.0		

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
F_2HRb	Rubidium hydrogen fluoride	-922.6			-855.6			120.1			79.4		
F_2Mg	Magnesium fluoride	-1124.2			-1071.1			57.2			61.6		
F_2N	Difluoroamidogen			43.1			57.8			249.9			41.0
F_2N_2	*cis*-Difluorodiazine			69.5									
F_2N_2	*trans*-Difluorodiazine			82.0									
F_2Ni	Nickel(II) fluoride	-651.4			-604.1			73.6			64.1		
F_2O	Fluorine monoxide			24.7			41.9			247.4			43.3
F_2OS	Thionyl fluoride									278.7			56.8
F_2O_2	Fluorine dioxide			18.0									
F_2O_2S	Sulfuryl fluoride									284.0			66.0
F_2O_2U	Uranyl fluoride	-1653.5			-1557.4			135.6			103.2		
F_2Pb	Lead(II) fluoride	-664.0			-617.1			110.5					
F_2Si	Difluorosilylene			-619.0			-628.0			252.7			43.9
F_2Sr	Strontium fluoride	-1216.3			-1164.8			82.1			70.0		
F_2Zn	Zinc fluoride	-764.4			-713.3			73.7			65.7		
F_3Ga	Gallium(III) fluoride	-1163.0			-1085.3			84.0					
F_3Gd	Gadolinium(III) fluoride			-1297.0									
F_3HSi	Trifluorosilane									271.9			60.5
F_3Ho	Holmium fluoride	-1707.0											
F_3N	Nitrogen trifluoride			-132.1			-90.6			260.8			53.4
F_3Nd	Neodymium fluoride	-1657.0											
F_3OP	Phosphorus(V) oxyfluoride			-1254.3			-1205.8			285.4			68.8
F_3P	Phosphorus(III) fluoride			-958.4			-936.9			273.1			58.7
F_3Sb	Antimony(III) fluoride	-915.5											
F_3Sc	Scandium fluoride	-1629.2		-1247.0	-1555.6		-1234.0	92.0		300.5			67.8
F_3Sm	Samarium(III) fluoride	-1778.0											
F_3Th	Thorium(III) fluoride			-1166.1			-1160.6			339.2			73.3
F_3U	Uranium(III) fluoride	-1502.1		-1058.5	-1433.4		-1051.9	123.4		331.9	95.1		74.3
F_3Y	Yttrium fluoride	-1718.8		-1288.7	-1644.7		-1277.8	100.0		311.8			70.3
F_4Ge	Germanium(IV) fluoride			-1190.2			-1150.0			301.9			
F_4Hf	Hafnium fluoride	-1930.5		-1669.8	-1830.4			113.0					
F_4N_2	Tetrafluorohydrazine			-8.4			79.9			301.2			79.2
F_4Pb	Lead(IV) fluoride	-941.8											
F_4S	Sulfur tetrafluoride			-763.2			-722.0			299.6			77.6
F_4Si	Tetrafluorosilane			-1615.0			-1572.8			282.8			73.6
F_4Th	Thorium(IV) fluoride	-2097.8		-1759.0	-2003.4		-1724.0	142.0		341.7	110.7		93.0
F_4U	Uranium(IV) fluoride	-1914.2		-1598.7	-1823.3		-1572.7	151.7		368.0	116.0		91.2
F_4V	Vanadium(IV) fluoride	-1403.3											
F_4Xe	Xenon tetrafluoride	-261.5											
F_4Zr	Zirconium(IV) fluoride	-1911.3			-1809.9			104.6			103.7		
F_5I	Iodine pentafluoride		-864.8	-822.5			-751.7			327.7			99.2
F_5Nb	Niobium(V) fluoride	-1813.8		-1739.7	-1699.0		-1673.6	160.2		321.9	134.7		97.1
F_5P	Phosphorus(V) fluoride			-1594.4			-1520.7			300.8			84.8
F_5Ta	Tantalum(V) fluoride	-1903.6											
F_5V	Vanadium(V) fluoride		-1480.3	-1433.9		-1373.1	-1369.8		175.7	320.9			98.6

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
$F_6H_8N_2Si$	Ammonium hexafluorosilicate	-2681.7			-2365.3			280.2			228.1		
F_6Ir	Iridium(VI) fluoride	-579.7		-544.0	-461.6		-460.0	247.7		357.8			121.1
F_6K_2Si	Potassium hexafluorosilicate	-2956.0			-2798.6			226.0					
F_6Mo	Molybdenum(VI) fluoride		-1585.5	-1557.7		-1473.0	-1472.2		259.7	350.5		169.8	120.6
F_6Na_2Si	Sodium hexafluorosilicate	-2909.6			-2754.2			207.1			187.1		
F_6Os	Osmium(VI) fluoride							246.0		358.1			120.8
F_6Pt	Platinum(VI) fluoride							235.6		348.3			122.8
F_6S	Sulfur hexafluoride			-1220.5			-1116.5			291.5			97.0
F_6Se	Selenium hexafluoride			-1117.0			-1017.0			313.9			110.5
F_6Te	Tellurium hexafluoride			-1318.0									
F_6U	Uranium(VI) fluoride	-2197.0		-2147.4	-2068.5		-2063.7	227.6		377.9	166.8		129.6
F_6W	Tungsten(VI) fluoride		-1747.7	-1721.7		-1631.4	-1632.1		251.5	341.1			119.0
Fe	Iron	0.0		416.3			370.7	27.3		180.5	25.1		25.7
FeI_2	Iron(II) iodide	-113.0											
FeI_3	Iron(III) iodide			71.0									
$FeMoO_4$	Iron(II) molybdate	-1075.0			-975.0			129.3			118.5		
FeO	Iron(II) oxide	-272.0											
FeO_4S	Iron(II) sulfate	-928.4			-820.8			107.5			100.6		
FeO_4W	Iron(II) tungstate	-1155.0			-1054.0			131.8			114.6		
FeS	Iron(II) sulfide	-100.0			-100.4			60.3			50.5		
FeS_2	Iron disulfide	-178.2			-166.9			52.9			62.2		
Fe_2O_3	Iron(III) oxide	-824.2			-742.2			87.4			103.9		
Fe_2O_4Si	Iron(II) orthosilicate	-1479.9			-1379.0			145.2			132.9		
Fe_3O_4	Iron(II,III) oxide	-1118.4			-1015.4			146.4			143.4		
Fm	Fermium	0.0											
Fr	Francium	0.0						95.4					
Ga	Gallium	0.0	5.6	272.0	0.0		233.7	40.8		169.0	26.1		25.3
GaH_3O_3	Gallium(III) hydroxide	-964.4			-831.3			100.0					
GaI_3	Gallium(III) iodide	-238.9						205.0			100.0		
GaN	Gallium nitride	-110.5											
GaO	Gallium monoxide			279.5			253.5			231.1			32.1
GaP	Gallium phosphide	-88.0											
GaSb	Gallium antimonide	-41.8			-38.9			76.1			48.5		
Ga_2	Digallium			438.5									
Ga_2O	Gallium suboxide	-356.0											
Ga_2O_3	Gallium(III) oxide	-1089.1			-998.3			85.0			92.1		
Gd	Gadolinium	0.0		397.5			359.8	68.1		194.3	37.0		27.5
Gd_2O_3	Gadolinium(III) oxide	-1819.6									106.7		
Ge	Germanium	0.0		372.0			331.2	31.1		167.9	23.3		30.7
GeH_3I	Iodogermane									283.2			57.5
GeH_4	Germane			90.8			113.4			217.1			45.0
GeI_4	Germanium(IV) iodide	-141.8		-56.9	-144.3		-106.3	271.1		428.9			104.1
GeO	Germanium(II) oxide	-261.9		-46.2	-237.2		-73.2	50.0		224.3			30.9
GeO_2	Germanium(IV) oxide	-580.0			-521.4			39.7			52.1		

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
GeP	Germanium phosphide	-21.0			-17.0			63.0					
GeS	Germanium(II) sulfide	-69.0		92.0	-71.5		42.0	71.0		234.0			33.7
GeTe	Germanium(II) telluride	20.0											
Ge_2	Digermanium			473.1			416.3			252.8			35.6
Ge_2H_6	Digermane		137.3	162.3									
Ge_3H_8	Trigermane		193.7	226.8									
H	Hydrogen (atomic)			218.0			203.3			114.7			20.8
HI	Hydrogen iodide			26.5			1.7			206.6			29.2
HIO_3	Iodic acid	-230.1											
HK	Potassium hydride	-57.7											
HKO	Potassium hydroxide	-424.6		-228.0	-378.7		-229.7	78.9		238.3	64.9		49.2
HKO_4S	Potassium hydrogen sulfate	-1160.6			-1031.3			138.1					
HLi	Lithium hydride	-90.5			-68.3			20.0			27.9		
HLiO	Lithium hydroxide	-484.9			-439.0			42.8			49.7		
HN	Imidogen			351.5			345.6			181.2			29.2
HNO_2	Nitrous acid			-79.5			-46.0			254.1			45.6
HNO_3	Nitric acid		-174.1	-133.9		-80.7	-73.5		155.6	266.9		109.9	54.1
HN_3	Hydrazoic acid		264.0	294.1		327.3	328.1		140.6	239.0			43.7
HNa	Sodium hydride	-56.3			-33.5			40.0			36.4		
HNaO	Sodium hydroxide	-425.6			-379.5			64.5			59.5		
$HNaO_4S$	Sodium hydrogen sulfate	-1125.5			-992.8			113.0					
HNa_2O_4P	Sodium hydrogen phosphate	-1748.1			-1608.2			150.5			135.3		
HO	Hydroxyl			39.0			34.2			183.7			29.9
HORb	Rubidium hydroxide	-418.2											
HOTl	Thallium(I) hydroxide	-238.9			-195.8			88.0					
HO_2	Hydroperoxy			10.5			22.6			229.0			34.9
HO_3P	Metaphosphoric acid	-948.5											
HO_4RbS	Rubidium hydrogen sulfate	-1159.0											
HO_4Re	Perrhenic acid	-762.3			-656.4			158.2					
HRb	Rubidium hydride	-52.3											
HS	Mercapto			142.7			113.3			195.7			32.3
HSi	Silylidyne			361.0									
HTa_2	Tantalum hydride	-32.6			-69.0			79.1			90.8		
H_2	Hydrogen			0.0						130.7			28.8
H_2KN	Potassium amide	-128.9											
H_2KO_4P	Potassium dihydrogen phosphate	-1568.3			-1415.9			134.9			116.6		
H_2LiN	Lithium amide	-179.5											
H_2Mg	Magnesium hydride	-75.3			-35.9			31.1			35.4		
H_2MgO_2	Magnesium hydroxide	-924.5			-833.5			63.2			77.0		
H_2N	Amidogen			184.9			194.6			195.0			33.9
H_2NNa	Sodium amide	-123.8			-64.0			76.9			66.2		
H_2NRb	Rubidium amide	-113.0											
$H_2N_2O_2$	Nitramide	-89.5											
H_2NiO_2	Nickel(II) hydroxide	-529.7			-447.2			88.0					

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
H_2O	Water		-285.8	-241.8		-237.1	-228.6		70.0	188.8		75.3	33.6
H_2O_2	Hydrogen peroxide		-187.8	-136.3		-120.4	-105.6		109.6	232.7		89.1	43.1
H_2O_2Sn	Tin(II) hydroxide	-561.1			-491.6			155.0					
H_2O_2Sr	Strontium hydroxide	-959.0											
H_2O_2Zn	Zinc hydroxide	-641.9			-553.5			81.2					
H_2O_3Si	Metasilicic acid	-1188.7			-1092.4			134.0					
H_2O_4S	Sulfuric acid		-814.0			-690.0			156.9			138.9	
H_2O_4Se	Selenic acid	-530.1											
H_2S	Hydrogen sulfide			-20.6			-33.4			205.8			34.2
H_2S_2	Hydrogen disulfide		-18.1	15.5								84.1	51.5
H_2Se	Hydrogen selenide			29.7			15.9			219.0			34.7
H_2Sr	Strontium hydride	-180.3											
H_2Te	Hydrogen telluride			99.6									
H_2Th	Thorium hydride	-139.7			-100.0			50.7			36.7		
H_2Zr	Zirconium(II) hydride	-169.0			-128.8			35.0			31.0		
H_3ISi	Iodosilane									270.9			54.4
H_3N	Ammonia			-45.9			-16.4			192.8			35.1
H_3NO	Hydroxylamine	-114.2											
H_3O_2P	Hypophosphorous acid	-604.6	-595.4										
H_3O_3P	Phosphorous acid	-964.4											
H_3O_4P	Phosphoric acid (orthophosphoric acid)	-1284.4	-1271.7		-1124.3	-1123.6		110.5	150.8		106.1	145.0	
H_3P	Phosphine			5.4			13.4			210.2			37.1
H_3Sb	Stibine			145.1			147.8			232.8			41.1
H_3U	Uranium(III) hydride	-127.2			-72.8			63.7			49.3		
H_4IN	Ammonium iodide	-201.4			-112.5			117.0					
H_4N_2	Hydrazine		50.6	95.4		149.3	159.4		121.2	238.5		98.9	48.4
$H_4N_2O_2$	Ammonium nitrite	-256.5											
$H_4N_2O_3$	Ammonium nitrate	-365.6			-183.9			151.1			139.3		
H_4N_4	Ammonium azide	115.5			274.2			112.5					
H_4O_4Si	Orthosilicic acid	-1481.1			-1332.9			192.0					
$H_4O_7P_2$	Pyrophosphoric acid	-2241.0	-2231.7										
H_4P_2	Diphosphine		-5.0	20.9									
H_4Si	Silane			34.3			56.9			204.6			42.8
H_4Sn	Stannane			162.8			188.3			227.7			49.0
H_5NO	Ammonium hydroxide		-361.2			-254.0			165.6			154.9	
H_5NO_3S	Ammonium hydrogen sulfite	-768.6											
H_5NO_4S	Ammonium hydrogen sulfate	-1027.0											
H_6Si_2	Disilane			80.3			127.3			272.7			80.8
$H_8N_2O_4S$	Ammonium sulfate	-1180.9			-901.7			220.1			187.5		
H_8Si_3	Trisilane		92.5	120.9									
$H_9N_2O_4P$	Diammonium hydrogen phosphate	-1566.9									188.0		
$H_{12}N_3O_4P$	Ammonium phosphate	-1671.9											
He	Helium			0.0						126.2			20.8

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
Hf	Hafnium	0.0		619.2			576.5	43.6		186.9	25.7		20.8
HfO_2	Hafnium oxide	-1144.7			-1088.2			59.3			60.3		
Hg	Mercury		0.0	61.4			31.8		75.9	175.0		28.0	20.8
HgI_2	Mercury(II) iodide	-105.4			-101.7			180.0					
HgO	Mercury(II) oxide	-90.8			-58.5			70.3			44.1		
HgO_4S	Mercury(II) sulfate	-707.5											
HgS	Mercury(II) sulfide	-58.2			-50.6			82.4			48.4		
HgTe	Mercury(II) telluride	-42.0											
Hg_2	Dimercury			108.8			68.2			288.1			37.4
Hg_2I_2	Mercury(I) iodide	-121.3			-111.0			233.5					
Hg_2O_4S	Mercury(I) sulfate	-743.1			-625.8			200.7			132.0		
Ho	Holmium	0.0		300.8			264.8	75.3		195.6	27.2		20.8
Ho_2O_3	Holmium oxide	-1880.7			-1791.1			158.2			115.0		
I	Iodine (atomic)			106.8			70.2			180.8			20.8
IIn	Indium(I) iodide	-116.3		7.5	-120.5		-37.7	130.0		267.3			36.8
IK	Potassium iodide	-327.9			-324.9			106.3			52.9		
IKO_3	Potassium iodate	-501.4			-418.4			151.5			106.5		
IKO_4	Potassium periodate	-467.2			-361.4			175.7					
ILi	Lithium iodide	-270.4			-270.3			86.8			51.0		
INa	Sodium iodide	-287.8			-286.1			98.5			52.1		
$INaO_3$	Sodium iodate	-481.8									92.0		
$INaO_4$	Sodium periodate	-429.3			-323.0			163.0					
IO	Iodine monoxide			175.1			149.8			245.5			32.9
IRb	Rubidium iodide	-333.8			-328.9			118.4			53.2		
ITl	Thallium(I) iodide	-123.8		7.1	-125.4			127.6					
I_2	Iodine (rhombic)	0.0		62.4			19.3	116.1		260.7	54.4		36.9
I_2Mg	Magnesium iodide	-364.0			-358.2			129.7					
I_2Ni	Nickel(II) iodide	-78.2											
I_2Pb	Lead(II) iodide	-175.5			-173.6			174.9			77.4		
I_2Sn	Tin(II) iodide	-143.5											
I_2Sr	Strontium iodide	-558.1									81.6		
I_2Zn	Zinc iodide	-208.0			-209.0			161.1					
I_3In	Indium(III) iodide	-238.0		-120.5									
I_3La	Lanthanum iodide	-668.9											
I_3Lu	Lutetium iodide	-548.0											
I_3P	Phosphorus(III) iodide	-45.6								374.4			78.4
I_3Ru	Ruthenium(III) iodide	-65.7											
I_3Sb	Antimony(III) iodide	-100.4											
I_4Pt	Platinum(IV) iodide	-72.8											
I_4Si	Tetraiodosilane	-189.5											
I_4Sn	Tin(IV) iodide									446.1	84.9		105.4
I_4Ti	Titanium(IV) iodide	-375.7		-277.8	-371.5			249.4			125.7		
I_4V	Vanadium(IV) iodide			-122.6									
I_4Zr	Zirconium(IV) iodide	-481.6											
In	Indium	0.0		243.3			208.7	57.8		173.8	26.7		20.8

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
InO	Indium monoxide			387.0			364.4			236.5			32.6
InP	Indium phosphide	-88.7			-77.0			59.8			45.4		
InS	Indium(II) sulfide	-138.1		238.0	-131.8			67.0					
InSb	Indium antimonide	-30.5		344.3	-25.5			86.2			49.5		
In_2	Diindium			380.9									
In_2O_3	Indium(III) oxide	-925.8			-830.7			104.2			92.0		
In_2S_3	Indium(III) sulfide	-427.0			-412.5			163.6			118.0		
Ir	Iridium	0.0		665.3			617.9	35.5		193.6	25.1		20.8
IrO_2	Iridium(IV) oxide	-274.1									57.3		
IrS_2	Iridium(IV) sulfide	-138.0											
Ir_2S_3	Iridium(III) sulfide	-234.0											
K	Potassium	0.0		89.0			60.5	64.7		160.3	29.6		20.8
$KMnO_4$	Potassium permanganate	-837.2			-737.6			171.7			117.6		
KNO_2	Potassium nitrite	-369.8			-306.6			152.1			107.4		
KNO_3	Potassium nitrate	-494.6			-394.9			133.1			96.4		
KNa	Potassium sodium		6.3										
KO_2	Potassium superoxide	-284.9			-239.4			116.7			77.5		
K_2	Dipotassium			123.7			87.5			249.7			37.9
K_2O	Potassium oxide	-361.5											
K_2O_2	Potassium peroxide	-494.1			-425.1			102.1					
K_2O_4S	Potassium sulfate	-1437.8			-1321.4			175.6			131.5		
K_2S	Potassium sulfide	-380.7			-364.0			105.0					
K_3O_4P	Potassium phosphate	-1950.2											
Kr	Krypton			0.0						164.1			20.8
La	Lanthanum	0.0		431.0			393.6	56.9		182.4	27.1		22.8
LaS	Lanthanum sulfide	-456.0			-451.5			73.2			59.0		
La_2O_3	Lanthanum oxide	-1793.7			-1705.8			127.3			108.8		
Li	Lithium	0.0		159.3			126.6	29.1		138.8	24.8		20.8
$LiNO_2$	Lithium nitrite	-372.4			-302.0			96.0					
$LiNO_3$	Lithium nitrate	-483.1			-381.1			90.0					
Li_2	Dilithium			215.9			174.4			197.0			36.1
Li_2O	Lithium oxide	-597.9			-561.2			37.6			54.1		
Li_2O_2	Lithium peroxide	-634.3											
Li_2O_3Si	Lithium metasilicate	-1648.1			-1557.2			79.8			99.1		
Li_2O_4S	Lithium sulfate	-1436.5			-1321.7			115.1			117.6		
Li_2S	Lithium sulfide	-441.4											
Li_3O_4P	Lithium phosphate	-2095.8											
Lr	Lawrencium	0.0											
Lu	Lutetium	0.0		427.6			387.8	51.0		184.8	26.9		20.9
Lu_2O_3	Lutetium oxide	-1878.2			-1789.0			110.0			101.8		
Md	Mendelevium	0.0											
Mg	Magnesium	0.0		147.1			112.5	32.7		148.6	24.9		20.8
MgN_2O_6	Magnesium nitrate	-790.7			-589.4			164.0			141.9		
MgO	Magnesium oxide	-601.6			-569.3			27.0			37.2		
MgO_4S	Magnesium sulfate	-1284.9			-1170.6			91.6			96.5		

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
MgO_4Se	Magnesium selenate	-968.5											
MgS	Magnesium sulfide	-346.0			-341.8			50.3			45.6		
Mg_2	Dimagnesium			287.7									
Mg_2O_4Si	Magnesium orthosilicate	-2174.0			-2055.1			95.1			118.5		
Mn	Manganese	0.0		280.7			238.5	32.0		173.7	26.3		20.8
MnN_2O_6	Manganese(II) nitrate	-576.3											
$MnNa_2O_4$	Sodium permanganate	-1156.0											
MnO	Manganese(II) oxide	-385.2			-362.9			59.7			45.4		
MnO_2	Manganese(IV) oxide	-520.0			-465.1			53.1			54.1		
MnO_3Si	Manganese(II) metasilicate	-1320.9			-1240.5			89.1			86.4		
MnS	Manganese(II) sulfide	-214.2			-218.4			78.2			50.0		
$MnSe$	Manganese(II) selenide	-106.7			-111.7			90.8			51.0		
Mn_2O_3	Manganese(III) oxide	-959.0			-881.1			110.5			107.7		
Mn_2O_4Si	Manganese(II) orthosilicate	-1730.5			-1632.1			163.2			129.9		
Mn_3O_4	Manganese(II,III) oxide	-1387.8			-1283.2			155.6			139.7		
Mo	Molybdenum	0.0		658.1			612.5	28.7		182.0	24.1		20.8
$MoNa_2O_4$	Sodium molybdate	-1468.1			-1354.3			159.7			141.7		
MoO_2	Molybdenum(IV) oxide	-588.9			-533.0			46.3			56.0		
MoO_3	Molybdenum(VI) oxide	-745.1			-668.0			77.7			75.0		
MoO_4Pb	Lead(II) molybdate	-1051.9			-951.4			166.1			119.7		
MoS_2	Molybdenum(IV) sulfide	-235.1			-225.9			62.6			63.6		
N	Nitrogen (atomic)			472.7			455.5			153.3			20.8
$NNaO_2$	Sodium nitrite	-358.7			-284.6			103.8					
$NNaO_3$	Sodium nitrate	-467.9			-367.0			116.5			92.9		
NO	Nitric oxide			91.3			87.6			210.8			29.9
NO_2	Nitrogen dioxide			33.2			51.3			240.1			37.2
NO_2Rb	Rubidium nitrite	-367.4			-306.2			172.0					
NO_3Rb	Rubidium nitrate	-495.1			-395.8			147.3			102.1		
NO_3Tl	Thallium(I) nitrate	-243.9			-152.4			160.7			99.5		
NP	Phosphorus nitride	-63.0											
N_2	Nitrogen			0.0						191.6			29.1
N_2O	Nitrous oxide			81.6			103.7			220.0			38.6
N_2O_3	Nitrogen trioxide		50.3	86.6			142.4			314.7			72.7
N_2O_4	Nitrogen tetroxide		-19.5	11.1		97.5	99.8		209.2	304.4		142.7	79.2
N_2O_4Sr	Strontium nitrite	-762.3											
N_2O_5	Nitrogen pentoxide	-43.1		13.3	113.9		117.1	178.2		355.7	143.1		95.3
N_2O_6Pb	Lead(II) nitrate	-451.9											
N_2O_6Ra	Radium nitrate	-992.0			-796.1			222.0					
N_2O_6Sr	Strontium nitrate	-978.2			-780.0			194.6			149.9		
N_2O_6Zn	Zinc nitrate	-483.7											
N_3Na	Sodium azide	21.7			93.8			96.9			76.6		
N_4Si_3	Silicon nitride	-743.5			-642.6			101.3					
Na	Sodium	0.0		107.5			77.0	51.3		153.7	28.2		20.8
NaO_2	Sodium superoxide	-260.2			-218.4			115.9			72.1		
Na_2	Disodium			142.1			103.9			230.2			37.6

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
Na_2O	Sodium oxide	-414.2			-375.5			75.1			69.1		
Na_2O_2	Sodium peroxide	-510.9			-447.7			95.0			89.2		
Na_2O_3S	Sodium sulfite	-1100.8			-1012.5			145.9			120.3		
Na_2O_3Si	Sodium metasilicate	-1554.9			-1462.8			113.9					
Na_2O_4S	Sodium sulfate	-1387.1			-1270.2			149.6			128.2		
Na_2S	Sodium sulfide	-364.8			-349.8			83.7					
Nb	Niobium	0.0		725.9			681.1	36.4		186.3	24.6		30.2
NbO	Niobium(II) oxide	-405.8			-378.6			48.1			41.3		
NbO_2	Niobium(IV) oxide	-796.2			-740.5			54.5			57.5		
Nb_2O_5	Niobium(V) oxide	-1899.5			-1766.0			137.2			132.1		
Nd	Neodymium	0.0		327.6			292.4	71.5		189.4	27.5		22.1
Nd_2O_3	Neodymium oxide	-1807.9			-1720.8			158.6			111.3		
Ne	Neon			0.0						146.3			20.8
Ni	Nickel	0.0		429.7			384.5	29.9		182.2	26.1		23.4
NiO_4S	Nickel(II) sulfate	-872.9			-759.7			92.0			138.0		
NiS	Nickel(II) sulfide	-82.0			-79.5			53.0			47.1		
Ni_2O_3	Nickel(III) oxide	-489.5											
No	Nobelium	0.0											
O	Oxygen (atomic)			249.2			231.7			161.1			21.9
OP	Phosphorus monoxide			-28.5			-51.9			222.8			31.8
OPb	Lead(II) oxide (massicot)	-217.3			-187.9			68.7			45.8		
OPb	Lead(II) oxide (litharge)	-219.0			-188.9			66.5			45.8		
OPd	Palladium(II) oxide	-85.4		348.9			325.9			218.0	31.4		
ORa	Radium oxide	-523.0											
ORb_2	Rubidium oxide	-339.0											
ORh	Rhodium monoxide			385.0									
OS	Sulfur monoxide			6.3			-19.9			222.0			30.2
OSe	Selenium monoxide			53.4			26.8			234.0			31.3
OSi	Silicon monoxide			-99.6			-126.4			211.6			29.9
OSn	Tin(II) oxide	-280.7		15.1	-251.9		-8.4	57.2		232.1	44.3		31.6
OSr	Strontium oxide	-592.0			-561.9			54.4			45.0		
OTi	Titanium(II) oxide	-519.7			-495.0			50.0			40.0		
OTl_2	Thallium(I) oxide	-178.7			-147.3			126.0					
OU	Uranium(II) oxide			21.0									
OV	Vanadium(II) oxide	-431.8			-404.2			38.9			45.4		
OZn	Zinc oxide	-350.5			-320.5			43.7			40.3		
O_2	Oxygen			0.0						205.2			29.4
O_2P	Phosphorus dioxide			-279.9			-281.6			252.1			39.5
O_2Pb	Lead(IV) oxide	-277.4			-217.3			68.6			64.6		
O_2Rb	Rubidium superoxide	-278.7											
O_2Rb_2	Rubidium peroxide	-472.0											
O_2Ru	Ruthenium(IV) oxide	-305.0											
O_2S	Sulfur dioxide		-320.5	-296.8			-300.1			248.2			39.9
O_2Se	Selenium dioxide	-225.4											
O_2Si	Silicon dioxide (α-quartz)	-910.7		-322.0	-856.3			41.5			44.4		

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O_2Sn	Tin(IV) oxide	-577.6			-515.8			49.0			52.6		
O_2Te	Tellurium dioxide	-322.6			-270.3			79.5					
O_2Th	Thorium(IV) oxide	-1226.4			-1169.2			65.2			61.8		
O_2Ti	Titanium(IV) oxide	-944.0			-888.8			50.6			55.0		
O_2U	Uranium(IV) oxide	-1085.0		-465.7	-1031.8		-471.5	77.0		274.6	63.6		51.4
O_2W	Tungsten(IV) oxide	-589.7			-533.9			50.5			56.1		
O_2Zr	Zirconium(IV) oxide	-1100.6			-1042.8			50.4			56.2		
O_3	Ozone			142.7			163.2			238.9			39.2
O_3PbS	Lead(II) sulfite	-669.9											
O_3PbSi	Lead(II) metasilicate	-1145.7			-1062.1			109.6			90.0		
O_3Pr_2	Praseodymium oxide	-1809.6									117.4		
O_3Rh_2	Rhodium(III) oxide	-343.0									103.8		
O_3S	Sulfur trioxide	-454.5	-441.0	-395.7	-374.2	-373.8	-371.1	70.7	113.8	256.8			50.7
O_3Sc_2	Scandium oxide	-1908.8			-1819.4			77.0			94.2		
O_3SiSr	Strontium metasilicate	-1633.9			-1549.7			96.7			88.5		
O_3Sm_2	Samarium(III) oxide	-1823.0			-1734.6			151.0			114.5		
O_3Tb_2	Terbium oxide	-1865.2									115.9		
O_3Ti_2	Titanium(III) oxide	-1520.9			-1434.2			78.8			97.4		
O_3Tm_2	Thulium oxide	-1888.7			-1794.5			139.7			116.7		
O_3U	Uranium(VI) oxide	-1223.8			-1145.7			96.1			81.7		
O_3V_2	Vanadium(III) oxide	-1218.8			-1139.3			98.3			103.2		
O_3W	Tungsten(VI) oxide	-842.9			-764.0			75.9			73.8		
O_3Y_2	Yttrium oxide	-1905.3			-1816.6			99.1			102.5		
O_3Yb_2	Ytterbium(III) oxide	-1814.6			-1726.7			133.1			115.4		
O_4Os	Osmium(VIII) oxide	-394.1		-337.2	-304.9		-292.8	143.9		293.8			74.1
O_4PbS	Lead(II) sulfate	-920.0			-813.0			148.5			103.2		
O_4PbSe	Lead(II) selenate	-609.2			-504.9			167.8					
O_4Pb_2Si	Lead(II) orthosilicate	-1363.1			-1252.6			186.6			137.2		
O_4Pb_3	Lead(II,II,IV) oxide	-718.4			-601.2			211.3			146.9		
O_4RaS	Radium sulfate	-1471.1			-1365.6			138.0					
O_4Rb_2S	Rubidium sulfate	-1435.6			-1316.9			197.4			134.1		
O_4Ru	Ruthenium(VIII) oxide	-239.3			-152.2			146.4					
O_4SSr	Strontium sulfate	-1453.1			-1340.9			117.0					
O_4STl_2	Thallium(I) sulfate	-931.8			-830.4			230.5					
O_4SZn	Zinc sulfate	-982.8			-871.5			110.5			99.2		
O_4SiSr_2	Strontium orthosilicate	-2304.5			-2191.1			153.1			134.3		
O_4SiZn_2	Zinc orthosilicate	-1636.7			-1523.2			131.4			123.3		
O_4SiZr	Zirconium(IV) orthosilicate	-2033.4			-1919.1			84.1			98.7		
O_5Sb_2	Antimony(V) oxide	-971.9			-829.2			125.1					
O_5Ta_2	Tantalum(V) oxide	-2046.0			-1911.2			143.1			135.1		
O_5Ti_3	Titanium(III,IV) oxide	-2459.4			-2317.4			129.3			154.8		
O_5V_2	Vanadium(V) oxide	-1550.6			-1419.5			131.0			127.7		
O_5V_3	Vanadium(III,IV) oxide	-1933.0			-1803.0			163.0					
O_7Re_2	Rhenium(VII) oxide	-1240.1		-1100.0	-1066.0		-994.0	207.1		452.0	166.1		
O_7U_3	Uranium(IV,VI) oxide	-3427.1			-3242.9			250.5			215.5		

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O_8S_2Zr	Zirconium(IV) sulfate	-2217.1									172.0		
O_8U_3	Uranium(V,VI) oxide	-3574.8			-3369.5			282.6			238.4		
O_9U_4	Uranium(IV,V) oxide	-4510.4			-4275.1			334.1			293.3		
Os	Osmium	0.0		791.0			745.0	32.6		192.6	24.7		20.8
P	Phosphorus (white)	0.0		316.5			280.1	41.1		163.2	23.8		20.8
P	Phosphorus (red)	-17.6						22.8			21.2		
P	Phosphorus (black)	-39.3											
P_2	Diphosphorus			144.0			103.5			218.1			32.1
P_4	Tetraphosphorus			58.9			24.4			280.0			67.2
Pa	Protactinium	0.0		607.0			563.0	51.9		198.1			22.9
Pb	Lead	0.0		195.2			162.2	64.8		175.4	26.4		20.8
PbS	Lead(II) sulfide	-100.4			-98.7			91.2			49.5		
PbSe	Lead(II) selenide	-102.9			-101.7			102.5			50.2		
PbTe	Lead(II) telluride	-70.7			-69.5			110.0			50.5		
Pd	Palladium	0.0		378.2			339.7	37.6		167.1	26.0		20.8
PdS	Palladium(II) sulfide	-75.0			-67.0			46.0					
Pm	Promethium	0.0								187.1			24.3
Po	Polonium	0.0											
Pr	Praseodymium	0.0		355.6			320.9	73.2		189.8	27.2		21.4
Pt	Platinum	0.0		565.3			520.5	41.6		192.4	25.9		25.5
PtS	Platinum(II) sulfide	-81.6			-76.1			55.1			43.4		
PtS_2	Platinum(IV) sulfide	-108.8			-99.6			74.7			65.9		
Pu	Plutonium	0.0											
Ra	Radium	0.0		159.0			130.0	71.0		176.5			20.8
Rb	Rubidium	0.0		80.9			53.1	76.8		170.1	31.1		20.8
Re	Rhenium	0.0		769.9			724.6	36.9		188.9	25.5		20.8
Rh	Rhodium	0.0		556.9			510.8	31.5		185.8	25.0		21.0
Rn	Radon			0.0						176.2			20.8
Ru	Ruthenium	0.0		642.7			595.8	28.5		186.5	24.1		21.5
S	Sulfur (rhombic)	0.0		277.2			236.7	32.1		167.8	22.6		23.7
S	Sulfur (monoclinic)	0.3											
SSi	Silicon monosulfide			112.5			60.9			223.7			32.3
SSn	Tin(II) sulfide	-100.0			-98.3			77.0			49.3		
SSr	Strontium sulfide	-472.4			-467.8			68.2			48.7		
STl_2	Thallium(I) sulfide	-97.1			-93.7			151.0					
SZn	Zinc sulfide (wurtzite)	-192.6											
SZn	Zinc sulfide (sphalerite)	-206.0			-201.3			57.7			46.0		
S_2	Disulfur			128.6			79.7			228.2			32.5
Sb	Antimony	0.0		262.3			222.1	45.7		180.3	25.2		20.8
Sb_2	Diantimony			235.6			187.0			254.9			36.4
Sc	Scandium	0.0		377.8			336.0	34.6		174.8	25.5		22.1
Se	Selenium	0.0		227.1			187.0	42.4		176.7	25.4		20.8
SeSr	Strontium selenide	-385.8											
$SeTl_2$	Thallium(I) selenide	-59.0			-59.0			172.0					
SeZn	Zinc selenide	-163.0			-163.0			84.0					

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Se_2	Diselenium			146.0			96.2			252.0			35.4
Si	Silicon	0.0		450.0			405.5	18.8		168.0	20.0		22.3
Si_2	Disilicon			594.0			536.0			229.9			34.4
Sm	Samarium	0.0		206.7			172.8	69.6		183.0	29.5		30.4
Sn	Tin (white)	0.0		301.2			266.2	51.2		168.5	27.0		21.3
Sn	Tin (gray)	-2.1			0.1			44.1			25.8		
Sr	Strontium	0.0		164.4			130.9	55.0		164.6	26.8		20.8
Ta	Tantalum	0.0		782.0			739.3	41.5		185.2	25.4		20.9
Tb	Terbium	0.0		388.7			349.7	73.2		203.6	28.9		24.6
Tc	Technetium	0.0		678.0						181.1			20.8
Te	Tellurium	0.0		196.7			157.1	49.7		182.7	25.7		20.8
Te_2	Ditellurium			168.2			118.0			268.1			36.7
Th	Thorium	0.0		602.0			560.7	51.8		190.2	27.3		20.8
Ti	Titanium	0.0		473.0			428.4	30.7		180.3	25.0		24.4
Tl	Thallium	0.0		182.2			147.4	64.2		181.0	26.3		20.8
Tm	Thulium	0.0		232.2			197.5	74.0		190.1	27.0		20.8
U	Uranium	0.0		533.0			488.4	50.2		199.8	27.7		23.7
V	Vanadium	0.0		514.2			754.4	28.9		182.3	24.9		26.0
W	Tungsten	0.0		849.4			807.1	32.6		174.0	24.3		21.3
Xe	Xenon			0.0						169.7			20.8
Y	Yttrium	0.0		421.3			381.1	44.4		179.5	26.5		25.9
Yb	Ytterbium	0.0		152.3			118.4	59.9		173.1	26.7		20.8
Zn	Zinc	0.0		130.4			94.8	41.6		161.0	25.4		20.8
Zr	Zirconium	0.0		608.8			566.5	39.0		181.4	25.4		26.7
C	Carbon (graphite)	0.0		716.7			671.3	5.7		158.1	8.5		20.8
C	Carbon (diamond)	1.9			2.9			2.4			6.1		
CAgN	Silver(I) cyanide	146.0			156.9			107.2			66.7		
CAg_2O_3	Silver(I) carbonate	-505.8			-436.8			167.4			112.3		
$CBaO_3$	Barium carbonate	-1213.0			-1134.4			112.1			86.0		
$CBeO_3$	Beryllium carbonate	-1025.0						52.0			65.0		
$CBrClF_2$	Bromochlorodifluoromethane									318.5			74.6
$CBrCl_2F$	Bromodichlorofluoromethane									330.6			80.0
$CBrCl_3$	Bromotrichloromethane			-41.1									85.3
$CBrF_3$	Bromotrifluoromethane			-648.3									69.3
CBrN	Cyanogen bromide	140.5		186.2			165.3			248.3			46.9
$CBrN_3O_6$	Bromotrinitromethane		32.5	80.3									
CBr_2ClF	Dibromochlorofluoromethane									342.8			82.4
CBr_2Cl_2	Dibromodichloromethane									347.8			87.1
CBr_2F_2	Dibromodifluoromethane									325.3			77.0
CBr_2O	Carbonyl bromide		-127.2	-96.2			-110.9			309.1			61.8
CBr_3Cl	Tribromochloromethane									357.8			89.4
CBr_3F	Tribromofluoromethane									345.9			84.4

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CBr_4	Tetrabromomethane	29.4		83.9	47.7		67.0	212.5		358.1	144.3		91.2
$CCaO_3$	Calcium carbonate (calcite)	-1207.6			-1129.1			91.7			83.5		
$CCaO_3$	Calcium carbonate (aragonite)	-1207.8			-1128.2			88.0			82.3		
$CCdO_3$	Cadmium carbonate	-750.6			-669.4			92.5					
$CClFO$	Carbonyl chloride fluoride									276.7			52.4
$CClF_3$	Chlorotrifluoromethane			-706.3									66.9
$CClN$	Cyanogen chloride		112.1	138.0			131.0			236.2			45.0
$CClN_3O_6$	Chlorotrinitromethane		-27.1	18.4									
CCl_2F_2	Dichlorodifluoromethane			-477.4			-439.4			300.8			72.3
CCl_2O	Carbonyl chloride			-219.1			-204.9			283.5			57.7
CCl_3	Trichloromethyl			59.0									
CCl_3F	Trichlorofluoromethane		-301.3	-268.3		-236.8			225.4			121.6	78.1
CCl_4	Tetrachloromethane		-128.2	-95.7								130.7	83.3
$CCoO_3$	Cobalt(II) carbonate	-713.0											
CCs_2O_3	Cesium carbonate	-1139.7			-1054.3			204.5			123.9		
$CCuN$	Copper(I) cyanide	96.2			111.3			84.5					
CFN	Cyanogen fluoride									224.7			41.8
CF_2O	Carbonyl fluoride			-639.8									46.8
CF_3	Trifluoromethyl			-477.0			-464.0			264.5			49.6
CF_3I	Trifluoroiodomethane			-587.8						307.4			70.9
CF_4	Tetrafluoromethane			-933.6						261.6			61.1
$CFeO_3$	Iron(II) carbonate	-740.6			-666.7			92.9			82.1		
CFe_3	Iron carbide	25.1			20.1			104.6			105.9		
CH	Methylidyne			595.8									
$CHBrClF$	Bromochlorofluoromethane									304.3			63.2
$CHBrCl_2$	Bromodichloromethane									316.4			67.4
$CHBrF_2$	Bromodifluoromethane			-424.9						295.1			58.7
$CHBr_2Cl$	Chlorodibromomethane									327.7			69.2
$CHBr_2F$	Dibromofluoromethane									316.8			65.1
$CHBr_3$	Tribromomethane		-22.3	23.8		-5.0	8.0		220.9	330.9		130.7	71.2
$CHClF_2$	Chlorodifluoromethane			-482.6						280.9			55.9
$CHCl_2F$	Dichlorofluoromethane									293.1			60.9
$CHCl_3$	Trichloromethane		-134.1	-102.7		-73.7	6.0		201.7	295.7		114.2	65.7
$CHCsO_3$	Cesium hydrogen carbonate	-966.1											
$CHFO$	Formyl fluoride									246.6			39.9
CHF_3	Trifluoromethane			-695.4						259.7			51.0
CHI_3	Triiodomethane	-181.1		251.0						356.2			75.0
$CHKO_2$	Potassium formate	-679.7											
$CHKO_3$	Potassium hydrogen carbonate	-963.2			-863.5			115.5					
CHN	Hydrogen cyanide		108.9	135.1		125.0	124.7		112.8	201.8		70.6	35.9
$CHNO$	Isocyanic acid (HNCO)									238.0			44.9
$CHNS$	Isothiocyanic acid			127.6			113.0			247.8			46.9
CHN_3O_6	Trinitromethane		-32.8	-0.2									
$CHNaO_2$	Sodium formate	-666.5			-599.9			103.8			82.7		

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
$CHNaO_3$	Sodium hydrogen carbonate	-950.8			-851.0			101.7			87.6		
CHO	Oxomethyl (HCO)			43.1			28.0			224.7			34.6
CH_2	Methylene			390.4			372.9			194.9			33.8
CH_2BrCl	Bromochloromethane									287.6			52.7
CH_2BrF	Bromofluoromethane									276.3			49.2
CH_2Br_2	Dibromomethane									293.2			54.7
CH_2ClF	Chlorofluoromethane									264.4			47.0
CH_2Cl_2	Dichloromethane		-124.2	-95.4					177.8	270.2		101.2	51.0
CH_2F_2	Difluoromethane			-452.3						246.7			42.9
CH_2I_2	Diiodomethane		68.5	119.5		90.4	95.8		174.1	309.7		134.0	57.7
CH_2N_2	Diazomethane									242.9			52.5
CH_2N_2	Cyanamide	58.8											
$CH_2N_2O_4$	Dinitromethane		-104.9	-58.9									
CH_2O	Formaldehyde			-108.6			-102.5			218.8			35.4
$(CH_2O)_x$	Paraformaldehyde	-177.6											
CH_2O_2	Formic acid		-425.0	-378.7		-361.4			129.0			99.0	
CH_2S_3	Trithiocarbonic acid		24.0										
CH_3	Methyl			145.7			147.9			194.2			38.7
CH_3BO	Borane carbonyl			-111.2			-92.9			249.4			59.5
CH_3Br	Bromomethane		-59.8	-35.4			-26.3			246.4			42.4
CH_3Cl	Chloromethane			-81.9						234.6			40.8
CH_3F	Fluoromethane									222.9			37.5
CH_3I	Iodomethane		-13.6	14.4					163.2	254.1		126.0	44.1
CH_3NO	Formamide		-254.0	-193.9									
CH_3NO_2	Nitromethane		-112.6	-74.3		-14.4	-6.8		171.8	275.0		106.6	57.3
CH_3NO_2	Methyl nitrite			-66.1									
CH_3NO_3	Methyl nitrate		-156.3	-122.4		-43.4	-39.2		217.1	318.5		157.3	
CH_4	Methane			-74.6			-50.5			186.3			35.7
CH_4N_2	Ammonium cyanide	0.4									134.0		
CH_4N_2O	Urea	-333.1		-245.8									
CH_4N_2S	Thiourea	-89.1		22.9									
$CH_4N_4O_2$	Nitroguanidine	-92.4											
CH_4O	Methanol		-239.2	-201.0		-166.6	-162.3		126.8	239.9		81.1	44.1
CH_4S	Methanethiol		-46.7	-22.9		-7.7	-9.3		169.2	255.2		90.5	50.3
CH_5N	Methylamine		-47.3	-22.5		35.7	32.7		150.2	242.9		102.1	50.1
CH_5NO_3	Ammonium hydrogen carbonate	-849.4			-665.9			120.9					
CH_5N_3	Guanidine	-56.0											
CH_5N_3S	Hydrazinecarbothioamide	24.7											
$CH_5N_5O_2$	3-Amino-1-nitroguanidine	22.1											
CH_6ClN	Methylamine hydrochloride	-298.1											
CH_6N_2	Methylhydrazine		54.2	94.7		180.0	187.0		165.9	278.8		134.9	71.1
CH_6Si	Methylsilane									256.5			65.9
CHg_2O_3	Mercury(I) carbonate	-553.5			-468.1			180.0					
CIN	Cyanogen iodide	166.2		225.5	185.0		196.6	96.2		256.8			48.3

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
CI_4	Tetraiodomethane	-392.9		474.0						391.9			95.9
CKN	Potassium cyanide	-113.0			-101.9			128.5			66.3		
CKNS	Potassium thiocyanate	-200.2			-178.3			124.3			88.5		
CK_2O_3	Potassium carbonate	-1151.0			-1063.5			155.5			114.4		
CLi_2O_3	Lithium carbonate	-1215.9			-1132.1			90.4			99.1		
$CMgO_3$	Magnesium carbonate	-1095.8			-1012.1			65.7			75.5		
$CMnO_3$	Manganese(II) carbonate	-894.1			-816.7			85.8			81.5		
CN	Cyanide			437.6			407.5			202.6			29.2
CNNa	Sodium cyanide	-87.5			-76.4			115.6			70.4		
CNNaO	Sodium cyanate	-405.4			-358.1			96.7			86.6		
CN_4O_8	Tetranitromethane		38.4	88.3									
CNa_2O_3	Sodium carbonate	-1130.7			-1044.4			135.0			112.3		
CO	Carbon monoxide			-110.5			-137.2			197.7			29.1
COS	Carbon oxysulfide			-142.0			-169.2			231.6			41.5
CO_2	Carbon dioxide			-393.5			-394.4			213.8			37.1
CO_3Pb	Lead(II) carbonate	-699.1			-625.5			131.0			87.4		
CO_3Rb_2	Rubidium carbonate	-1136.0			-1051.0			181.3			117.6		
CO_3Sr	Strontium carbonate	-1220.1			-1140.1			97.1			81.4		
CO_3Tl_2	Thallium(I) carbonate	-700.0			-614.6			155.2					
CO_3Zn	Zinc carbonate	-812.8			-731.5			82.4			79.7		
CS	Carbon sulfide			234.0			184.0			210.6			29.8
CS_2	Carbon disulfide		89.0	116.7		64.6	67.1		151.3	237.8		76.4	45.4
CSe_2	Carbon diselenide		164.8										
CSi	Silicon carbide (cubic)	-65.3			-62.8			16.6			26.9		
CSi	Silicon carbide (hexagonal)	-62.8			-60.2			16.5			26.7		
C_2	Dicarbon			831.9			775.9			199.4			43.2
C_2BrF_5	Bromopentafluoroethane			-1064.4									
$C_2Br_2ClF_3$	1,2-Dibromo-1-chloro-1,2,2-trifluoroethane		-691.7	-656.6									
$C_2Br_2F_4$	1,2-Dibromotetrafluoroethane		-817.7	-789.1									
C_2Br_4	Tetrabromoethylene									387.1			102.7
C_2Br_6	Hexabromoethane									441.9			139.3
C_2Ca	Calcium carbide	-59.8			-64.9			70.0			62.7		
C_2CaN_2	Calcium cyanide	-184.5											
C_2CaO_4	Calcium oxalate	-1360.6											
C_2ClF_3	Chlorotrifluoroethylene		-522.7	-505.5			-523.8			322.1			83.9
C_2ClF_5	Chloropentafluoroethane			-1118.8									184.2
$C_2Cl_2F_4$	1,2-Dichlorotetrafluoroethane		-960.2	-937.0								111.7	
$C_2Cl_2O_2$	Ethanedioyl dichloride		-367.6	-335.8									
$C_2Cl_3F_3$	1,1,2-Trichlorotrifluoroethane		-745.0	-716.8								170.1	
C_2Cl_3N	Trichloroacetonitrile									336.6			96.1
C_2Cl_4	Tetrachloroethylene		-50.6	-10.9		3.0			266.9			143.4	

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_2Cl_4F_2$	1,1,1,2-Tetrachloro-2,2-difluoroethane			-489.9			-407.0			382.9			123.4
$C_2Cl_4F_2$	1,1,2,2-Tetrachloro-1,2-difluoroethane											173.6	
C_2Cl_4O	Trichloroacetyl chloride		-280.8	-239.8									
C_2Cl_6	Hexachloroethane	-202.8		-143.6				237.3			198.2		
C_2F_3N	Trifluoroacetonitrile			-497.9						298.1			77.9
C_2F_4	Tetrafluoroethylene	-820.5		-658.9						300.1			80.5
C_2F_6	Hexafluoroethane			-1344.2						332.3			106.7
C_2HBr	Bromoacetylene									253.7			55.7
$C_2HBrClF_3$	1-Bromo-2-chloro-1,1,2-trifluoroethane		-675.3	-644.8									
$C_2HBrClF_3$	2-Bromo-2-chloro-1,1,1-trifluoroethane		-720.0	-690.4									
C_2HCl	Chloroacetylene									242.0			54.3
C_2HClF_2	1-Chloro-2,2-difluoroethylene			-315.5			-289.1			303.0			72.1
C_2HCl_2F	1,1-Dichloro-2-fluoroethylene									313.9			76.5
$C_2HCl_2F_3$	2,2-Dichloro-1,1,1-trifluoroethane									352.8			102.5
C_2HCl_3	Trichloroethylene		-43.6	-9.0					228.4	324.8		124.4	80.3
C_2HCl_3O	Trichloroacetaldehyde		-234.5	-196.6								151.0	
C_2HCl_3O	Dichloroacetyl chloride		-280.4	-241.0									
$C_2HCl_3O_2$	Trichloroacetic acid	-503.3											
C_2HCl_5	Pentachloroethane		-187.6	-142.0								173.8	
C_2HF	Fluoroacetylene									231.7			52.4
C_2HF_3	Trifluoroethylene			-490.5									
$C_2HF_3O_2$	Trifluoroacetic acid		-1069.9	-1031.4									
C_2HF_5	Pentafluoroethane			-1100.4									
C_2H_2	Acetylene			227.4			209.9			200.9			44.0
$C_2H_2BrF_3$	2-Bromo-1,1,1-trifluoroethane			-694.5									
$C_2H_2Br_2$	*cis*-1,2-Dibromoethylene									311.3			68.8
$C_2H_2Br_2$	*trans*-1,2-Dibromoethylene									313.5			70.3
$C_2H_2Br_2Cl_2$	1,2-Dibromo-1,2-dichloroethane			-36.9									
$C_2H_2Br_4$	1,1,2,2-Tetrabromoethane											165.7	
$C_2H_2ClF_3$	2-Chloro-1,1,1-trifluoroethane									326.5			89.1
$C_2H_2Cl_2$	1,1-Dichloroethylene		-23.9	2.8		24.1	25.4		201.5	289.0		111.3	67.1
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethylene		-26.4	4.6					198.4	289.6		116.4	65.1
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethylene		-24.3	5.0		27.3	28.6		195.9	290.0		116.8	66.7
$C_2H_2Cl_2O$	Chloroacetyl chloride		-283.7	-244.8									
$C_2H_2Cl_2O_2$	Dichloroacetic acid		-496.3										

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
$C_2H_2Cl_3NO$	2,2,2-Trichloroacetamide	-358.0											
$C_2H_2Cl_4$	1,1,1,2-Tetrachloroethane									356.0			102.7
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane		-195.0	-149.2					246.9	362.8		162.3	100.8
$C_2H_2F_2$	1,1-Difluoroethylene			-335.0						266.2			60.1
$C_2H_2F_2$	*cis*-1,2-Difluoroethylene									268.3			58.2
$C_2H_2F_3I$	1,1,1-Trifluoro-2-iodoethane			-644.5									
$C_2H_2I_2$	*cis*-1,2-Diiodoethylene			-207.4									
C_2H_2O	Ketene		-67.9	-47.5			-48.3			247.6			51.8
$C_2H_2O_2$	Glyoxal			-212.0									
$C_2H_2O_4$	Oxalic acid	-821.7		-723.7				109.8			91.0		
$C_2H_2O_4Sr$	Strontium formate	-1393.3											
$C_2H_2S_2$	Thiirene			300.0			275.8			255.3			54.7
C_2H_3Br	Bromoethylene			79.2			81.8			275.8			55.5
C_2H_3BrO	Acetyl bromide		-223.5	-190.4									
C_2H_3Cl	Chloroethylene	-94.1	14.6	37.2			53.6			264.0	59.4		53.7
$C_2H_3ClF_2$	1-Chloro-1,1-difluoroethane									307.2			82.5
C_2H_3ClO	Acetyl chloride		-272.9	-242.8		-208.0	-205.8		200.8	295.1		117.0	67.8
$C_2H_3ClO_2$	Chloroacetic acid	-510.5		-435.2									
$C_2H_3Cl_2F$	1,1-Dichloro-1-fluoroethane									320.2			88.7
$C_2H_3Cl_3$	1,1,1-Trichloroethane		-177.4	-144.4					227.4	323.1		144.3	93.3
$C_2H_3Cl_3$	1,1,2-Trichloroethane		-190.8	-151.3					232.6	337.2		150.9	89.0
C_2H_3F	Fluoroethylene			-138.8									
C_2H_3FO	Acetyl fluoride		-467.2	-442.1									
$C_2H_3F_3$	1,1,1-Trifluoroethane			-744.6						279.9			78.2
$C_2H_3F_3$	1,1,2-Trifluoroethane			-730.7									
$C_2H_3F_3O$	2,2,2-Trifluoroethanol		-932.4	-888.4									
C_2H_3I	Iodoethylene									285.0			57.9
C_2H_3IO	Acetyl iodide		-163.5	-126.4									
$C_2H_3KO_2$	Potassium acetate	-723.0											
C_2H_3N	Acetonitrile		40.6	74.0		86.5	91.9		149.6	243.4		91.5	52.2
C_2H_3N	Isocyanomethane		130.8	163.5		159.5	165.7		159.0	246.9			52.9
C_2H_3NO	Methylisocyanate		-92.0										
$C_2H_3NO_3$	Oxamic acid	-661.2		-552.3									
C_2H_3NS	Methyl isothiocyanate	79.4											
$C_2H_3NaO_2$	Sodium acetate	-708.8			-607.2			123.0			79.9		
C_2H_4	Ethylene			52.4			68.4			219.3			42.9
C_2H_4BrCl	1-Bromo-2-chloroethane											130.1	
$C_2H_4Br_2$	1,1-Dibromoethane		-66.2							327.7			80.8
$C_2H_4Br_2$	1,2-Dibromoethane		-79.2	-37.5					223.3			136.0	
C_2H_4ClF	1-Chloro-1-fluoroethane			-313.4									
$C_2H_4Cl_2$	1,1-Dichloroethane		-158.4	-127.7		-73.8	-70.8		211.8	305.1		126.3	76.2
$C_2H_4Cl_2$	1,2-Dichloroethane		-166.8	-126.4						308.4		128.4	78.7

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_2H_4F_2$	1,1-Difluoroethane			-497.0						282.5			67.8
$C_2H_4I_2$	1,2-Diiodoethane	9.3		75.0									
$C_2H_4N_2O_2$	Oxamide	-504.4		-387.1									
$C_2H_4N_2O_2$	Ethanedial, dioxime	-90.5											
$C_2H_4N_2O_4$	1,1-Dinitroethane		-148.2										
$C_2H_4N_2O_4$	1,2-Dinitroethane		-165.2										
$C_2H_4N_2S_2$	Ethanedithioamide	-20.8		83.0									
$C_2H_4N_4$	1*H*-1,2,4-Triazol-3-amine	76.8											
C_2H_4O	Acetaldehyde		-192.2	-166.2		-127.6	-133.0		160.2	263.8		89.0	55.3
C_2H_4O	Ethylene oxide		-78.0	-52.6		-11.8	-13.0		153.9	242.5		88.0	47.9
C_2H_4OS	Thioacetic acid		-216.9	-175.1									
$C_2H_4O_2$	Acetic acid		-484.3	-432.2		-389.9	-374.2		159.8	283.5		123.3	63.4
$C_2H_4O_2$	Methyl formate		-386.1	-357.4						285.3		119.1	64.4
C_2H_4S	Thiirane		51.6	82.0			96.8			255.2			53.3
C_2H_4Si	Ethynylsilane									269.4			72.6
C_2H_5Br	Bromoethane		-90.5	-61.9		-25.8	-23.9		198.7	286.7		100.8	64.5
C_2H_5Cl	Chloroethane		-136.8	-112.1		-59.3	-60.4		190.8	276.0		104.3	62.8
C_2H_5ClO	Ethylene chlorohydrin		-295.4										
C_2H_5F	Fluoroethane									264.5			58.6
C_2H_5I	Iodoethane		-40.0	-8.1		14.7	19.2		211.7	306.0		115.1	66.9
C_2H_5N	Ethyleneimine		91.9	126.5									
C_2H_5NO	Acetamide	-317.0		-238.3				115.0			91.3		
C_2H_5NO	*N*-Methylformamide											123.8	
$C_2H_5NO_2$	Nitroethane		-143.9	-102.3								134.4	
$C_2H_5NO_2$	Glycine	-528.5		-392.1									
$C_2H_5NO_3$	2-Nitroethanol		-350.7										
$C_2H_5NO_3$	Ethyl nitrate		-190.4	-154.1									
C_2H_5NS	Thioacetamide	-71.7		11.4									
C_2H_6	Ethane			-84.0			-32.0			229.2			52.5
C_2H_6Cd	Dimethyl cadmium		63.6	101.6		139.0	146.9		201.9	303.0		132.0	
C_2H_6Hg	Dimethyl mercury		59.8	94.4		140.3	146.1		209.0	306.0			83.3
$C_2H_6N_2O$	*N*-Methylurea	-332.8											
$C_2H_6N_4O_2$	1,2-Hydrazinedicarboxamide	-498.7											
$C_2H_6N_4O_2$	Ethanedioic acid, dihydrazide	-295.2											
C_2H_6O	Ethanol		-277.6	-234.8		-174.8	-167.9		160.7	281.6		112.3	65.6
C_2H_6O	Dimethyl ether		-203.3	-184.1			-112.6			266.4			64.4
C_2H_6OS	Dimethyl sulfoxide		-204.2	-151.3		-99.9			188.3			153.0	
$C_2H_6O_2$	Ethylene glycol		-460.0	-392.2					163.2	303.8		148.6	82.7
$C_2H_6O_2S$	Dimethyl sulfone	-450.1		-373.1	-302.4		-272.7	142.0		310.6			100.0
$C_2H_6O_3S$	Dimethyl sulfite		-523.6	-483.4									
$C_2H_6O_4S$	Dimethyl sulfate		-735.5	-687.0									
C_2H_6S	Ethanethiol		-73.6	-46.1		-5.5	-4.8		207.0	296.2		117.9	72.7
C_2H_6S	Dimethyl sulfide		-65.3	-37.4					196.4	286.0		118.1	74.1
$C_2H_6S_2$	1,2-Ethanedithiol		-54.3	-9.7									
$C_2H_6S_2$	Dimethyl disulfide		-62.6	-24.7					235.4			146.1	

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
C_2H_6Zn	Dimethyl zinc		23.4	53.0					201.6			129.2	
C_2H_7N	Ethylamine		-74.1	-47.5			36.3			283.8		130.0	71.5
C_2H_7N	Dimethylamine		-43.9	-18.8		70.0	68.5		182.3	273.1		137.7	70.7
C_2H_7NO	Ethanolamine											195.5	
C_2H_8ClN	Dimethylamine hydrochloride	-289.3											
$C_2H_8N_2$	1,2-Ethanediamine		-63.0	-18.0								172.6	
$C_2H_8N_2$	1,1-Dimethylhydrazine		48.9	84.1		206.4			198.0			164.1	
$C_2H_8N_2$	1,2-Dimethylhydrazine		52.7	92.2									
$C_2H_8N_2O_4$	Ammonium oxalate	-1123.0									226.0		
C_2HgO_4	Mercury(II) oxalate	-678.2											
C_2I_2	Diiodoacetylene									313.1			70.3
C_2I_4	Tetraiodoethylene	305.0											
$C_2K_2O_4$	Potassium oxalate	-1346.0											
C_2MgO_4	Magnesium oxalate	-1269.0											
C_2N_2	Cyanogen		285.9	306.7						241.9			56.8
$C_2N_4O_6$	Trinitroacetonitrile		183.7										
$C_2Na_2O_4$	Sodium oxalate			-1318.0									
C_2O_4Pb	Lead(II) oxalate	-851.4			-750.1			146.0			105.4		
C_3F_8	Perfluoropropane			-1783.2									
$C_3H_2N_2$	Malononitrile	186.4		265.5									
$C_3H_2O_2$	2-Propynoic acid		-193.2										
$C_3H_2O_3$	1,3-Dioxol-2-one		-459.9	-418.6									
$C_3H_3Cl_3$	1,2,3-Trichloropropene		-101.8										
$C_3H_3F_3$	3,3,3-Trifluoropropene			-614.2									
C_3H_3N	2-Propenenitrile		147.1	180.6									
C_3H_3NO	Oxazole		-48.0	-15.5									
C_3H_3NO	Isoxazole		42.1	78.6									
C_3H_4	Allene			190.5									
C_3H_4	Propyne			184.9									
C_3H_4	Cyclopropene			277.1									
$C_3H_4Cl_2$	2,3-Dichloropropene		-73.3										
$C_3H_4Cl_4$	1,1,1,3-Tetrachloropropane		-208.7										
$C_3H_4Cl_4$	1,2,2,3-Tetrachloropropane		-251.8										
$C_3H_4F_4O$	2,2,3,3-Tetrafluoro-1-propanol		-1114.9	-1061.3									
$C_3H_4N_2$	1*H*-Pyrazole		105.4	179.4									
$C_3H_4N_2$	Imidazole	49.8		132.9									
$C_3H_4O_2$	1,2-Propanedione		-309.1	-271.0									
$C_3H_4O_2$	Propenoic acid		-383.8									145.7	
$C_3H_4O_2$	2-Oxetanone		-329.9	-282.9					175.3			122.1	
$C_3H_4O_3$	Ethylene carbonate		-571.5	-508.4								133.9	
C_3H_5Br	*cis*-1-Bromopropene		7.9	40.8									
C_3H_5Br	3-Bromopropene		12.2	45.2									
C_3H_5BrO	Bromoacetone			-181.0									

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
C_3H_5Cl	2-Chloropropene			-21.0									
C_3H_5Cl	3-Chloropropene											125.1	
C_3H_5ClO	Epichlorohydrin		-148.4	-107.8								131.6	
$C_3H_5ClO_2$	2-Chloropropanoic acid		-522.5	-475.8									
$C_3H_5ClO_2$	3-Chloropropanoic acid	-549.3											
$C_3H_5ClO_2$	Ethyl chloroformate		-505.3	-462.9									
$C_3H_5Cl_3$	1,2,3-Trichloropropane		-230.6	-182.9								183.6	
C_3H_5I	3-Iodopropene		53.7	91.5									
C_3H_5IO	Iodoacetone			-130.5									
$C_3H_5IO_2$	3-Iodopropanoic acid	-460.0											
C_3H_5N	Propanenitrile		15.5	51.7								119.3	
C_3H_5N	2-Propyn-1-amine		205.7										
C_3H_5N	Ethyl isocyanide		108.6	141.7									
$C_3H_5NO_3$	Nitroacetone		-278.6										
$C_3H_5NO_4$	Methyl nitroacetate		-464.0										
$C_3H_5N_3O_9$	Trinitroglycerol		-370.9	-270.9									
C_3H_6	Propene		4.0	20.0									
C_3H_6	Cyclopropane		35.2	53.3			104.5			237.5			55.6
$C_3H_6Br_2$	1,2-Dibromopropane		-113.6	-71.6									
$C_3H_6Cl_2$	1,2-Dichloropropane		-198.8	-162.8								149.1	
$C_3H_6Cl_2$	1,3-Dichloropropane		-199.9	-159.2									
$C_3H_6Cl_2$	2,2-Dichloropropane		-205.8	-173.2									
$C_3H_6Cl_2O$	2,3-Dichloro-1-propanol		-381.5	-316.3									
$C_3H_6Cl_2O$	1,3-Dichloro-2-propanol		-385.3	-318.4									
$C_3H_6I_2$	1,2-Diiodopropane			35.6									
$C_3H_6I_2$	1,3-Diiodopropane		-9.0										
$C_3H_6N_2O_2$	Propanediamide	-546.1											
$C_3H_6N_2O_2$	*N*-(Aminocarbonyl) acetamide	-544.2		-441.2									
$C_3H_6N_2O_4$	1,1-Dinitropropane		-163.2	-100.7									
$C_3H_6N_2O_4$	1,3-Dinitropropane		-207.1										
$C_3H_6N_2O_4$	2,2-Dinitropropane		-181.2										
C_3H_6O	Allyl alcohol		-171.8	-124.5								138.9	
C_3H_6O	Propanal		-215.6	-185.6						304.5			80.7
C_3H_6O	Acetone		-248.4	-217.1			-152.7		199.8	295.3		126.3	74.5
C_3H_6O	Methyloxirane		-123.0	-94.7					196.5	286.9		120.4	72.6
C_3H_6O	Oxetane		-110.8	-80.5									
$C_3H_6O_2$	Propanoic acid		-510.7	-455.7					191.0			152.8	
$C_3H_6O_2$	Ethyl formate											149.3	
$C_3H_6O_2$	Methyl acetate		-445.9	-413.3						324.4		141.9	86.0
$C_3H_6O_2$	1,3-Dioxolane		-333.5	-298.0								118.0	
$C_3H_6O_2S$	Thiolactic acid		-468.4										
$C_3H_6O_3$	Trioxane	-522.5		-465.9				133.0			111.4		
C_3H_6S	Thiacyclobutane		24.7	60.6			107.1		184.9	285.0			68.3
C_3H_6S	Methylthiirane		11.3	45.8									

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_3H_6S_2$	1,2-Dithiolane			0.0			47.7			313.5			86.5
$C_3H_6S_2$	1,3-Dithiolane			10.0			54.7			323.3			84.7
C_3H_7Br	1-Bromopropane		-121.9	-87.0									
C_3H_7Br	2-Bromopropane		-130.5	-99.4									
C_3H_7Cl	1-Chloropropane		-160.5	-131.9									
C_3H_7Cl	2-Chloropropane		-172.3	-144.9									
$C_3H_7ClO_2$	3-Chloro-1,2-propanediol		-525.3										
$C_3H_7ClO_2$	2-Chloro-1,3-propanediol		-517.5										
C_3H_7F	1-Fluoropropane			-285.9									
C_3H_7F	2-Fluoropropane			-293.5									
C_3H_7I	1-Iodopropane		-66.0	-30.0									
C_3H_7I	2-Iodopropane		-74.8	-40.3									
C_3H_7N	Allylamine		-10.0										
C_3H_7N	Cyclopropylamine		45.8	77.0					187.7			147.1	
C_3H_7NO	*N*,*N*-Dimethylformamide		-239.3	-192.4								150.6	
C_3H_7NO	Propanamide	-338.2		-259.0									
$C_3H_7NO_2$	1-Nitropropane		-167.2	-123.8									
$C_3H_7NO_2$	2-Nitropropane		-180.3	-138.9								170.3	
$C_3H_7NO_2$	*DL*-Alanine	-563.6											
$C_3H_7NO_2$	*D*-Alanine	-561.2											
$C_3H_7NO_2$	*L*-Alanine	-604.0		-465.9									
$C_3H_7NO_2$	β-Alanine	-558.0		-424.0									
$C_3H_7NO_2$	*N*-Methylglycine	-513.3		-367.3									
$C_3H_7NO_2S$	*L*-Cysteine	-534.1											
$C_3H_7NO_3$	Propyl nitrate		-214.5	-173.9									
$C_3H_7NO_3$	Isopropyl nitrate		-229.7	-191.0									
$C_3H_7NO_3$	*DL*-Serine	-739.0											
$C_3H_7NO_3$	*L*-Serine	-732.7											
C_3H_8	Propane		-120.9	-103.8			-23.4			270.3			73.6
$C_3H_8N_2O$	*N*-Ethylurea	-357.8											
$C_3H_8N_2O$	*N*,*N*-Dimethylurea	-319.1											
$C_3H_8N_2O$	*N*,*N'*-Dimethylurea	-312.1											
$C_3H_8N_2O_3$	Oxymethurea	-717.0											
C_3H_8O	1-Propanol		-302.6	-255.1					193.6	322.6		143.9	85.6
C_3H_8O	2-Propanol		-318.1	-272.6					181.1	309.2		156.5	89.3
C_3H_8O	Ethyl methyl ether			-216.4						309.2			93.3
$C_3H_8O_2$	1,2-Propylene glycol		-501.0	-429.8								190.8	
$C_3H_8O_2$	1,3-Propylene glycol		-480.8	-408.0									
$C_3H_8O_2$	Ethylene glycol monomethyl ether											171.1	
$C_3H_8O_2$	Dimethoxymethane		-377.8	-348.5					244.0			162.0	
$C_3H_8O_3$	Glycerol		-669.6	-577.9					206.3			218.9	
C_3H_8S	1-Propanethiol		-99.9	-67.8					242.5			144.6	
C_3H_8S	2-Propanethiol		-105.9	-76.2					233.5			145.3	
C_3H_8S	Ethyl methyl sulfide		-91.6	-59.6					239.1			144.6	

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_3H_8S_2$	1,3-Propanedithiol		-79.4	-29.8									
C_3H_9Al	Trimethyl aluminum		-136.4	-74.1		-9.9			209.4			155.6	
C_3H_9B	Trimethylborane		-143.1	-124.3		-32.1	-35.9		238.9	314.7			88.5
C_3H_9ClSi	Trimethylchlorosilane		-382.8	-352.8		-246.4	-243.5		278.2	369.1			
C_3H_9N	Propylamine		-101.5	-70.1			39.9			325.4		164.1	91.2
C_3H_9N	Isopropylamine		-112.3	-83.7			32.2		218.3	312.2		163.8	97.5
C_3H_9N	Trimethylamine		-45.7	-23.6					208.5	287.1		137.9	91.8
$C_3H_{10}ClN$	Propylamine hydrochloride	-354.7											
$C_3H_{10}ClN$	Trimethylamine hydrochloride	-282.9											
$C_3H_{10}N_2$	1,2-Propanediamine, (±)-		-97.8	-53.6									
$C_3H_{10}Si$	Trimethylsilane									331.0			117.9
$C_3H_{12}BN$	Trimethylamine borane	-142.5			70.7			187.0					
$C_3H_{12}BN$	Aminetrimethylboron	-284.1			-79.3			218.0					
C_4F_8	Perfluorocyclobutane			-1542.6									
C_4F_{10}	Perfluorobutane											127.2	
$C_4H_2N_2$	*trans*-2-Butenedinitrile	268.2		340.2									
$C_4H_2O_3$	Maleic anhydride	-469.8		-398.3									
$C_4H_2O_4$	2-Butynedioic acid	-577.3											
$C_4H_3NO_3$	2-Nitrofuran	-104.1		-28.8									
$C_4H_4BrNO_2$	*N*-Bromosuccinimide	-335.9											
$C_4H_4ClNO_2$	*N*-Chlorosuccinimide	-357.9											
$C_4H_4N_2$	Succinonitrile		139.7	209.7					191.6			145.6	
$C_4H_4N_2$	Pyrazine	139.8		196.1									
$C_4H_4N_2$	Pyrimidine		145.9	195.7									
$C_4H_4N_2$	Pyridazine		224.9	278.3									
$C_4H_4N_2O_2$	Uracil	-429.4		-302.9							120.5		
$C_4H_4N_2O_3$	2,4,6-Trihydroxypyrimidine	-634.7											
C_4H_4O	Furan		-62.3	-34.8					177.0	267.2		114.8	65.4
$C_4H_4O_2$	Diketene		-233.1	-190.3									
$C_4H_4O_3$	Succinic anhydride	-608.6		-527.9									
$C_4H_4O_4$	Maleic acid	-789.4		-679.4				160.8			137.0		
$C_4H_4O_4$	Fumaric acid	-811.7		-675.8				168.0			142.0		
C_4H_4S	Thiophene		80.2	114.9			126.1		181.2	278.8		123.8	72.8
C_4H_5N	*trans*-2-Butenenitrile		95.1	134.3									
C_4H_5N	3-Butenenitrile		117.8	159.7									
C_4H_5N	Pyrrole		63.1	108.2					156.4			127.7	
C_4H_5N	Cyclopropanecarbonitrile		140.8	182.8									
$C_4H_5NO_2$	Succinimide	-459.0		-375.4									
C_4H_5NS	4-Methylthiazole		67.9	111.8									
$C_4H_5N_3O$	Cytosine	-221.3									132.6		
C_4H_6	1,2-Butadiene		138.6	162.3									
C_4H_6	1,3-Butadiene		88.5	110.0					199.0			123.6	
C_4H_6	1-Butyne		141.4	165.2									
C_4H_6	2-Butyne		119.1	145.7									

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
C_4H_6	Cyclobutene			156.7									
$C_4H_6N_2O_2$	2,5-Piperazinedione	-446.5											
C_4H_6O	Divinyl ether		-39.8	-13.6									
C_4H_6O	*trans*-2-Butenal		-138.7	-100.6									
$C_4H_6O_2$	*trans*-Crotonic acid												
$C_4H_6O_2$	Methacrylic acid											161.1	
$C_4H_6O_2$	Vinyl acetate		-349.2	-314.4									
$C_4H_6O_2$	Methyl acrylate		-362.2	-333.0					239.5			158.8	
$C_4H_6O_2$	γ-Butyrolactone		-420.9	-366.5								141.4	
$C_4H_6O_3$	Acetic anhydride		-624.4	-572.5									
$C_4H_6O_3$	Propylene carbonate		-613.2	-582.5								218.6	
$C_4H_6O_4$	Succinic acid	-940.5		-823.0				167.3			153.1		
$C_4H_6O_4$	Dimethyl oxalate	-756.3		-708.9									
C_4H_6S	2,3-Dihydrothiophene		52.9	90.7			133.5			303.5			79.8
C_4H_6S	2,5-Dihydrothiophene		47.0	86.9			131.6			297.1			83.3
C_4H_7ClO	2-Chloroethyl vinyl ether		-208.1	-170.1									
$C_4H_7ClO_2$	2-Chlorobutanoic acid		-575.5										
$C_4H_7ClO_2$	3-Chlorobutanoic acid		-556.3										
$C_4H_7ClO_2$	4-Chlorobutanoic acid		-566.3										
$C_4H_7ClO_2$	Propyl chlorocarbonate		-533.4	-492.7									
C_4H_7N	Butanenitrile		-5.8	33.6									
C_4H_7N	2-Methylpropanenitrile		-13.8	23.4									
C_4H_7NO	2-Pyrrolidone		-286.2										
C_4H_7NO	2-Methyl-2-oxazoline		-169.5	-130.5									
$C_4H_7NO_4$	Iminodiacetic acid	-932.6											
$C_4H_7NO_4$	Ethyl nitroacetate		-487.1										
$C_4H_7NO_4$	*L*-Aspartic acid	-973.3											
$C_4H_7N_3O$	4*H*-Imidazol-4-one, 2-amino-1,5-dihydro-1-methyl-	-238.5											
C_4H_8	1-Butene		-20.8	0.1					227.0			118.0	
C_4H_8	*cis*-2-Butene		-29.8	-7.1					219.9			127.0	
C_4H_8	*trans*-2-Butene		-33.3	-11.4									
C_4H_8	Isobutene		-37.5	-16.9									
C_4H_8	Cyclobutane		3.7	27.7									
C_4H_8	Methylcyclopropane		1.7										
$C_4H_8Br_2$	1,2-Dibromobutane		-142.1	-91.6									
$C_4H_8Br_2$	1,3-Dibromobutane		-148.0										
$C_4H_8Br_2$	1,4-Dibromobutane		-140.3	-87.8									
$C_4H_8Br_2$	2,3-Dibromobutane		-139.6	-102.0									
$C_4H_8Br_2$	1,2-Dibromo-2-methylpropane		-156.6	-113.3									
$C_4H_8Cl_2$	1,3-Dichlorobutane		-237.3	-195.0									
$C_4H_8Cl_2$	1,4-Dichlorobutane		-229.8	-183.4									
$C_4H_8Cl_2O$	Bis(2-chloroethyl) ether											220.9	

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_4H_8I_2$	1,4-Diiodobenzene		-30.0										
$C_4H_8N_2O_2$	Succinamide	-581.2											
$C_4H_8N_2O_2$	Dimethylglyoxime	-199.7											
$C_4H_8N_2O_3$	*L*-Asparagine	-789.4											
$C_4H_8N_2O_3$	*N*-Glycylglycine	-747.7											
$C_4H_8N_2O_4$	1,4-Dinitrobutane		-237.5										
C_4H_8O	Ethyl vinyl ether		-167.4	-140.8									
C_4H_8O	1,2-Epoxybutane		-168.9						230.9			147.0	
C_4H_8O	Butanal		-239.2	-204.8					246.6	343.7		163.7	103.4
C_4H_8O	Isobutanal		-247.3	-215.7									
C_4H_8O	2-Butanone		-273.3	-238.5					239.1	339.9		158.7	101.7
C_4H_8O	Tetrahydrofuran		-216.2	-184.1					204.3	302.4		124.0	76.3
C_4H_8OS	*S*-Ethyl thioacetate		-268.2	-228.1									
$C_4H_8O_2$	Butanoic acid		-533.8	-475.9					222.2			178.6	
$C_4H_8O_2$	2-Methylpropanoic acid											173.0	
$C_4H_8O_2$	Propyl formate		-500.3	-462.7									
$C_4H_8O_2$	Ethyl acetate		-479.3	-443.6					257.7			170.7	
$C_4H_8O_2$	1,3-Dioxane		-379.7	-340.6								143.9	
$C_4H_8O_2$	1,4-Dioxane		-353.9	-315.3					270.2			152.1	
$C_4H_8O_2$	2-Methyl-1,3-dioxolane		-386.9	-352.0									
$C_4H_8O_2S$	Sulfolane											180.0	
C_4H_8S	Tetrahydrothiophene		-72.9	-34.1			45.8			309.6			92.5
$C_4H_8S_2$	1,3-Dithiane			-10.0			72.4			333.5			110.4
C_4H_9Br	1-Bromobutane		-143.8	-107.1									
C_4H_9Br	2-Bromobutane		-154.9	-120.3									
C_4H_9Br	2-Bromo-2-methylpropane		-164.4	-132.4									
C_4H_9Cl	1-Chlorobutane		-188.1	-154.4									
C_4H_9Cl	2-Chlorobutane		-192.8	-161.1									
C_4H_9Cl	1-Chloro-2-methylpropane		-191.1	-159.3									
C_4H_9Cl	2-Chloro-2-methylpropane		-211.3	-182.2									
C_4H_9ClO	2-Chloroethyl ethyl ether		-335.6	-301.3									
C_4H_9I	1-Iodo-2-methylpropane											162.3	
C_4H_9I	2-Iodo-2-methylpropane		-107.5	-72.1									
C_4H_9N	Cyclobutanamine		5.6	41.2									
C_4H_9N	Pyrrolidine		-41.1	-3.6					204.1			156.6	
C_4H_9NO	Butanamide		-346.9	-282.0									
C_4H_9NO	*N*-Methylpropanamide											179.0	
C_4H_9NO	2-Methylpropanamide	-368.6		-282.6									
C_4H_9NO	*N*,*N*-Dimethylacetamide		-278.3	-228.0								175.6	
C_4H_9NO	Morpholine											164.8	
$C_4H_9NO_2$	1-Nitrobutane		-192.5	-143.9									
$C_4H_9NO_2$	2-Nitroisobutane		-217.2	-177.1									
$C_4H_9NO_2$	Propyl carbamate	-552.6		-471.4									
$C_4H_9NO_2$	4-Aminobutanoic acid	-581.0		-441.0									
$C_4H_9NO_3$	3-Nitro-2-butanol		-390.0										

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
$C_4H_9NO_3$	2-Methyl-2-nitro-1-propanol	-410.1											
$C_4H_9NO_3$	*DL*-Threonine	-758.8											
$C_4H_9NO_3$	*L*-Threonine	-807.2											
$C_4H_9N_3O_2$	Creatine	-537.2											
C_4H_{10}	Butane		-147.3	-125.7								140.9	
C_4H_{10}	Isobutane		-154.2	-134.2									
$C_4H_{10}Hg$	Diethyl mercury		30.1	75.3								182.8	
$C_4H_{10}N_2$	Piperazine	-45.6											
$C_4H_{10}N_2O$	Trimethylurea	-330.5											
$C_4H_{10}N_2O_2$	*N*-Nitrodiethylamine		-106.2	-53.0									
$C_4H_{10}N_2O_4$	*L*-Asparagine, monohydrate	-1086.6											
$C_4H_{10}O$	1-Butanol		-327.3	-274.9					225.8			177.2	
$C_4H_{10}O$	2-Butanol		-342.6	-292.8					214.9	359.5		196.9	112.7
$C_4H_{10}O$	2-Methyl-1-propanol		-334.7	-283.8					214.7			181.5	
$C_4H_{10}O$	2-Methyl-2-propanol		-359.2	-312.5					193.3	326.7		218.6	113.6
$C_4H_{10}O$	Diethyl ether		-279.5	-252.1					172.4	342.7		175.6	119.5
$C_4H_{10}O$	Methyl propyl ether		-266.0	-238.1					262.9			165.4	
$C_4H_{10}O$	Isopropyl methyl ether		-278.8	-252.0					253.8			161.9	
$C_4H_{10}OS$	Diethyl sulfoxide		-268.0	-205.6									
$C_4H_{10}O_2$	1,2-Butanediol, (±)-		-523.6										
$C_4H_{10}O_2$	1,3-Butanediol		-501.0	-433.2									
$C_4H_{10}O_2$	1,4-Butanediol		-505.3	-428.7					223.4			200.1	
$C_4H_{10}O_2$	2,3-Butanediol		-541.5	-482.3								213.0	
$C_4H_{10}O_2$	2-Methyl-1,2-propanediol		-539.7										
$C_4H_{10}O_2$	Ethylene glycol monoethyl ether											210.8	
$C_4H_{10}O_2$	Ethylene glycol dimethyl ether		-376.6									193.3	
$C_4H_{10}O_2$	Dimethylacetal		-420.6	-389.7									
$C_4H_{10}O_2$	*tert*-Butyl hydroperoxide		-293.6	-245.9									
$C_4H_{10}O_3$	Diethylene glycol		-628.5	-571.2								244.8	
$C_4H_{10}O_3S$	Diethyl sulfite		-600.7	-552.2									
$C_4H_{10}O_4S$	Sulfuric acid, diethyl ester		-813.2	-756.3									
$C_4H_{10}S$	1-Butanethiol		-124.7	-88.0								171.2	
$C_4H_{10}S$	2-Butanethiol		-131.0	-96.9									
$C_4H_{10}S$	2-Methyl-1-propanethiol		-132.0	-97.3									
$C_4H_{10}S$	2-Methyl-2-propanethiol		-140.5	-109.6									
$C_4H_{10}S$	Diethyl sulfide		-119.4	-83.5					269.3	368.1		171.4	117.0
$C_4H_{10}S$	Methyl propyl sulfide		-118.5	-82.2					272.5			171.6	
$C_4H_{10}S$	Isopropyl methyl sulfide		-124.7	-90.5					263.1			172.4	
$C_4H_{10}S_2$	1,4-Butanedithiol		-105.7	-50.6									
$C_4H_{10}S_2$	Diethyl disulfide		-120.1	-79.4					269.3			171.4	
$C_4H_{11}N$	Butylamine		-127.6	-91.9								179.2	
$C_4H_{11}N$	*sec*-Butylamine		-137.5	-104.6									
$C_4H_{11}N$	*tert*-Butylamine		-150.6	-121.0								192.1	
$C_4H_{11}N$	Isobutylamine		-132.6	-98.7								183.2	
$C_4H_{11}N$	Diethylamine		-103.7	-72.2								169.2	

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_4H_{11}NO$	*N*,*N*-Dimethylethanolamine		-253.7	-203.6									
$C_4H_{11}NO_2$	Diethanolamine	-493.8		-397.1							233.5		
$C_4H_{11}NO_3$	2-Amino-2-(hydroxymethyl)-1,3-propanediol	-717.8											
$C_4H_{12}BrN$	Tetramethylammonium bromide	-251.0											
$C_4H_{12}ClN$	Diethylamine hydrochloride	-358.6											
$C_4H_{12}ClN$	Tetramethylammonium chloride	-276.4											
$C_4H_{12}IN$	Tetramethylammonium iodide	-203.9											
$C_4H_{12}N_2$	2-Methyl-1,2-propanediamine		-133.9	-90.3									
$C_4H_{12}Pb$	Tetramethyl lead		97.9	135.9									
$C_4H_{12}Si$	Tetramethylsilane		-264.0	-239.1		-100.0	-99.9		277.3	359.0		204.1	143.9
$C_4H_{12}Sn$	Tetramethylstannane		-52.3	-18.8									
$C_4H_{13}N_3$	Diethylenetriamine											254.0	
C_4N_2	2-Butynedinitrile		500.4	529.2									
C_4NiO_4	Nickel carbonyl		-633.0	-602.9		-588.2	-587.2		313.4	410.6		204.6	145.2
C_5FeO_5	Iron pentacarbonyl		-774.0			-705.3			338.1			240.6	
$C_5H_2F_6O_2$	Hexafluoroacetylacetone	-2286.7											
$C_5H_3NO_5$	5-Nitro-2-furancarboxylic acid	-516.8											
$C_5H_4N_4$	1*H*-Purine	169.4											
$C_5H_4N_4O$	Hypoxanthine	-110.8						145.6			134.5		
$C_5H_4N_4O_2$	Xanthine	-379.6						161.1			151.3		
$C_5H_4N_4O_3$	Uric acid	-618.8						173.2			166.1		
$C_5H_4O_2$	Furfural		-201.6	-151.0								163.2	
$C_5H_4O_3$	2-Furancarboxylic acid	-498.4		-390.0									
$C_5H_4O_3$	3-Methyl-2,5-furandione		-504.5	-447.2									
$C_5H_5F_3O_2$	1,1,1-Trifluoro-2,4-pentanedione		-1040.2	-993.3									
C_5H_5N	Pyridine		100.2	140.4								132.7	
C_5H_5NO	1*H*-Pyrrole-2-carboxaldehyde	-106.4											
$C_5H_5N_5$	Adenine	96.9		205.7							147.0		
$C_5H_5N_5O$	Guanine	-183.9											
C_5H_6	*cis*-3-Penten-1-yne		226.5										
C_5H_6	*trans*-3-Penten-1-yne		228.2										
C_5H_6	1,3-Cyclopentadiene		105.9	134.3									
$C_5H_6N_2O_2$	Thymine	-462.8		-328.7							150.8		
$C_5H_6O_2$	Furfuryl alcohol		-276.2	-211.8								204.0	
$C_5H_6O_4$	*trans*-1-Propene-1,2-dicarboxylic acid	-824.4											
C_5H_6S	2-Methylthiophene		44.6	83.5					218.5			149.8	
C_5H_6S	3-Methylthiophene		43.1	82.5									
C_5H_7N	*trans*-3-Pentenenitrile		80.9	125.7									
C_5H_7N	Cyclobutanecarbonitrile		103.0	147.4									

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
C_5H_7N	1-Methylpyrrole		62.4	103.1									
C_5H_7N	2-Methylpyrrole		23.3	74.0									
C_5H_7N	3-Methylpyrrole		20.5	70.2									
$C_5H_7NO_2$	Ethyl cyanoacetate											220.2	
C_5H_8	1,2-Pentadiene			140.7									
C_5H_8	*cis*-1,3-Pentadiene			81.4									
C_5H_8	*trans*-1,3-Pentadiene			76.1									
C_5H_8	1,4-Pentadiene			105.7									
C_5H_8	2,3-Pentadiene			133.1									
C_5H_8	3-Methyl-1,2-butadiene		101.2										
C_5H_8	2-Methyl-1,3-butadiene		48.2	75.5					229.3			152.6	
C_5H_8	Cyclopentene		4.3	34.0					201.2			122.4	
C_5H_8	Methylenecyclobutane		93.8	121.6									
C_5H_8	Spiropentane		157.5	185.2					193.7			134.5	
$C_5H_8N_4O_{12}$	Pentaerythritol tetranitrate	-538.6											
C_5H_8O	Cyclopentanone		-235.9	-192.1									
$C_5H_8O_2$	4-Pentenoic acid	-430.6											
$C_5H_8O_2$	Methyl *trans*-2-butenoate		-382.9	-341.9									
$C_5H_8O_2$	Methyl methacrylate											191.2	
$C_5H_8O_2$	Allyl acetate											184.1	
$C_5H_8O_2$	2,4-Pentanedione		-423.8	-382.0									
$C_5H_8O_2$	4-Methyl-gamma-butyrolactone		-461.3	-406.5									
$C_5H_8O_2$	Tetrahydro-2*H*-pyran-2-one		-436.7	-379.6									
$C_5H_8O_4$	Glutaric acid	-960.0											
$C_5H_9ClO_2$	Propyl chloroacetate		-515.5	-467.0									
C_5H_9N	Pentanenitrile		-33.1	10.5									
C_5H_9N	2,2-Dimethylpropanenitrile		-39.8	-2.3					232.0			179.4	
C_5H_9N	1,2,5,6-Tetrahydropyridine		33.5										
C_5H_9NO	2-Piperidinone	-306.6											
C_5H_9NO	*N*-Methyl-2-pyrrolidone		-262.2									307.8	
$C_5H_9NO_2$	*L*-Proline	-515.2		-366.2									
$C_5H_9NO_4$	*D*-Glutamic acid	-1005.3											
$C_5H_9NO_4$	*L*-Glutamic acid	-1009.7											
C_5H_{10}	1-Pentene		-46.9	-21.1					262.6			154.0	
C_5H_{10}	*cis*-2-Pentene		-53.7	-27.6					258.6			151.7	
C_5H_{10}	*trans*-2-Pentene		-58.2	-31.9					256.5			157.0	
C_5H_{10}	2-Methyl-1-butene		-61.1	-35.2					254.0			157.2	
C_5H_{10}	3-Methyl-1-butene		-51.5	-27.5					253.3			156.1	
C_5H_{10}	2-Methyl-2-butene		-68.6	-41.7					251.0			152.8	
C_5H_{10}	Cyclopentane		-105.1	-76.4					204.5			128.8	
C_5H_{10}	Methylcyclobutane		-44.5										
C_5H_{10}	Ethylcyclopropane		-24.8										
C_5H_{10}	1,1-Dimethylcyclopropane		-33.3	-8.2									
C_5H_{10}	*cis*-1,2-Dimethylcyclopropane		-26.3										

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
C_5H_{10}	*trans*-1,2-Dimethylcyclopropane		-30.7										
$C_5H_{10}Br_2$	1,3-Dibromo-2-methylpropane			-137.6									
$C_5H_{10}N_2O$	*N*-Nitrosopiperidine		-31.1	16.6									
$C_5H_{10}N_2O_2$	*N*-Nitropiperidine		-93.0	-44.5									
$C_5H_{10}N_2O_3$	*L*-Glutamine	-826.4											
$C_5H_{10}O$	Cyclopentanol		-300.1	-242.5					206.3			184.1	
$C_5H_{10}O$	Pentanal		-267.2	-228.4									
$C_5H_{10}O$	2-Pentanone		-297.3	-258.8								184.1	
$C_5H_{10}O$	3-Pentanone		-296.5	-257.9					266.0			190.9	
$C_5H_{10}O$	3-Methyl-2-butanone		-299.5	-262.6					268.5			179.9	
$C_5H_{10}O$	3,3-Dimethyloxetane		-182.2	-148.2									
$C_5H_{10}O$	Tetrahydropyran		-258.3	-223.4									
$C_5H_{10}OS$	S-Propyl thioacetate		-294.5	-250.4									
$C_5H_{10}O_2$	Pentanoic acid		-559.4	-491.9					259.8			210.3	
$C_5H_{10}O_2$	2-Methylbutanoic acid		-554.5										
$C_5H_{10}O_2$	3-Methylbutanoic acid		-561.6	-510.0									
$C_5H_{10}O_2$	2,2-Dimethylpropanoic acid	-564.5		-491.3									
$C_5H_{10}O_2$	Butyl formate											200.2	
$C_5H_{10}O_2$	Propyl acetate											196.2	
$C_5H_{10}O_2$	Isopropyl acetate		-518.9	-481.6								199.4	
$C_5H_{10}O_2$	Ethyl propanoate		-502.7	-463.4									
$C_5H_{10}O_2$	*cis*-1,2-Cyclopentanediol	-485.0											
$C_5H_{10}O_2$	*trans*-1,2-Cyclopentanediol	-490.1											
$C_5H_{10}O_2$	4-Methyl-1,3-dioxane	-416.1		-376.9									
$C_5H_{10}O_2$	(Ethoxymethyl)oxirane		-296.5										
$C_5H_{10}O_2$	Tetrahydrofurfuryl alcohol		-435.7	-369.1									
$C_5H_{10}O_3$	Diethyl carbonate		-681.5	-637.9									
$C_5H_{10}O_3$	Ethylene glycol momomethyl ether acetate											310.0	
$C_5H_{10}O_3$	Ethyl lactate											254.0	
$C_5H_{10}O_4$	1,2,3-Propanetriol, 1-acetate, (±)-		-909.2										
$C_5H_{10}O_5$	*D*-Ribose	-1047.2											
$C_5H_{10}O_5$	*D*-Xylose	-1057.8											
$C_5H_{10}O_5$	α-*D*-Arabinopyranose	-1057.9											
$C_5H_{10}S$	Thiacyclohexane		-106.3	-63.5			53.1		218.2	323.0		163.3	109.7
$C_5H_{10}S$	Cyclopentanethiol		-89.5	-48.1					256.9			165.2	
$C_5H_{11}Br$	1-Bromopentane		-170.2	-128.9									
$C_5H_{11}Cl$	1-Chloropentane		-213.2	-174.9									
$C_5H_{11}Cl$	2-Chloro-2-methylbutane		-235.7	-202.2									
$C_5H_{11}Cl$	1-Chloro-3-methylbutane		-216.0	-179.7									
$C_5H_{11}Cl$	2-Chloro-3-methylbutane		-226.6	-185.1									
$C_5H_{11}N$	Cyclopentylamine		-95.1	-54.9					241.0			181.2	

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_5H_{11}N$	Piperidine		-86.4	-47.1					210.0			179.9	
$C_5H_{11}NO$	Pentanamide	-379.5		-290.2									
$C_5H_{11}NO$	2,2-Dimethylpropanamide	-399.7		-313.1									
$C_5H_{11}NO_2$	1-Nitropentane		-215.4										
$C_5H_{11}NO_2$	*DL*-Valine	-628.9											
$C_5H_{11}NO_2$	*L*-Valine	-617.9		-455.1									
$C_5H_{11}NO_2$	5-Aminopentanoic acid	-604.1		-460.0									
$C_5H_{11}NO_2S$	*L*-Methionine	-577.5		-413.5									
$C_5H_{11}NO_4$	2-Ethyl-2-nitro-1,3-propanediol	-606.4											
C_5H_{12}	Pentane		-173.5	-146.9								167.2	
C_5H_{12}	Isopentane		-178.4	-153.6					260.4			164.8	
C_5H_{12}	Neopentane		-190.2	-168.0									
$C_5H_{12}N_2O$	Butylurea	-419.5											
$C_5H_{12}N_2O$	*tert*-Butylurea	-417.4											
$C_5H_{12}N_2O$	*N*,*N*-Diethylurea	-372.2											
$C_5H_{12}N_2O$	Tetramethylurea	-262.2											
$C_5H_{12}N_2S$	Tetramethylthiourea	-38.1		44.9									
$C_5H_{12}O$	1-Pentanol		-351.6	-294.6								208.1	
$C_5H_{12}O$	2-Pentanol		-365.2	-311.0									
$C_5H_{12}O$	3-Pentanol		-368.9	-314.9								239.7	
$C_5H_{12}O$	2-Methyl-1-butanol		-356.6	-301.4									
$C_5H_{12}O$	3-Methyl-1-butanol		-356.4	-300.7									
$C_5H_{12}O$	2-Methyl-2-butanol		-379.5	-329.3								247.1	
$C_5H_{12}O$	3-Methyl-2-butanol		-366.6	-313.5									
$C_5H_{12}O$	2,2-Dimethyl-1-propanol		-399.4										
$C_5H_{12}O$	Butyl methyl ether		-290.6	-258.1					295.3			192.7	
$C_5H_{12}O$	*tert*-Butyl methyl ether		-313.6	-283.7					265.3			187.5	
$C_5H_{12}O$	Ethyl propyl ether		-303.6	-272.0					295.0			197.2	
$C_5H_{12}O_2$	1,5-Pentanediol		-528.8	-450.8									
$C_5H_{12}O_2$	2,2-Dimethyl-1,3-propanediol	-551.2											
$C_5H_{12}O_2$	Diethoxymethane		-450.5	-414.7									
$C_5H_{12}O_2$	1,1-Dimethoxypropane		-443.6										
$C_5H_{12}O_2$	2,2-Dimethoxypropane		-459.4	-429.9									
$C_5H_{12}O_3$	Diethylene glycol monomethyl ether											271.1	
$C_5H_{12}O_3$	2-(Hydroxymethyl)-2-methyl-1,3-propanediol	-744.6											
$C_5H_{12}O_4$	Pentaerythritol	-920.6		-776.7									
$C_5H_{12}O_5$	Xylitol	-1118.5											
$C_5H_{12}S$	1-Pentanethiol		-151.3	-110.0									
$C_5H_{12}S$	2-Methyl-1-butanethiol		-154.4	-114.9									
$C_5H_{12}S$	3-Methyl-1-butanethiol		-154.4	-114.9									
$C_5H_{12}S$	2-Methyl-2-butanethiol		-162.8	-127.1					290.1			198.1	
$C_5H_{12}S$	3-Methyl-2-butanethiol		-158.8	-121.3									

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
$C_5H_{12}S$	2,2-Dimethyl-1-propanethiol		-165.4	-129.0									
$C_5H_{12}S$	Butyl methyl sulfide		-142.9	-102.4					307.5			200.9	
$C_5H_{12}S$	*tert*-Butyl methyl sulfide		-157.1	-121.3					276.1			199.9	
$C_5H_{12}S$	Ethyl propyl sulfide		-144.8	-104.8					309.5			198.4	
$C_5H_{12}S$	Ethyl isopropyl sulfide		-156.1	-118.3									
$C_5H_{13}N$	Pentylamine											218.0	
$C_5H_{14}N_2$	*N,N,N′,N′*-Tetramethyl-methanediamine		-51.1	-18.2									
C_6ClF_5	Chloropentafluorobenzene	-858.4		-809.3									
C_6Cl_6	Hexachlorobenzene	-127.6		-35.5				260.2			201.2		
C_6F_6	Hexafluorobenzene		-991.3	-955.4					280.8			221.6	
C_6F_{10}	Perfluorocyclohexene		-1963.5	-1932.7									
C_6F_{12}	Perfluorocyclohexane		-2406.3	-2370.4									
C_6HF_5	Pentafluorobenzene	-852.7	-841.8	-806.5									
C_6HF_5O	Pentafluorophenol	-1024.1	-1007.7										
$C_6H_2F_4$	1,2,4,5-Tetrafluorobenzene		-683.8										
$C_6H_3Cl_3$	1,2,3-Trichlorobenzene	-70.8		3.8									
$C_6H_3Cl_3$	1,2,4-Trichlorobenzene		-63.1	-8.1									
$C_6H_3Cl_3$	1,3,5-Trichlorobenzene	-78.4		-13.4									
$C_6H_3N_3O_8$	2,4,6-Trinitro-1,3-benzenediol	-467.5											
$C_6H_4Cl_2$	*o*-Dichlorobenzene		-17.5	30.2								162.4	
$C_6H_4Cl_2$	*m*-Dichlorobenzene		-20.7	25.7									
$C_6H_4Cl_2$	*p*-Dichlorobenzene	-42.3		22.5				175.4			147.8		
$C_6H_4F_2$	*o*-Difluorobenzene		-330.0	-293.8					222.6			159.0	
$C_6H_4F_2$	*m*-Difluorobenzene		-343.9	-309.2					223.8			159.1	
$C_6H_4F_2$	*p*-Difluorobenzene		-342.3	-306.7								157.5	
$C_6H_4N_2O_5$	2,4-Dinitrophenol	-232.7		-128.1									
$C_6H_4O_2$	*p*-Benzoquinone	-185.7		-122.9							129.0		
C_6H_5Br	Bromobenzene		60.9						219.2			154.3	
C_6H_5Cl	Chlorobenzene		11.1	52.0								150.1	
C_6H_5ClO	*m*-Chlorophenol	-206.4	-189.3										
C_6H_5ClO	*p*-Chlorophenol	-197.7	-181.3										
C_6H_5F	Fluorobenzene		-150.6	-115.9					205.9			146.4	
C_6H_5I	Iodobenzene		117.2	164.9					205.4			158.7	
$C_6H_5NO_2$	Nitrobenzene		12.5	67.5								185.8	
$C_6H_5NO_2$	3-Pyridinecarboxylic acid	-344.9		-221.5									
$C_6H_5NO_3$	2-Nitrophenol	-202.4											
$C_6H_5N_3$	1*H*-Benzotriazole	236.5		335.5									
$C_6H_5N_3O_4$	2,3-Dinitroaniline	-11.7											
$C_6H_5N_3O_4$	2,4-Dinitroaniline	-67.8											
$C_6H_5N_3O_4$	2,5-Dinitroaniline	-44.3											
$C_6H_5N_3O_4$	2,6-Dinitroaniline	-50.6											
$C_6H_5N_3O_4$	3,5-Dinitroaniline	-38.9											
C_6H_6	1,5-Hexadiyne		384.2										
C_6H_6	Benzene		49.1	82.9		124.5	129.7		173.4	269.2		136.0	82.4

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_6H_6N_2O_2$	*o*-Nitroaniline	-26.1	-9.4	63.8							166.0		
$C_6H_6N_2O_2$	*m*-Nitroaniline	-38.3	-14.4	58.4							158.8		
$C_6H_6N_2O_2$	*p*-Nitroaniline	-42.0	-20.7	58.8							167.0		
C_6H_6O	Phenol	-165.1		-96.4				144.0			127.4		
C_6H_6O	2-Vinylfuran		-10.3	27.8									
$C_6H_6O_2$	*p*-Hydroquinone	-364.5		-265.3							136.0		
$C_6H_6O_2$	Pyrocatechol	-354.1		-267.5									
$C_6H_6O_2$	Resorcinol	-368.0		-274.7									
$C_6H_6O_3$	1,2,3-Benzenetriol	-551.1		-434.2									
$C_6H_6O_3$	1,2,4-Benzenetriol	-563.8		-444.0									
$C_6H_6O_3$	1,3,5-Benzenetriol	-584.6		-452.9									
$C_6H_6O_3$	3,4-Dimethyl-2,5-furandione	-581.4											
$C_6H_6O_6$	*cis*-1-Propene-1,2,3-tricarboxylic acid	-1224.4											
$C_6H_6O_6$	*trans*-1-Propene-1,2,3-tricarboxylic acid	-1232.7											
C_6H_6S	Benzenethiol		63.7	111.3					222.8			173.2	
C_6H_7N	Aniline		31.6	87.5			-7.0			317.9		191.9	107.9
C_6H_7N	2-Methylpyridine		56.7	99.2								158.6	
C_6H_7N	3-Methylpyridine		61.9	106.4					216.3			158.7	
C_6H_7N	4-Methylpyridine		59.2	103.8					209.1			159.0	
C_6H_7N	1-Cyclopentenecarbonitrile		111.5	156.5									
$C_6H_8N_2$	Adiponitrile		85.1	149.5								128.7	
$C_6H_8N_2$	*o*-Phenylenediamine	-0.3											
$C_6H_8N_2$	*m*-Phenylenediamine	-7.8						154.5			159.6		
$C_6H_8N_2$	*p*-Phenylenediamine	3.0											
$C_6H_8N_2$	Phenylhydrazine		141.0	202.9								217.0	
$C_6H_8N_2S$	Bis(2-cyanoethyl) sulfide		96.3										
$C_6H_8O_4$	Dimethyl maleate											263.2	
$C_6H_8O_6$	*L*-Ascorbic acid	-1164.6											
$C_6H_8O_7$	2-Hydroxy-1,2,3-propanetricarboxylic acid	-1543.8											
$C_6H_9Cl_3O_2$	Butyl trichloroacetate		-545.8	-492.3									
$C_6H_9Cl_3O_2$	Isobutyl trichloroacetate		-553.4	-500.2									
C_6H_9N	Cyclopentanecarbonitrile		0.7	44.1									
C_6H_9N	2,4-Dimethylpyrrole	-422.3											
C_6H_9N	2,5-Dimethylpyrrole		-16.7	39.8									
$C_6H_9NO_3$	Triacetamide		-610.5	-550.1									
$C_6H_9NO_6$	Nitrilotriacetic acid	-1311.9											
$C_6H_9N_3O_2$	*L*-Histidine	-466.7											
C_6H_{10}	1,5-Hexadiene		54.1	84.2									
C_6H_{10}	3,3-Dimethyl-1-butyne		78.4										
C_6H_{10}	Cyclohexene		-38.5	-5.0					214.6			148.3	
C_6H_{10}	1-Methylcyclopentene		-36.4	-3.8									
C_6H_{10}	3-Methylcyclopentene		-23.7	7.4									

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
C_6H_{10}	4-Methylcyclopentene		-17.6	14.6									
$C_6H_{10}Cl_2O_2$	Butyl dichloroacetate		-550.1	-497.8									
$C_6H_{10}O$	Cyclohexanone		-271.2	-226.1								182.2	
$C_6H_{10}O$	2-Methylcyclopentanone		-265.2										
$C_6H_{10}O$	Mesityl oxide											212.5	
$C_6H_{10}O_2$	Ethyl *trans*-2-butenoate		-420.0	-375.6									
$C_6H_{10}O_2$	Methyl cyclobutane-carboxylate		-395.0	-350.2									
$C_6H_{10}O_3$	Ethyl acetoacetate											248.0	
$C_6H_{10}O_3$	Propanoic anhydride		-679.1	-626.5									
$C_6H_{10}O_4$	Adipic acid	-994.3											
$C_6H_{10}O_4$	Diethyl oxalate		-805.5	-742.0									
$C_6H_{10}O_4$	Ethylene glycol diacetate											310.0	
$C_6H_{11}Cl$	Chlorocyclohexane		-207.2	-163.7									
$C_6H_{11}ClO_2$	Ethyl 4-chlorobutanoate		-566.5	-513.8									
$C_6H_{11}ClO_2$	Propyl 3-chloropropanoate		-537.6	-485.7									
$C_6H_{11}ClO_2$	Butyl chloroacetate		-538.4	-487.4									
$C_6H_{11}NO$	Caprolactam	-329.4		-239.6							156.8		
$C_6H_{11}NO$	1-Methyl-2-piperidinone		-293.0										
C_6H_{12}	1-Hexene		-74.2	-43.5					295.2			183.3	
C_6H_{12}	*cis*-2-Hexene		-83.9	-52.3									
C_6H_{12}	*trans*-2-Hexene		-85.5	-53.9									
C_6H_{12}	*cis*-3-Hexene		-78.9	-47.6									
C_6H_{12}	*trans*-3-Hexene		-86.1	-54.4									
C_6H_{12}	2-Methyl-1-pentene		-90.0	-59.4									
C_6H_{12}	3-Methyl-1-pentene		-78.2	-49.5									
C_6H_{12}	4-Methyl-1-pentene		-80.0	-51.3									
C_6H_{12}	3-Methyl-*cis*-2-pentene		-94.5	-62.3									
C_6H_{12}	4-Methyl-*cis*-2-pentene		-87.0	-57.5									
C_6H_{12}	3-Methyl-*trans*-2-pentene		-94.6	-63.1									
C_6H_{12}	4-Methyl-*trans*-2-pentene		-91.6	-61.5									
C_6H_{12}	2-Ethyl-1-butene		-87.1	-56.0									
C_6H_{12}	2,3-Dimethyl-1-butene		-93.2	-62.4									
C_6H_{12}	3,3-Dimethyl-1-butene		-87.5	-60.3									
C_6H_{12}	2,3-Dimethyl-2-butene		-101.4	-68.1					270.2			174.7	
C_6H_{12}	Cyclohexane		-156.4	-123.4								154.9	
C_6H_{12}	Methylcyclopentane		-137.9	-106.2									
C_6H_{12}	Ethylcyclobutane		-59.0	-27.5									
C_6H_{12}	1,1,2-Trimethylcyclo-propane		-96.2										
C_6H_{12}	2-Methyl-2-pentene		-98.5	-66.9									
$C_6H_{12}N_2O_4S_2$	*L*-Cystine	-1032.7											
$C_6H_{12}O$	Cyclohexanol		-348.2	-286.2								208.2	
$C_6H_{12}O$	*cis*-2-Methylcyclopentanol		-345.5										
$C_6H_{12}O$	Butyl vinyl ether		-218.8	-182.6								232.0	

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_6H_{12}O$	2-Hexanone		-322.0	-278.9								213.3	
$C_6H_{12}O$	3-Hexanone		-320.2	-277.6					305.3			216.9	
$C_6H_{12}O$	Methyl isobutyl ketone											213.3	
$C_6H_{12}O$	2-Methyl-3-pentanone		-325.9	-286.0									
$C_6H_{12}O$	3,3-Dimethyl-2-butanone		-328.6	-290.6									
$C_6H_{12}O_2$	Hexanoic acid		-583.8	-511.9									
$C_6H_{12}O_2$	Butyl acetate		-529.2	-485.3								227.8	
$C_6H_{12}O_2$	Isobutyl acetate											233.8	
$C_6H_{12}O_2$	Ethyl butanoate											228.0	
$C_6H_{12}O_2$	Methyl pentanoate		-514.2	-471.1								229.3	
$C_6H_{12}O_2$	Methyl 2,2-dimethyl-propanoate		-530.0	-491.2								257.9	
$C_6H_{12}O_2$	Diacetone alcohol											221.3	
$C_6H_{12}O_3$	Ethylene glycol ethyl ether acetate											376.0	
$C_6H_{12}O_3$	Paraldehyde		-673.1	-631.7									
$C_6H_{12}O_6$	β-*D*-Fructose	-1265.6											
$C_6H_{12}O_6$	*D*-Galactose	-1286.3											
$C_6H_{12}O_6$	α-*D*-Glucose	-1273.3											
$C_6H_{12}O_6$	*D*-Mannose	-1263.0											
$C_6H_{12}O_6$	*L*-Sorbose	-1271.5											
$C_6H_{12}S$	Cyclohexanethiol		-140.7	-96.2					255.6			192.6	
$C_6H_{12}S$	Cyclopentyl methyl sulfide		-109.8	-64.7									
$C_6H_{13}Br$	1-Bromohexane		-194.2	-148.3					453.0			203.5	
$C_6H_{13}Cl$	2-Chlorohexane		-246.1	-204.3									
$C_6H_{13}N$	Cyclohexylamine		-147.6	-104.0									
$C_6H_{13}N$	(±)-2-Methylpiperidine		-124.9	-84.4									
$C_6H_{13}NO$	Hexanamide		-397.9	-324.2									
$C_6H_{13}NO$	*N*-Butylacetamide		-380.9	-305.9									
$C_6H_{13}NO_2$	*DL*-Leucine	-640.6											
$C_6H_{13}NO_2$	*D*-Leucine	-637.3											
$C_6H_{13}NO_2$	*L*-Leucine	-637.4		-486.8							200.1		
$C_6H_{13}NO_2$	*DL*-Isoleucine	-635.3											
$C_6H_{13}NO_2$	*L*-Isoleucine	-637.8											
$C_6H_{13}NO_2$	Norleucine	-639.1											
$C_6H_{13}NO_2$	6-Aminohexanoic acid	-637.3											
C_6H_{14}	Hexane		-198.7	-166.9								195.6	
C_6H_{14}	2-Methylpentane		-204.6	-174.6					290.6			193.7	
C_6H_{14}	3-Methylpentane		-202.4	-171.9					292.5			190.7	
C_6H_{14}	2,2-Dimethylbutane		-213.8	-185.9					272.5			191.9	
C_6H_{14}	2,3-Dimethylbutane		-207.4	-178.1					287.8			189.7	
$C_6H_{14}N_2$	Azopropane		11.5	51.3									
$C_6H_{14}N_2O_2$	Lysine	-678.7											
$C_6H_{14}N_4O_2$	*D*-Arginine	-623.5						250.6			232.0		
$C_6H_{14}O$	1-Hexanol		-377.5	-315.9					287.4			240.4	

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$C_6H_{14}O$	2-Hexanol		-392.0	-333.5									
$C_6H_{14}O$	3-Hexanol		-392.4									286.2	
$C_6H_{14}O$	2-Methyl-1-pentanol											248.0	
$C_6H_{14}O$	3-Methyl-2-pentanol											275.9	
$C_6H_{14}O$	4-Methyl-2-pentanol		-394.7									273.0	
$C_6H_{14}O$	2-Methyl-3-pentanol		-396.4										
$C_6H_{14}O$	3-Methyl-3-pentanol											293.4	
$C_6H_{14}O$	Dipropyl ether		-328.8	-293.0					323.9			221.6	
$C_6H_{14}O$	Diisopropyl ether		-351.5	-319.2								216.8	
$C_6H_{14}O$	Butyl ethyl ether											159.0	
$C_6H_{14}O$	Ethyl *tert*-butyl ether			-313.9									
$C_6H_{14}OS$	Dipropyl sulfoxide		-329.4	-254.9									
$C_6H_{14}O_2$	1,2-Hexanediol		-577.1	-490.1									
$C_6H_{14}O_2$	1,6-Hexanediol	-569.9	-548.6	-461.2									
$C_6H_{14}O_2$	Hexylene glycol											336.0	
$C_6H_{14}O_2$	Ethylene glycol monobutyl ether											281.0	
$C_6H_{14}O_2$	1,1-Diethoxyethane		-491.4	-453.5									
$C_6H_{14}O_2$	1,2-Diethoxyethane		-451.4	-408.1								259.4	
$C_6H_{14}O_3$	Diethylene glycol monoethyl ether											301.0	
$C_6H_{14}O_3$	Diethylene glycol dimethyl ether											274.1	
$C_6H_{14}O_3$	Trimethylolpropane	-750.9											
$C_6H_{14}O_4$	Triethylene glycol		-804.3	-725.0									
$C_6H_{14}O_4S$	Dipropyl sulfate		-859.0	-792.0									
$C_6H_{14}O_6$	Galactitol		-1317.0										
$C_6H_{14}O_6$	*D*-Mannitol		-1314.5										
$C_6H_{14}S$	1-Hexanethiol		-175.7	-129.9									
$C_6H_{14}S$	2-Methyl-2-pentanethiol		-188.3	-148.3									
$C_6H_{14}S$	2,3-Dimethyl-2-butanethiol		-187.1	-147.9									
$C_6H_{14}S$	Diisopropyl sulfide		-181.6	-142.0					313.0			232.0	
$C_6H_{14}S$	Butyl ethyl sulfide		-172.3	-127.8									
$C_6H_{14}S$	Methyl pentyl sulfide		-167.1	-121.8									
$C_6H_{14}S_2$	Dipropyl disulfide		-171.5	-118.3									
$C_6H_{15}B$	Triethylborane		-194.6	-157.7		9.4	16.1		336.7	437.8		241.2	
$C_6H_{15}N$	Dipropylamine		-156.1	-116.0									
$C_6H_{15}N$	Diisopropylamine		-178.5	-143.8									
$C_6H_{15}N$	Triethylamine		-127.7	-92.7								219.9	
$C_6H_{15}NO$	2-Diethylaminoethanol		-305.9										
$C_6H_{15}NO_3$	Triethanolamine	-664.2		-558.3							389.0		
$C_6H_{18}N_3OP$	Hexamethylphosphoric triamide											321.0	
$C_6H_{18}OSi_2$	Hexamethyldisiloxane		-815.0	-777.7		-541.5	-534.5		433.8	535.0		311.4	238.5
C_6MoO_6	Molybdenum hexacarbonyl	-982.8		-912.1	-877.7		-856.0	325.9		490.0	242.3		205.0

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
C_6N_4	Tetracyanoethylene	623.8		705.0									
C_7F_8	Perfluorotoluene		-1311.1						355.5			262.3	
C_7F_{14}	Perfluoromethylcyclohexane		-2931.1	-2897.2								353.1	
C_7F_{16}	Perfluoroheptane		-3420.0	-3383.6					561.8			419.0	
$C_7H_3F_5$	2,3,4,5,6-Pentafluorotoluene		-883.8	-842.7					306.4			225.8	
$C_7H_4Cl_2O$	*m*-Chlorobenzoyl chloride		-189.7										
$C_7H_4N_2O_6$	3,5-Dinitrobenzoic acid	-409.8											
C_7H_5ClO	Benzoyl chloride		-158.0	-103.2									
$C_7H_5ClO_2$	*o*-Chlorobenzoic acid	-404.5		-325.0									
$C_7H_5ClO_2$	*o*-Chlorobenzoic acid	-424.3		-342.3									
$C_7H_5ClO_2$	*p*-Chlorobenzoic acid	-428.9		-341.0							163.2		
$C_7H_5F_3$	(Trifluoromethyl)benzene											188.4	
C_7H_5N	Benzonitrile		163.2	215.7					209.1			165.2	
C_7H_5NO	Benzoxazole	-24.2		44.8									
$C_7H_5NO_4$	2-Nitrobenzoic acid	-378.8											
$C_7H_5NO_4$	3-Nitrobenzoic acid	-394.7											
$C_7H_5NO_4$	4-Nitrobenzoic acid	-392.2											
$C_7H_6N_2$	1*H*-Benzimidazole	79.5		181.7									
$C_7H_6N_2$	1*H*-Indazole	151.9		243.0									
C_7H_6O	Benzaldehyde		-87.0	-36.7					221.2			172.0	
$C_7H_6O_2$	Benzoic acid	-385.2		-294.0				167.6			146.8		
$C_7H_6O_2$	3-(2-Furanyl)-2-propenal	-182.0		-105.9									
$C_7H_6O_2$	Salicylaldehyde											222.0	
$C_7H_6O_3$	Salicylic acid	-589.9		-494.8									
C_7H_7Cl	*o*-Chlorotoluene											166.8	
C_7H_7Cl	(Chloromethyl)benzene		-32.5	18.9									
C_7H_7F	*p*-Fluorotoluene		-186.9	-147.4								171.2	
C_7H_7NO	Benzamide	-202.6		-100.9									
$C_7H_7NO_2$	2-Aminobenzoic acid		-380.4	-296.0									
$C_7H_7NO_2$	Aniline-3-carboxylic acid		-389.8	-283.6									
$C_7H_7NO_2$	Aniline-4-carboxylic acid		-391.9	-296.7									
$C_7H_7NO_2$	*o*-Nitrotoluene		-9.7										
$C_7H_7NO_2$	*m*-Nitrotoluene		-31.5										
$C_7H_7NO_2$	*p*-Nitrotoluene	-48.1		31.0							172.3		
$C_7H_7NO_2$	(Nitromethyl)benzene		-22.8	30.7									
$C_7H_7NO_2$	Salicylaldoxime	-183.7											
C_7H_8	Toluene		12.4	50.5								157.3	
$C_7H_8N_2O$	Phenylurea	-218.6											
C_7H_8O	*o*-Cresol	-204.6		-128.6				165.4			154.6		
C_7H_8O	*m*-Cresol		-194.0	-132.3					212.6			224.9	
C_7H_8O	*p*-Cresol	-199.3		-125.4				167.3			150.2		
C_7H_8O	Benzyl alcohol		-160.7	-100.4					216.7			217.9	
C_7H_8O	Anisole		-114.8	-67.9									
C_7H_9N	Benzylamine		34.2	94.4									
C_7H_9N	*o*-Methylaniline		-6.3	56.4			167.6			351.0			130.2

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	**Liq.**	**Gas**	**Crys.**	**Liq.**	**Gas**	**Crys.**	**Liq.**	**Gas**	**Crys.**	**Liq.**	**Gas**
C_7H_9N	*m*-Methylaniline		-8.1	54.6			165.4			352.5			125.5
C_7H_9N	*p*-Methylaniline	-23.5		55.3			167.7			347.0			126.2
C_7H_9N	*N*-Methylaniline											207.1	
C_7H_9N	1-Cyclohexenecarbonitrile		48.1	101.6									
C_7H_9N	2,3-Dimethylpyridine		19.4	67.1					243.7			189.5	
C_7H_9N	2,4-Dimethylpyridine		16.1	63.6					248.5			184.8	
C_7H_9N	2,5-Dimethylpyridine		18.7	66.5					248.8			184.7	
C_7H_9N	2,6-Dimethylpyridine		12.7	58.1					244.2			185.2	
C_7H_9N	3,4-Dimethylpyridine		18.3	68.8					240.7			191.8	
C_7H_9N	3,5-Dimethylpyridine		22.5	72.0					241.7			184.5	
$C_7H_{10}O_2$	Ethyl 2-pentynoate		-301.8	-250.3									
$C_7H_{10}O_2$	Methyl 2-hexynoate		-242.7										
$C_7H_{11}Cl_3O_2$	3-Methylbutyl trichloroacetate		-580.9	-523.1									
$C_7H_{11}N$	Cyclohexanecarbonitrile		-47.2	4.8									
C_7H_{12}	Methylenecyclohexane		-61.3	-25.2									
C_7H_{12}	Vinylcyclopentane		-34.8										
C_7H_{12}	1-Ethylcyclopentene		-53.3	-19.8									
C_7H_{12}	Bicyclo[2.2.1]heptane	-95.1		-54.8									
C_7H_{12}	1-Methylbicyclo(3,1,0) hexane		-33.2	1.7									
$C_7H_{12}O$	2-Methylenecyclohexanol	-277.6											
$C_7H_{12}O_4$	Diethyl malonate											285.0	
$C_7H_{13}ClO_2$	Butyl 2-chloropropanoate		-571.7	-517.3									
$C_7H_{13}ClO_2$	Isobutyl 2-chloropropanoate		-603.1	-549.6									
$C_7H_{13}ClO_2$	Butyl 3-chloropropanoate		-557.9	-502.3									
$C_7H_{13}ClO_2$	Isobutyl 3-chloropropanoate		-572.6	-517.3									
$C_7H_{13}ClO_2$	Propyl 2-chlorobutanoate		-630.7	-578.4									
$C_7H_{13}N$	Heptanenitrile		-82.8	-31.0									
C_7H_{14}	1-Heptene		-97.9	-62.3					327.6			211.8	
C_7H_{14}	*cis*-2-Heptene		-105.1										
C_7H_{14}	*trans*-2-Heptene		-109.5										
C_7H_{14}	*cis*-3-Heptene		-104.3										
C_7H_{14}	*trans*-3-Heptene		-109.3										
C_7H_{14}	5-Methyl-1-hexene		-100.0	-65.7									
C_7H_{14}	3-Methyl-*cis*-3-hexene		-115.9	-79.4									
C_7H_{14}	3-Methyl-*trans*-3-hexene		-112.7	-76.8									
C_7H_{14}	2,4-Dimethyl-1-pentene		-117.0	-83.8									
C_7H_{14}	4,4-Dimethyl-1-pentene		-110.6	-81.6									
C_7H_{14}	2,4-Dimethyl-2-pentene		-123.1	-88.7									
C_7H_{14}	*cis*-4,4-Dimethyl-2-pentene		-105.3	-72.6									
C_7H_{14}	*trans*-4,4-Dimethyl-2-pentene		-121.7	-88.8									
C_7H_{14}	2-Ethyl-3-methyl-1-butene		-114.1	-79.5									
C_7H_{14}	2,3,3-Trimethyl-1-butene		-117.7	-85.5									
C_7H_{14}	Cycloheptane		-156.6	-118.1									
C_7H_{14}	Methylcyclohexane		-190.1	-154.7								184.8	

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	$\Delta_f H°$/kJ mol^{-1} Liq.	$\Delta_f H°$/kJ mol^{-1} Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	$\Delta_f G°$/kJ mol^{-1} Liq.	$\Delta_f G°$/kJ mol^{-1} Gas	$S°$/J mol^{-1} K^{-1} Crys.	$S°$/J mol^{-1} K^{-1} Liq.	$S°$/J mol^{-1} K^{-1} Gas	C_p/J mol^{-1} K^{-1} Crys.	C_p/J mol^{-1} K^{-1} Liq.	C_p/J mol^{-1} K^{-1} Gas
C_7H_{14}	Ethylcyclopentane		-163.4	-126.9					279.9				
C_7H_{14}	1,1-Dimethylcyclopentane		-172.1	-138.2									
C_7H_{14}	*cis*-1,2-Dimethylcyclopentane		-165.3	-129.5					269.2				
C_7H_{14}	*trans*-1,2-Dimethylcyclopentane		-171.2	-136.6									
C_7H_{14}	*cis*-1,3-Dimethylcyclopentane		-170.1	-135.8									
C_7H_{14}	*trans*-1,3-Dimethylcyclopentane		-168.1	-133.6									
C_7H_{14}	1,1,2,2-Tetramethylcyclopropane		-119.8										
$C_7H_{14}Br_2$	1,2-Dibromoheptane		-212.3	-157.9									
$C_7H_{14}O$	1-Heptanal		-311.5	-263.8					335.4			230.1	
$C_7H_{14}O$	2-Heptanone											232.6	
$C_7H_{14}O$	2,2-Dimethyl-3-pentanone		-356.1	-313.6									
$C_7H_{14}O$	2,4-Dimethyl-3-pentanone		-352.9	-311.3					318.0			233.7	
$C_7H_{14}O$	*cis*-2-Methylcyclohexanol		-390.2	-327.0									
$C_7H_{14}O$	*trans*-2-Methylcyclohexanol		-415.7	-352.5									
$C_7H_{14}O$	*cis*-3-Methylcyclohexanol		-416.1	-350.9									
$C_7H_{14}O$	*trans*-3-Methylcyclohexanol		-394.4	-329.1									
$C_7H_{14}O$	*cis*-4-Methylcyclohexanol		-413.2	-347.5									
$C_7H_{14}O$	*trans*-4-Methylcyclohexanol		-433.3	-367.2									
$C_7H_{14}O_2$	Heptanoic acid		-610.2	-536.2								265.4	
$C_7H_{14}O_2$	Pentyl acetate											261.0	
$C_7H_{14}O_2$	Isopentyl acetate											248.5	
$C_7H_{14}O_2$	Ethyl pentanoate		-553.0	-505.9									
$C_7H_{14}O_2$	Ethyl 3-methylbutanoate		-571.0	-527.0									
$C_7H_{14}O_2$	Ethyl 2,2-dimethylpropanoate		-577.2	-536.0									
$C_7H_{14}O_2$	Methyl hexanoate		-540.2	-492.2									
$C_7H_{14}O_6$	α-Methylglucoside	-1233.3											
$C_7H_{15}Br$	1-Bromoheptane		-218.4	-167.8									
C_7H_{16}	Heptane		-224.2	-187.6								224.7	
C_7H_{16}	2-Methylhexane		-229.5	-194.5					323.3			222.9	
C_7H_{16}	3-Methylhexane		-226.4	-191.3									
C_7H_{16}	3-Ethylpentane		-224.9	-189.5					314.5			219.6	
C_7H_{16}	2,2-Dimethylpentane		-238.3	-205.7					300.3			221.1	
C_7H_{16}	2,3-Dimethylpentane		-233.1	-198.7									
C_7H_{16}	2,4-Dimethylpentane		-234.6	-201.6					303.2			224.2	
C_7H_{16}	3,3-Dimethylpentane		-234.2	-201.0									
C_7H_{16}	2,2,3-Trimethylbutane		-236.5	-204.4					292.2			213.5	
$C_7H_{16}O$	1-Heptanol		-403.3	-336.5								272.1	
$C_7H_{16}O$	*tert*-Butyl isopropyl ether		-392.8	-358.1									
$C_7H_{16}O_2$	1,7-Heptanediol		-574.2										

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_7H_{16}O_2$	2,2-Diethoxypropane		-538.9	-506.9									
$C_7H_{16}S$	1-Heptanethiol		-200.5	-149.9									
$C_8H_4O_3$	Phthalic anhydride	-460.1		-371.4				180.0			160.0		
$C_8H_5NO_2$	1*H*-Indole-2,3-dione	-268.2											
$C_8H_6O_4$	Phthalic acid	-782.0						207.9			188.1		
$C_8H_6O_4$	Isophthalic acid	-803.0		-696.3									
$C_8H_6O_4$	Terephthalic acid	-816.1		-717.9									
C_8H_6S	Benzo[b]thiophene	100.6		166.3									
C_8H_7N	1*H*-Indole	86.6		156.5									
C_8H_8	Styrene		103.8	147.9								182.0	
C_8H_8O	Phenyl vinyl ether		-26.2	22.7									
C_8H_8O	Acetophenone		-142.5	-86.7									
$C_8H_8O_2$	*o*-Toluic acid	-416.5									174.9		
$C_8H_8O_2$	*m*-Toluic acid	-426.1									163.6		
$C_8H_8O_2$	*p*-Toluic acid	-429.2									169.0		
$C_8H_8O_2$	Methyl benzoate		-343.5	-287.9								221.3	
$C_8H_8O_3$	Methyl salicylate											249.0	
C_8H_{10}	1,7-Octadiyne		334.4										
C_8H_{10}	Ethylbenzene		-12.3	29.9								183.2	
C_8H_{10}	*o*-Xylene		-24.4	19.1								186.1	
C_8H_{10}	*m*-Xylene		-25.4	17.3								183.0	
C_8H_{10}	*p*-Xylene		-24.4	18.0								181.5	
$C_8H_{10}O$	*o*-Ethylphenol		-208.8	-145.2									
$C_8H_{10}O$	*m*-Ethylphenol		-214.3	-146.1									
$C_8H_{10}O$	*p*-Ethylphenol	-224.4		-144.1							206.9		
$C_8H_{10}O$	2,3-Xylenol	-241.1		-157.2									
$C_8H_{10}O$	2,4-Xylenol		-228.7	-163.8									
$C_8H_{10}O$	2,5-Xylenol	-246.6		-161.6									
$C_8H_{10}O$	2,6-Xylenol	-237.4		-162.1									
$C_8H_{10}O$	3,4-Xylenol	-242.3		-157.3									
$C_8H_{10}O$	3,5-Xylenol	-244.4		-162.4									
$C_8H_{10}O$	Phenetole		-152.6	-101.6								228.5	
$C_8H_{10}O_2$	Veratrole		-290.3	-223.3									
$C_8H_{11}N$	*N*-Ethylaniline		4.0	56.3									
$C_8H_{11}N$	*N*,*N*-Dimethylaniline		47.7	100.5									
$C_8H_{11}N$	2,6-Xylidine											238.9	
C_8H_{12}	1-Octen-3-yne		140.7										
C_8H_{12}	*cis*-1,2-Divinylcyclobutane		124.3	166.5									
C_8H_{12}	*trans*-1,2-Divinylcyclobutane		101.3	143.5									
$C_8H_{12}N_4$	2,2′-Azobis[isobutyronitrile]	228.9											
$C_8H_{12}O_2$	2,2,4,4-Tetramethyl-1,3-cyclobutanedione	-379.9		-307.6									
C_8H_{14}	Ethylidenecyclohexane		-103.5	-59.5									

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
C_8H_{14}	Allylcyclopentane		-64.5	-24.1									
$C_8H_{14}O_3$	Butanoic anhydride											283.7	
$C_8H_{15}ClO_2$	3-Methylbutyl 2-chloropropanoate		-627.3	-575.0									
$C_8H_{15}ClO_2$	3-Methylbutyl 3-chloropropanoate		-593.4	-539.4									
$C_8H_{15}N$	Octanenitrile		-107.3	-50.5									
C_8H_{16}	1-Octene		-121.8	-81.3								241.0	
C_8H_{16}	*cis*-2-Octene		-135.7									239.0	
C_8H_{16}	*trans*-2-Octene		-135.7									239.0	
C_8H_{16}	2,2-Dimethyl-*cis*-3-hexene		-126.4	-89.3									
C_8H_{16}	2,2-Dimethyl-*trans*-3-hexene		-144.9	-107.7									
C_8H_{16}	3-Ethyl-2-methyl-1-pentene		-137.9	-100.3									
C_8H_{16}	2,4,4-Trimethyl-1-pentene		-145.9	-110.5									
C_8H_{16}	2,4,4-Trimethyl-2-pentene		-142.4	-104.9									
C_8H_{16}	Cyclooctane		-167.7	-124.4									
C_8H_{16}	Ethylcyclohexane		-212.1	-171.5					280.9			211.8	
C_8H_{16}	1,1-Dimethylcyclohexane		-218.7	-180.9					267.2			209.2	
C_8H_{16}	*cis*-1,2-Dimethylcyclohexane		-211.8	-172.1					274.1			210.2	
C_8H_{16}	*trans*-1,2-Dimethylcyclohexane		-218.2	-179.9					273.2			209.4	
C_8H_{16}	*cis*-1,3-Dimethylcyclohexane		-222.9	-184.6					272.6			209.4	
C_8H_{16}	*trans*-1,3-Dimethylcyclohexane		-215.7	-176.5					276.3			212.8	
C_8H_{16}	*cis*-1,4-Dimethylcyclohexane		-215.6	-176.6					271.1			212.1	
C_8H_{16}	*trans*-1,4-Dimethylcyclohexane		-222.4	-184.5					268.0			210.2	
C_8H_{16}	Propylcyclopentane		-188.8	-147.7					310.8			216.3	
C_8H_{16}	1-Ethyl-1-methylcyclopentane		-193.8										
C_8H_{16}	*cis*-1-Ethyl-2-methylcyclopentane		-190.8										
C_8H_{16}	*trans*-1-Ethyl-2-methylcyclopentane		-195.1	-156.2									
C_8H_{16}	*cis*-1-Ethyl-3-methylcyclopentane		-194.4										
C_8H_{16}	*trans*-1-Ethyl-3-methylcyclopentane		-196.0										
$C_8H_{16}O$	2-Ethylhexanal		-348.5	-299.6									
$C_8H_{16}O$	2-Octanone											273.3	
$C_8H_{16}O$	2,2,4-Trimethyl-3-pentanone		-381.6	-338.3									
$C_8H_{16}O_2$	Octanoic acid		-636.0	-554.3								297.9	
$C_8H_{16}O_2$	2-Ethylhexanoic acid		-635.1	-559.5									
$C_8H_{16}O_2$	Hexyl acetate											282.8	
$C_8H_{16}O_2$	Propyl pentanoate		-583.0	-533.6									
$C_8H_{16}O_2$	Isopropyl pentanoate		-592.2	-544.9									

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
$C_8H_{16}O_2$	Methyl heptanoate		-567.1	-515.5								285.1	
$C_8H_{17}Br$	1-Bromooctane		-245.1	-189.3									
$C_8H_{17}Cl$	1-Chlorooctane		-291.3	-238.9									
$C_8H_{17}NO$	Octanamide	-473.2		-362.7									
C_8H_{18}	Octane		-250.1	-208.5								254.6	
C_8H_{18}	2-Methylheptane		-255.0	-215.3					356.4			252.0	
C_8H_{18}	3-Methylheptane		-252.3	-212.5					362.6			250.2	
C_8H_{18}	4-Methylheptane		-251.6	-211.9								251.1	
C_8H_{18}	3-Ethylhexane		-250.4	-210.7									
C_8H_{18}	2,2-Dimethylhexane		-261.9	-224.5									
C_8H_{18}	2,3-Dimethylhexane		-252.6	-213.8									
C_8H_{18}	2,4-Dimethylhexane		-257.0	-219.2									
C_8H_{18}	2,5-Dimethylhexane		-260.4	-222.5								249.2	
C_8H_{18}	3,3-Dimethylhexane		-257.5	-219.9								246.6	
C_8H_{18}	3,4-Dimethylhexane		-251.8	-212.8									
C_8H_{18}	3-Ethyl-2-methylpentane		-249.6	-211.0									
C_8H_{18}	3-Ethyl-3-methylpentane		-252.8	-214.8									
C_8H_{18}	2,2,3-Trimethylpentane		-256.9	-220.0									
C_8H_{18}	2,2,4-Trimethylpentane		-259.2	-224.0								239.1	
C_8H_{18}	2,3,3-Trimethylpentane		-253.5	-216.3								245.6	
C_8H_{18}	2,3,4-Trimethylpentane		-255.0	-217.3					329.3			247.3	
C_8H_{18}	2,2,3,3-Tetramethylbutane	-269.0		-226.0				273.7			239.2		
$C_8H_{18}N_2$	Azobutane		-40.1	9.2									
$C_8H_{18}O$	1-Octanol		-426.5	-355.6								305.2	
$C_8H_{18}O$	2-Octanol											330.1	
$C_8H_{18}O$	2-Ethyl-1-hexanol		-432.8	-365.3					347.0			317.5	
$C_8H_{18}O$	Dibutyl ether		-377.9	-332.8								278.2	
$C_8H_{18}O$	Di-*sec*-butyl ether		-401.5	-360.6									
$C_8H_{18}O$	Di-*tert*-butyl ether		-399.6	-362.0								276.1	
$C_8H_{18}O$	*tert*-Butyl isobutyl ether		-409.1	-369.0									
$C_8H_{18}O_2$	1,8-Octanediol	-626.6											
$C_8H_{18}O_2$	2,5-Dimethyl-2,5-hexanediol	-681.7											
$C_8H_{18}O_3$	Diethylene glycol diethyl ether											341.4	
$C_8H_{18}O_3S$	Dibutyl sulfite		-693.1	-625.3									
$C_8H_{18}O_5$	Tetraethylene glycol		-981.7	-883.0								428.8	
$C_8H_{18}S$	Dibutyl sulfide		-220.7	-167.7					405.1			284.3	
$C_8H_{18}S$	Di-*sec*-butyl sulfide		-220.7	-167.7									
$C_8H_{18}S$	Di-*tert*-butyl sulfide		-232.6	-188.8									
$C_8H_{18}S$	Diisobutyl sulfide		-229.2	-180.5									
$C_8H_{18}S_2$	Dibutyl disulfide		-222.9	-160.6									
$C_8H_{18}S_2$	Di-*tert*-butyl disulfide		-255.2	-201.0									
$C_8H_{19}N$	Dibutylamine		-206.0	-156.6								292.9	
$C_8H_{19}N$	Diisobutylamine		-218.5	-179.2									

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
$C_8H_{20}BrN$	Tetraethylammonium bromide	-342.7											
$C_8H_{20}Pb$	Tetraethyl lead		52.7	109.6					464.6			307.4	
$C_8H_{20}Si$	Tetraethylsilane											298.1	
C_9H_7N	Quinoline		141.2	200.5									
C_9H_7N	Isoquinoline		144.3	204.6					216.0			196.2	
C_9H_7NO	2-Hydroxyquinoline	-144.9		-25.5									
C_9H_8	Indene		110.6	163.4					215.3			186.9	
$C_9H_8O_4$	2-(Acetyloxy)benzoic acid	-815.6											
C_9H_{10}	Cyclopropylbenzene		100.3	150.5									
C_9H_{10}	Indan		11.5	60.3					56.0			190.2	
$C_9H_{10}N_2$	2,2′-Dipyrrolylmethane	126.2											
$C_9H_{10}O_2$	Benzyl acetate											148.5	
$C_9H_{10}O_2$	Ethyl benzoate											246.0	
$C_9H_{11}NO_2$	*L*-Phenylalanine	-466.9		-312.9				213.6			203.0		
$C_9H_{11}NO_3$	*L*-Tyrosine	-685.1						214.0			216.4		
C_9H_{12}	Propylbenzene		-38.3	7.9					287.8			214.7	
C_9H_{12}	Cumene		-41.1	4.0								210.7	
C_9H_{12}	*o*-Ethyltoluene		-46.4	1.3									
C_9H_{12}	*m*-Ethyltoluene		-48.7	-1.8									
C_9H_{12}	*p*-Ethyltoluene		-49.8	-3.2									
C_9H_{12}	1,2,3-Trimethylbenzene		-58.5	-9.5					267.9			216.4	
C_9H_{12}	1,2,4-Trimethylbenzene		-61.8	-13.8								215.0	
C_9H_{12}	Mesitylene		-63.4	-15.9								209.3	
$C_9H_{12}O$	2-Isopropylphenol		-233.7	-182.2									
$C_9H_{12}O$	3-Isopropylphenol		-252.5	-196.0									
$C_9H_{12}O$	4-Isopropylphenol		-265.9	-209.4									
$C_9H_{12}O_2$	Hydroperoxide, 1-methyl-1-phenylethyl		-148.3	-78.4									
$C_9H_{13}NO_2$	Ethyl 3,5-dimethylpyrrole-2-carboxylate	-474.5											
$C_9H_{13}NO_2$	Ethyl 2,4-dimethylpyrrole-3-carboxylate	-463.2											
$C_9H_{13}NO_2$	Ethyl 2,5-dimethylpyrrole-3-carboxylate	-478.7											
$C_9H_{13}NO_2$	Ethyl 4,5-dimethylpyrrole-3-carboxylate	-470.3											
$C_9H_{14}O$	Isophorone											253.5	
$C_9H_{14}O_6$	Triacetin		-1330.8	-1245.0					458.3			384.7	
$C_9H_{15}N$	3-Ethyl-2,4,5-trimethyl-pyrrole	-89.2											
$C_9H_{16}O_4$	Nonanedioic acid	-1054.3											
$C_9H_{17}NO$	2,2,6,6-Tetramethyl-4-piperidinone	-334.2		-273.4									
C_9H_{18}	Propylcyclohexane		-237.4	-192.3					311.9			242.0	

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
C_9H_{18}	1,3,5-Trimethylcyclohexane (1′,3′,5′)			-212.1									
$C_9H_{18}O$	2-Nonanone		-397.2	-340.7									
$C_9H_{18}O$	5-Nonanone		-398.2	-344.9					401.4			303.6	
$C_9H_{18}O$	2,6-Dimethyl-4-heptanone		-408.5	-357.6								297.3	
$C_9H_{18}O_2$	Nonanoic acid		-659.7	-577.3								362.4	
$C_9H_{18}O_2$	Butyl pentanoate	-613.3		-560.2									
$C_9H_{18}O_2$	*sec*-Butyl pentanoate		-624.2	-573.2									
$C_9H_{18}O_2$	Isobutyl pentanoate		-620.0	-568.6									
$C_9H_{18}O_2$	Methyl octanoate		-590.3	-533.9									
$C_9H_{19}N$	*N*-Butylpiperidine		-171.8										
$C_9H_{19}N$	2,2,6,6-Tetramethylpiperidine		-206.9	-159.9									
C_9H_{20}	Nonane		-274.7	-228.2								284.4	
C_9H_{20}	2,2-Dimethylheptane		-288.1										
C_9H_{20}	2,2,3-Trimethylhexane		-282.7										
C_9H_{20}	2,2,4-Trimethylhexane		-282.8										
C_9H_{20}	2,2,5-Trimethylhexane		-293.3										
C_9H_{20}	2,3,3-Trimethylhexane		-281.1										
C_9H_{20}	2,3,5-Trimethylhexane		-284.0	-242.6									
C_9H_{20}	2,4,4-Trimethylhexane		-280.2										
C_9H_{20}	3,3,4-Trimethylhexane		-277.5										
C_9H_{20}	3,3-Diethylpentane		-275.4	-233.3								278.2	
C_9H_{20}	3-Ethyl-2,2-dimethylpentane		-272.7										
C_9H_{20}	3-Ethyl-2,4-dimethylpentane		-269.7										
C_9H_{20}	2,2,3,3-Tetramethylpentane		-278.3	-237.1								271.5	
C_9H_{20}	2,2,3,4-Tetramethylpentane		-277.7	-236.9									
C_9H_{20}	2,2,4,4-Tetramethylpentane		-280.0	-241.6								266.3	
C_9H_{20}	2,3,3,4-Tetramethylpentane		-277.9	-236.1									
$C_9H_{20}N_2O$	Tetraethylurea	-403.0											
$C_9H_{20}O$	1-Nonanol		-453.4	-376.5									
$C_9H_{20}O_2$	1,9-Nonanediol	-657.6											
$C_9H_{21}N$	Tripropylamine		-207.1	-161.0									
$C_{10}H_6N_2O_4$	1,5-Dinitronaphthalene	29.8											
$C_{10}H_6N_2O_4$	1,8-Dinitronaphthalene	39.7											
$C_{10}H_7Cl$	1-Chloronaphthalene		54.6	119.8								212.6	
$C_{10}H_7Cl$	2-Chloronaphthalene	55.4		137.4									
$C_{10}H_7I$	1-Iodonaphthalene		161.5	233.8									
$C_{10}H_7I$	2-Iodonaphthalene	144.3		235.1									
$C_{10}H_7NO_2$	1-Nitronaphthalene	42.6		111.2									
$C_{10}H_8$	Naphthalene	78.5		150.6	201.6		224.1	167.4		333.1	165.7		131.9
$C_{10}H_8$	Azulene	212.3		289.1									
$C_{10}H_8O$	1-Naphthol	-121.5		-30.4							166.9		
$C_{10}H_8O$	2-Naphthol		-124.1	-29.9									
$C_{10}H_9N$	1-Naphthalenamine	67.8		132.8									

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1}			$\Delta_f G°$/kJ mol^{-1}			$S°$/J mol^{-1} K^{-1}			C_p/J mol^{-1} K^{-1}		
		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
$C_{10}H_9N$	2-Naphthalenamine	60.2		134.3									
$C_{10}H_{10}$	1,2-Dihydronaphthalene		71.6										
$C_{10}H_{10}$	1,4-Dihydronaphthalene		84.2										
$C_{10}H_{10}O$	1-Tetralone	-209.6											
$C_{10}H_{10}O_4$	Dimethyl phthalate											303.1	
$C_{10}H_{10}O_4$	Dimethyl isophthalate	-730.9											
$C_{10}H_{10}O_4$	Dimethyl terephthalate	-732.6									261.1		
$C_{10}H_{12}$	1,2,3,4-Tetrahydronaphthalene		-29.2	26.0								217.5	
$C_{10}H_{14}$	Butylbenzene		-63.2	-11.8					321.2			243.4	
$C_{10}H_{14}$	*sec*-Butylbenzene		-66.4	-18.4									
$C_{10}H_{14}$	*tert*-Butylbenzene		-70.7	-23.0									
$C_{10}H_{14}$	Isobutylbenzene		-69.8	-21.9									
$C_{10}H_{14}$	*o*-Cymene		-73.3										
$C_{10}H_{14}$	*m*-Cymene		-78.6										
$C_{10}H_{14}$	*p*-Cymene		-78.0									236.4	
$C_{10}H_{14}$	*o*-Diethylbenzene		-68.5										
$C_{10}H_{14}$	*m*-Diethylbenzene		-73.5										
$C_{10}H_{14}$	*p*-Diethylbenzene		-72.8										
$C_{10}H_{14}$	3-Ethyl-*o*-xylene		-80.5										
$C_{10}H_{14}$	4-Ethyl-1,2-dimethylbenzene		-86.0										
$C_{10}H_{14}$	2-Ethyl-1,3-dimethylbenzene		-80.1										
$C_{10}H_{14}$	2-Ethyl-1,4-dimethylbenzene		-84.8										
$C_{10}H_{14}$	1-Ethyl-2,4-dimethylbenzene		-84.1										
$C_{10}H_{14}$	1-Ethyl-3,5-dimethylbenzene		-87.8										
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene	-119.9						245.6			215.1		
$C_{10}H_{14}O$	Thymol	-309.7		-218.5									
$C_{10}H_{16}$	*cis*, *cis*-2,6-Dimethyl-2,4,6-octatriene		-24.0										
$C_{10}H_{16}$	Dipentene		-50.8	-2.6								249.4	
$C_{10}H_{16}$	*D*-Limonene		-54.5									249.0	
$C_{10}H_{16}$	β-Myrcene		14.5										
$C_{10}H_{16}$	α-Pinene		-16.4	28.3									
$C_{10}H_{16}$	β-Pinene		-7.7	38.7									
$C_{10}H_{16}$	α-Terpinene			-20.6									
$C_{10}H_{16}N_2O_8$	Glycine, *N*,*N′*-1,2-ethanediylbis[*N*-(carboxymethyl)-	-1759.5											
$C_{10}H_{16}O$	Camphor	-319.4		-267.5							271.2		
$C_{10}H_{18}$	1,1′-Bicyclopentyl		-178.9										
$C_{10}H_{18}$	*cis*-Decahydronaphthalene		-219.4	-169.2					265.0			232.0	
$C_{10}H_{18}$	*trans*-Decahydronaphthalene		-230.6	-182.1					264.9			228.5	
$C_{10}H_{18}O_4$	Sebacic acid	-1082.6		-921.9									
$C_{10}H_{19}N$	Decanenitrile		-158.4	-91.5									
$C_{10}H_{20}$	1-Decene		-173.8	-123.3					425.0			300.8	
$C_{10}H_{20}$	*cis*-1,2-Di-*tert*-butylethylene		-163.6										

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		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
$C_{10}H_{20}$	Butylcyclohexane		-263.1	-213.7					345.0			271.0	
$C_{10}H_{20}O_2$	Decanoic acid	-713.7	-684.3	-594.9									
$C_{10}H_{20}O_2$	Methyl nonanoate		-616.2	-554.2									
$C_{10}H_{21}NO_2$	1-Nitrodecane		-351.5										
$C_{10}H_{22}$	Decane		-300.9	-249.5								314.4	
$C_{10}H_{22}$	2-Methylnonane		-309.8	-260.2					420.1			313.3	
$C_{10}H_{22}$	5-Methylnonane		-307.9	-258.6					423.8			314.4	
$C_{10}H_{22}O$	1-Decanol		-478.1	-396.6								370.6	
$C_{10}H_{22}O$	Dipentyl ether											250.0	
$C_{10}H_{22}O$	Diisopentyl ether											379.0	
$C_{10}H_{22}O_2$	1,10-Decanediol	-678.9											
$C_{10}H_{22}O_2$	Ethylene glycol dibutyl ether											350.0	
$C_{10}H_{22}S$	1-Decanethiol	-309.9	-276.5	-211.5					476.1			350.4	
$C_{10}H_{22}S$	Dipentyl sulfide		-266.4	-204.9									
$C_{10}H_{22}S$	Diisopentylsulfide		-281.8	-221.5									
$C_{11}H_8O_2$	1-Naphthalenecarboxylic acid	-333.5		-223.1									
$C_{11}H_8O_2$	2-Naphthoic acid	-346.1		-232.5									
$C_{11}H_{10}$	1-Methylnaphthalene		56.3						254.8			224.4	
$C_{11}H_{10}$	2-Methylnaphthalene	44.9		106.7				220.0			196.0		
$C_{11}H_{12}N_2O_2$	*L*-Tryptophan	-415.3						251.0			238.1		
$C_{11}H_{14}$	1,1-Dimethylindan		-53.6	-1.6									
$C_{11}H_{16}$	Pentamethylbenzene	-144.6		-67.2									
$C_{11}H_{20}$	Spiro[5.5]undecane		-244.5	-188.3									
$C_{11}H_{22}$	1-Undecene											344.9	
$C_{11}H_{22}O_2$	Methyl decanoate		-640.5	-573.8									
$C_{11}H_{24}$	Undecane		-327.2	-270.8								344.9	
$C_{11}H_{24}O$	1-Undecanol		-504.8										
$C_{12}F_{27}N$	Trinonafluorobutylamine											418.4	
$C_{12}H_8$	Acenaphthylene	186.7		259.7							166.4		
$C_{12}H_8N_2$	Phenazine	237.0		328.8									
$C_{12}H_8O$	Dibenzofuran	-5.3		83.4									
$C_{12}H_8S$	Dibenzothiophene	120.0		205.1									
$C_{12}H_8S_2$	Thianthrene	182.0		286.0									
$C_{12}H_9N$	Carbazole	101.7		200.7									
$C_{12}H_{10}$	Acenaphthene	70.3		156.0				188.9			190.4		
$C_{12}H_{10}$	Biphenyl	99.4		181.4				209.4			198.4		
$C_{12}H_{10}N_2O$	*trans*-Azoxybenzene	243.4		342.0									
$C_{12}H_{10}N_2O$	*N*-Nitrosodiphenylamine	227.2											
$C_{12}H_{10}O$	Diphenyl ether	-32.1	-14.9	52.0				233.9			216.6		
$C_{12}H_{10}O_2$	1-Naphthaleneacetic acid	-359.2											
$C_{12}H_{10}O_2$	2-Naphthaleneacetic acid	-371.9											
$C_{12}H_{11}N$	2-Aminobiphenyl	93.8		184.4									
$C_{12}H_{11}N$	*p*-Biphenylamine	81.0											
$C_{12}H_{11}N$	Diphenylamine	130.2		219.3									
$C_{12}H_{12}N_2$	*p*-Benzidine	70.7											

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		Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas	Crys.	Liq.	Gas
$C_{12}H_{14}O_4$	Diethyl phthalate		-776.6	-688.4					425.1			366.1	
$C_{12}H_{16}$	Cyclohexylbenzene		-76.6	-16.7									
$C_{12}H_{17}NO_4$	Diethyl 3,5-dimethyl-pyrrole-2,4-dicarboxylate	-916.7											
$C_{12}H_{18}$	3,9-Dodecadiyne		197.8										
$C_{12}H_{18}$	5,7-Dodecadiyne		181.5										
$C_{12}H_{18}$	Hexamethylbenzene	-162.4		-77.4				306.3			245.6		
$C_{12}H_{22}$	Cyclohexylcyclohexane		-273.7	-215.7									
$C_{12}H_{22}O_4$	Dodecanedioic acid	-1130.0		-976.9									
$C_{12}H_{22}O_{11}$	Sucrose	-2226.1											
$C_{12}H_{22}O_{11}$	β-Lactose	-2236.7											
$C_{12}H_{24}$	1-Dodecene		-226.2	-165.4					484.8			360.7	
$C_{12}H_{24}O_2$	Dodecanoic acid	-774.6	-737.9	-642.0							404.3		
$C_{12}H_{24}O_2$	Methyl undecanoate		-665.2	-593.8									
$C_{12}H_{24}O_{12}$	α-Lactose monohydrate	-2484.1											
$C_{12}H_{25}Br$	1-Bromododecane		-344.7	-269.9									
$C_{12}H_{25}Cl$	1-Chlorododecane		-392.3	-321.1									
$C_{12}H_{26}$	Dodecane		-350.9	-289.4								375.8	
$C_{12}H_{26}O$	1-Dodecanol		-528.5	-436.6								438.1	
$C_{12}H_{26}O_3$	Diethylene glycol dibutyl ether											452.0	
$C_{12}H_{27}N$	Tributylamine		-281.6										
$C_{13}H_8O_2$	Xanthone	-191.5											
$C_{13}H_9N$	Acridine	179.4		273.9									
$C_{13}H_9N$	Phenanthridine	141.9		240.5									
$C_{13}H_9N$	Benzo[f]quinoline	150.6		233.7									
$C_{13}H_{10}N_2$	9-Acridinamine	159.2											
$C_{13}H_{10}O$	Benzophenone	-34.5		54.9							224.8		
$C_{13}H_{11}N$	9-Methylcarbazole	105.5		201.0									
$C_{13}H_{12}$	Diphenylmethane	71.5	89.7	139.0				239.3					
$C_{13}H_{24}O_4$	Tridecanedioic acid	-1148.3											
$C_{13}H_{26}$	1-Tridecene											391.8	
$C_{13}H_{26}O_2$	Methyl dodecanoate		-693.0	-614.9									
$C_{13}H_{28}$	Tridecane											406.7	
$C_{13}H_{28}O$	1-Tridecanol	-599.4											
$C_{14}H_8O_2$	9,10-Anthracenedione	-188.5		-75.7									
$C_{14}H_8O_2$	9,10-Phenanthrenedione	-154.7		-46.6									
$C_{14}H_8O_4$	1,4-Dihydroxy-9,10-anthracenedione	-595.8		-471.7									
$C_{14}H_{10}$	Anthracene	129.2		230.9				207.5			210.5		
$C_{14}H_{10}$	Phenanthrene	116.2		207.5				215.1			220.6		
$C_{14}H_{10}$	Diphenylacetylene	312.4									225.9		
$C_{14}H_{10}O_2$	Benzil	-153.9		-55.5									
$C_{14}H_{12}$	*cis*-Stilbene		183.3	252.3									
$C_{14}H_{12}$	*trans*-Stilbene	136.9		236.1									

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_{14}H_{14}$	1,1-Diphenylethane		48.7										
$C_{14}H_{14}$	1,2-Diphenylethane	51.5		142.9									
$C_{14}H_{23}N_3O_{10}$	Glycine, *N*,*N*-bis[2-[bis(carboxymethyl) amino]ethyl]	-2225.2											
$C_{14}H_{27}N$	Tetradecanenitrile		-260.2	-174.9									
$C_{14}H_{28}O_2$	Tetradecanoic acid	-833.5	-788.8	-693.7							432.0		
$C_{14}H_{28}O_2$	Methyl tridecanoate		-717.9	-635.3									
$C_{14}H_{30}O$	1-Tetradecanol	-629.6	-580.6								388.0		
$C_{15}H_{16}O_2$	2,2-Bis(4-hydroxyphenyl) propane	-368.6											
$C_{15}H_{30}$	Decylcyclopentane		-367.3										
$C_{15}H_{30}O_2$	Pentadecanoic acid	-861.7	-811.7	-699.0							443.3		
$C_{15}H_{30}O_2$	Methyl tetradecanoate		-743.9	-656.9									
$C_{15}H_{32}O$	1-Pentadecanol	-658.2											
$C_{16}H_{10}$	Fluoranthene	189.9		289.0				230.6			230.2		
$C_{16}H_{10}$	Pyrene	125.5		225.7				224.9			229.7		
$C_{16}H_{22}O_4$	Dibutyl phthalate		-842.6	-750.9									
$C_{16}H_{22}O_{11}$	α-*D*-Glucose pentaacetate	-2249.4											
$C_{16}H_{22}O_{11}$	β-*D*-Glucose pentaacetate	-2232.6											
$C_{16}H_{26}$	Decylbenzene		-218.3	-138.6									
$C_{16}H_{32}$	1-Hexadecene		-328.7	-248.4					587.9			488.9	
$C_{16}H_{32}O_2$	Hexadecanoic acid	-891.5	-838.1	-737.1				452.4			460.7		
$C_{16}H_{32}O_2$	Methyl pentadecanoate		-771.0	-680.0									
$C_{16}H_{33}Br$	1-Bromohexadecane		-444.5	-350.2									
$C_{16}H_{34}$	Hexadecane		-456.1	-374.8								501.6	
$C_{16}H_{34}O$	1-Hexadecanol	-686.5		-517.0							422.0		
$C_{16}H_{36}IN$	Tetrabutyl ammonium iodide	-498.6											
$C_{17}H_{34}O_2$	Margaric acid	-924.4	-865.6								475.7		
$C_{18}H_{12}$	Benz[a]anthracene	170.8		293.0									
$C_{18}H_{12}$	Chrysene	145.3		269.8									
$C_{18}H_{15}N$	Triphenylamine	234.7		326.8									
$C_{18}H_{34}O_2$	Oleic acid											577.0	
$C_{18}H_{34}O_4$	Dibutyl sebacate											619.0	
$C_{18}H_{36}O_2$	Stearic acid	-947.7	-884.7	-781.2							501.5		
$C_{18}H_{37}Cl$	1-Chlorooctadecane		-544.1	-446.0									
$C_{18}H_{38}$	Octadecane	-567.4		-414.6				480.2			485.6		
$C_{18}H_{39}N$	Trihexylamine		-433.0										
$C_{19}H_{16}O$	Triphenylmethanol	-2.5											
$C_{19}H_{36}O_2$	Methyl oleate		-734.5	-649.9									
$C_{19}H_{36}O_2$	Methyl *trans*-9-octadecenoate		-737.0										
$C_{20}H_{12}$	Perylene	182.8						264.6			274.9		
$C_{20}H_{14}O_4$	1,2-Benzenedicarboxylic acid, diphenyl ester	-489.2											
$C_{20}H_{38}O_2$	Ethyl *cis*-9-octadecenoate		-775.8										

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Molecular formula	Name	$\Delta_f H°$/kJ mol^{-1} Crys.	Liq.	Gas	$\Delta_f G°$/kJ mol^{-1} Crys.	Liq.	Gas	$S°$/J mol^{-1} K^{-1} Crys.	Liq.	Gas	C_p/J mol^{-1} K^{-1} Crys.	Liq.	Gas
$C_{20}H_{38}O_2$	Ethyl *trans*-9-octadecenoate		-773.3										
$C_{20}H_{40}O_2$	Arachidic acid	-1011.9	-940.0	-812.4							545.1		
$C_{22}H_{42}O_2$	Brassidic acid	-960.7											
$C_{22}H_{42}O_2$	Butyl oleate		-816.9										
$C_{22}H_{44}O_2$	Butyl stearate												
$C_{24}H_{38}O_4$	Bis(2-ethylhexyl) phthalate											704.7	
$C_{24}H_{51}N$	Trioctylamine		-585.0										
$C_{26}H_{18}$	9,10-Diphenylanthracene	308.7		465.6									
$C_{26}H_{54}$	5-Butyldocosane		-713.5	-587.6									
$C_{26}H_{54}$	11-Butyldocosane		-716.0	-593.4									
$C_{28}H_{18}$	9,9′-Bianthracene	326.2		454.3									
$C_{31}H_{64}$	11-Decylheneicosane		-848.0	-705.8									
$C_{32}H_{66}$	Dotriacontane		-968.3	-697.2									
C_{60}	Fullerene-C_{60}	2327.0		2502.0	2302.0		2442.0	426.0		544.0	520.0		512.0
C_{70}	Fullerene-C_{70}	2555.0		2755.0	2537.0		2692.0	464.0		614.0	650.0		585.0

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THERMODYNAMIC PROPERTIES AS A FUNCTION OF TEMPERATURE

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The thermodynamic properties $C_p^\circ(T)$, $S^\circ(T)$, $H^\circ(T)$-$H^\circ(T_r)$, -[$G^\circ(T)$-$H^\circ(T_r)$]/T and formation properties $\Delta_f H^\circ(T)$, $\Delta_f G^\circ(T)$, log $K_f^\circ(T)$ are tabulated as functions of temperature in the range 298.15 to 1500 K for 80 substances in the standard state. The reference temperature, T_r, is equal to 298.15 K. The standard state pressure is taken as 1 bar (100,000 Pa). The tables are presented in the JANAF Thermochemical Tables format (Reference 2). The numerical data are extracted from IVTANTHERMO databases except for C_2H_4O, C_3H_6O, C_6H_6, C_6H_6O, $C_{10}H_8$, and CH_5N, which are based upon TRC Tables. See the references for information on standard states and other details.

REFERENCES

1. Gurvich, L. V., Veyts, I. V., and Alcock, C. B., Eds., *Thermodynamic Properties of Individual Substances, 4th ed.*, Hemisphere Publishing Corp., New York, 1989.
2. Chase, M. W., et al., *JANAF Thermochemical Tables, 3rd ed., J. Phys. Chem. Ref. Data*, 14, Suppl. 1, 1985.

Order of Listing of Tables

No.	Formula	Name	State	No.	Formula	Name	State
1	Ar	Argon	g	41	$CuCl_2$	Copper dichloride	cr, l
2	Br	Bromine	g	42	$CuCl_2$	Copper dichloride	g
3	Br_2	Dibromine	g	43	F	Fluorine	g
4	BrH	Hydrogen bromide	g	44	F_2	Difluorine	g
5	C	Carbon (graphite)	cr	45	FH	Hydrogen fluoride	g
6	C	Carbon (diamond)	cr	46	Ge	Germanium	cr, l
7	C_2	Dicarbon	g	47	Ge	Germanium	g
8	C_3	Tricarbon	g	48	GeO_2	Germanium dioxide	cr, l
9	CO	Carbon oxide	g	49	$GeCl_4$	Germanium tetrachloride	g
10	CO_2	Carbon dioxide	g	50	H	Hydrogen	g
11	CH_4	Methane	g	51	H_2	Dihydrogen	g
12	C_2H_2	Acetylene	g	52	HO	Hydroxyl	g
13	C_2H_4	Ethylene	g	53	H_2O	Water	l
14	C_2H_6	Ethane	g	54	H_2O	Water	g
15	C_3H_6	Cyclopropane	g	55	I	Iodine	g
16	C_3H_8	Propane	g	56	I_2	Diiodine	cr, l
17	C_6H_6	Benzene	l	57	I_2	Diiodine	g
18	C_6H_6	Benzene	g	58	IH	Hydrogen iodide	g
19	$C_{10}H_8$	Naphthalene	cr, l	59	K	Potassium	cr, l
20	$C_{10}H_8$	Naphthalene	g	60	K	Potassium	g
21	CH_2O	Formaldehyde	g	61	K_2O	Dipotassium oxide	cr, l
22	CH_4O	Methanol	g	62	KOH	Potassium hydroxide	cr, l
23	C_2H_4O	Acetaldehyde	g	63	KOH	Potassium hydroxide	g
24	C_2H_6O	Ethanol	g	64	KCl	Potassium chloride	cr, l
25	$C_2H_4O_2$	Acetic acid	g	65	KCl	Potassium chloride	g
26	C_3H_6O	Acetone	g	66	N_2	Dinitrogen	g
27	C_6H_6O	Phenol	g	67	NO	Nitric oxide	g
28	CF_4	Carbon tetrafluoride	g	68	NO_2	Nitrogen dioxide	g
29	CHF_3	Trifluoromethane	g	69	NH_3	Ammonia	g
30	$CClF_3$	Chlorotrifluoromethane	g	70	O	Oxygen	g
31	CCl_2F_2	Dichlorodifluoromethane	g	71	O_2	Dioxygen	g
32	$CHClF_2$	Chlorodifluoromethane	g	72	S	Sulfur	cr, l
33	CH_5N	Methylamine	g	73	S	Sulfur	g
34	Cl	Chlorine	g	74	S_2	Disulfur	g
35	Cl_2	Dichlorine	g	75	S_8	Octasulfur	g
36	ClH	Hydrogen chloride	g	76	SO_2	Sulfur dioxide	g
37	Cu	Copper	cr, l	77	Si	Silicon	cr
38	Cu	Copper	g	78	Si	Silicon	g
39	CuO	Copper oxide	cr	79	SiO_2	Silicon dioxide	cr
40	Cu_2O	Dicopper oxide	cr	80	$SiCl_4$	Silicon tetrachloride	g

	J/K·mol			kJ/mol			
***T*/K**	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	**Log** K_f
1. ARGON Ar (g)							
298.15	20.786	154.845	154.845	0.000	0.000	0.000	0.000
300	20.786	154.973	154.845	0.038	0.000	0.000	0.000
400	20.786	160.953	155.660	2.117	0.000	0.000	0.000
500	20.786	165.591	157.200	4.196	0.000	0.000	0.000
600	20.786	169.381	158.924	6.274	0.000	0.000	0.000
700	20.786	172.585	160.653	8.353	0.000	0.000	0.000
800	20.786	175.361	162.322	10.431	0.000	0.000	0.000
900	20.786	177.809	163.909	12.510	0.000	0.000	0.000
1000	20.786	179.999	165.410	14.589	0.000	0.000	0.000
1100	20.786	181.980	166.828	16.667	0.000	0.000	0.000
1200	20.786	183.789	168.167	18.746	0.000	0.000	0.000
1300	20.786	185.453	169.434	20.824	0.000	0.000	0.000
1400	20.786	186.993	170.634	22.903	0.000	0.000	0.000
1500	20.786	188.427	171.773	24.982	0.000	0.000	0.000
2. BROMINE Br (g)							
298.15	20.786	175.017	175.017	0.000	111.870	82.379	–14.432
300	20.786	175.146	175.018	0.038	111.838	82.196	–14.311
400	20.787	181.126	175.833	2.117	96.677	75.460	–9.854
500	20.798	185.765	177.373	4.196	96.910	70.129	–7.326
600	20.833	189.559	179.097	6.277	97.131	64.752	–5.637
700	20.908	192.776	180.827	8.364	97.348	59.338	–4.428
800	21.027	195.575	182.499	10.461	97.568	53.893	–3.519
900	21.184	198.061	184.093	12.571	97.796	48.420	–2.810
1000	21.365	200.302	185.604	14.698	98.036	42.921	–2.242
1100	21.559	202.347	187.034	16.844	98.291	37.397	–1.776
1200	21.752	204.231	188.390	19.010	98.560	31.850	–1.386
1300	21.937	205.980	189.676	21.195	98.844	26.279	–1.056
1400	22.107	207.612	190.900	23.397	99.141	20.686	–0.772
1500	22.258	209.142	192.065	25.615	99.449	15.072	–0.525
3. DIBROMINE Br_2 (g)							
298.15	36.057	245.467	245.467	0.000	30.910	3.105	–0.544
300	36.074	245.690	245.468	0.067	30.836	2.933	–0.511
332.25	36.340	249.387	245.671	1.235		pressure = 1 bar	
400	36.729	256.169	246.892	3.711	0.000	0.000	0.000
500	37.082	264.406	249.600	7.403	0.000	0.000	0.000
600	37.305	271.188	252.650	11.123	0.000	0.000	0.000
700	37.464	276.951	255.720	14.862	0.000	0.000	0.000
800	37.590	281.962	258.694	18.615	0.000	0.000	0.000
900	37.697	286.396	261.530	22.379	0.000	0.000	0.000
1000	37.793	290.373	264.219	26.154	0.000	0.000	0.000
1100	37.883	293.979	266.763	29.938	0.000	0.000	0.000
1200	37.970	297.279	269.170	33.730	0.000	0.000	0.000
1300	38.060	300.322	271.451	37.532	0.000	0.000	0.000
1400	38.158	303.146	273.615	41.343	0.000	0.000	0.000
1500	38.264	305.782	275.673	45.164	0.000	0.000	0.000
4. HYDROGEN BROMIDE HBr (g)							
298.15	29.141	198.697	198.697	0.000	–36.290	–53.360	9.348
300	29.141	198.878	198.698	0.054	–36.333	–53.466	9.309
400	29.220	207.269	199.842	2.971	–52.109	–55.940	7.305
500	29.454	213.811	202.005	5.903	–52.484	–56.854	5.939
600	29.872	219.216	204.436	8.868	–52.844	–57.694	5.023
700	30.431	223.861	206.886	11.882	–53.168	–58.476	4.363
800	31.063	227.965	209.269	14.957	–53.446	–59.214	3.866

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f

4. HYDROGEN BROMIDE HBr (g) (continued)

T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
900	31.709	231.661	211.555	18.095	–53.677	–59.921	3.478
1000	32.335	235.035	213.737	21.298	–53.864	–60.604	3.166
1100	32.919	238.145	215.816	24.561	–54.012	–61.271	2.909
1200	33.454	241.032	217.799	27.880	–54.129	–61.925	2.696
1300	33.938	243.729	219.691	31.250	–54.220	–62.571	2.514
1400	34.374	246.261	221.499	34.666	–54.291	–63.211	2.358
1500	34.766	248.646	223.230	38.123	–54.348	–63.846	2.223

5. CARBON (GRAPHITE) C (cr; graphite)

T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	8.536	5.740	5.740	0.000	0.000	0.000	0.000
300	8.610	5.793	5.740	0.016	0.000	0.000	0.000
400	11.974	8.757	6.122	1.054	0.000	0.000	0.000
500	14.537	11.715	6.946	2.385	0.000	0.000	0.000
600	16.607	14.555	7.979	3.945	0.000	0.000	0.000
700	18.306	17.247	9.113	5.694	0.000	0.000	0.000
800	19.699	19.785	10.290	7.596	0.000	0.000	0.000
900	20.832	22.173	11.479	9.625	0.000	0.000	0.000
1000	21.739	24.417	12.662	11.755	0.000	0.000	0.000
1100	22.452	26.524	13.827	13.966	0.000	0.000	0.000
1200	23.000	28.502	14.968	16.240	0.000	0.000	0.000
1300	23.409	30.360	16.082	18.562	0.000	0.000	0.000
1400	23.707	32.106	17.164	20.918	0.000	0.000	0.000
1500	23.919	33.749	18.216	23.300	0.000	0.000	0.000

6. CARBON (DIAMOND) C (cr; diamond)

T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	6.109	2.362	2.362	0.000	1.850	2.857	–0.501
300	6.201	2.400	2.362	0.011	1.846	2.863	–0.499
400	10.321	4.783	2.659	0.850	1.645	3.235	–0.422
500	13.404	7.431	3.347	2.042	1.507	3.649	–0.381
600	15.885	10.102	4.251	3.511	1.415	4.087	–0.356
700	17.930	12.709	5.274	5.205	1.361	4.537	–0.339
800	19.619	15.217	6.361	7.085	1.338	4.993	–0.326
900	21.006	17.611	7.479	9.118	1.343	5.450	–0.316
1000	22.129	19.884	8.607	11.277	1.372	5.905	–0.308
1100	23.020	22.037	9.731	13.536	1.420	6.356	–0.302
1200	23.709	24.071	10.842	15.874	1.484	6.802	–0.296
1300	24.222	25.990	11.934	18.272	1.561	7.242	–0.291
1400	24.585	27.799	13.003	20.714	1.646	7.675	–0.286
1500	24.824	29.504	14.047	23.185	1.735	8.103	–0.282

7. DICARBON C_2 (g)

T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	43.548	197.095	197.095	0.000	830.457	775.116	–135.795
300	43.575	197.365	197.096	0.081	830.506	774.772	–134.898
400	42.169	209.809	198.802	4.403	832.751	755.833	–98.700
500	39.529	218.924	201.959	8.483	834.170	736.423	–76.933
600	37.837	225.966	205.395	12.342	834.909	716.795	–62.402
700	36.984	231.726	208.758	16.078	835.148	697.085	–52.016
800	36.621	236.637	211.943	19.755	835.020	677.366	–44.227
900	36.524	240.943	214.931	23.411	834.618	657.681	–38.170
1000	36.569	244.793	217.728	27.065	834.012	638.052	–33.328
1100	36.696	248.284	220.349	30.728	833.252	618.492	–29.369
1200	36.874	251.484	222.812	34.406	832.383	599.006	–26.074
1300	37.089	254.444	225.133	38.104	831.437	579.596	–23.288
1400	37.329	257.201	227.326	41.824	830.445	560.261	–20.903
1500	37.589	259.785	229.405	45.570	829.427	540.997	–18.839

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
8. TRICARBON C_3 (g)							
298.15	42.202	237.611	237.611	0.000	839.958	774.249	–135.643
300	42.218	237.872	237.611	0.078	839.989	773.841	–134.736
400	43.383	250.164	239.280	4.354	841.149	751.592	–98.147
500	44.883	260.003	242.471	8.766	841.570	729.141	–76.172
600	46.406	268.322	246.104	13.331	841.453	706.659	–61.519
700	47.796	275.582	249.807	18.042	840.919	684.230	–51.057
800	48.997	282.045	253.440	22.884	840.053	661.901	–43.217
900	50.006	287.876	256.948	27.835	838.919	639.698	–37.127
1000	50.844	293.189	260.310	32.879	837.572	617.633	–32.261
1100	51.535	298.069	263.524	37.999	836.059	595.711	–28.288
1200	52.106	302.578	266.593	43.182	834.420	573.933	–24.982
1300	52.579	306.768	269.524	48.417	832.690	552.295	–22.191
1400	52.974	310.679	272.326	53.695	830.899	530.793	–19.804
1500	53.307	314.346	275.006	59.010	829.068	509.421	–17.739
9. CARBON OXIDE CO (g)							
298.15	29.141	197.658	197.658	0.000	–110.530	–137.168	24.031
300	29.142	197.838	197.659	0.054	–110.519	–137.333	23.912
400	29.340	206.243	198.803	2.976	–110.121	–146.341	19.110
500	29.792	212.834	200.973	5.930	–110.027	–155.412	16.236
600	30.440	218.321	203.419	8.941	–110.157	–164.480	14.319
700	31.170	223.067	205.895	12.021	–110.453	–173.513	12.948
800	31.898	227.277	208.309	15.175	–110.870	–182.494	11.915
900	32.573	231.074	210.631	18.399	–111.378	–191.417	11.109
1000	33.178	234.538	212.851	21.687	–111.952	–200.281	10.461
1100	33.709	237.726	214.969	25.032	–112.573	–209.084	9.928
1200	34.169	240.679	216.990	28.426	–113.228	–217.829	9.482
1300	34.568	243.430	218.920	31.864	–113.904	–226.518	9.101
1400	34.914	246.005	220.763	35.338	–114.594	–235.155	8.774
1500	35.213	248.424	222.527	38.845	–115.291	–243.742	8.488
10. CARBON DIOXIDE CO_2 (g)							
298.15	37.135	213.783	213.783	0.000	–393.510	–394.373	69.092
300	37.220	214.013	213.784	0.069	–393.511	–394.379	68.667
400	41.328	225.305	215.296	4.004	–393.586	–394.656	51.536
500	44.627	234.895	218.280	8.307	–393.672	–394.914	41.256
600	47.327	243.278	221.762	12.909	–393.791	–395.152	34.401
700	49.569	250.747	225.379	17.758	–393.946	–395.367	29.502
800	51.442	257.492	228.978	22.811	–394.133	–395.558	25.827
900	53.008	263.644	232.493	28.036	–394.343	–395.724	22.967
1000	54.320	269.299	235.895	33.404	–394.568	–395.865	20.678
1100	55.423	274.529	239.172	38.893	–394.801	–395.984	18.803
1200	56.354	279.393	242.324	44.483	–395.035	–396.081	17.241
1300	57.144	283.936	245.352	50.159	–395.265	–396.159	15.918
1400	57.818	288.196	248.261	55.908	–395.488	–396.219	14.783
1500	58.397	292.205	251.059	61.719	–395.702	–396.264	13.799
11. METHANE CH_4 (g)							
298.15	35.695	186.369	186.369	0.000	–74.600	–50.530	8.853
300	35.765	186.590	186.370	0.066	–74.656	–50.381	8.772
400	40.631	197.501	187.825	3.871	–77.703	–41.827	5.462
500	46.627	207.202	190.744	8.229	–80.520	–32.525	3.398
600	52.742	216.246	194.248	13.199	–82.969	–22.690	1.975
700	58.603	224.821	198.008	18.769	–85.023	–12.476	0.931
800	64.084	233.008	201.875	24.907	–86.693	–1.993	0.130

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
11. METHANE CH_4 (g) (continued)							
900	69.137	240.852	205.773	31.571	–88.006	8.677	–0.504
1000	73.746	248.379	209.660	38.719	–88.996	19.475	–1.017
1100	77.919	255.607	213.511	46.306	–89.698	30.358	–1.442
1200	81.682	262.551	217.310	54.289	–90.145	41.294	–1.797
1300	85.067	269.225	221.048	62.630	–90.367	52.258	–2.100
1400	88.112	275.643	224.720	71.291	–90.390	63.231	–2.359
1500	90.856	281.817	228.322	80.242	–90.237	74.200	–2.584
12. ACETYLENE C_2H_2 (g)							
298.15	44.036	200.927	200.927	0.000	227.400	209.879	–36.769
300	44.174	201.199	200.927	0.082	227.397	209.770	–36.524
400	50.388	214.814	202.741	4.829	227.161	203.928	–26.630
500	54.751	226.552	206.357	10.097	226.846	198.154	–20.701
600	58.121	236.842	210.598	15.747	226.445	192.452	–16.754
700	60.970	246.021	215.014	21.704	225.968	186.823	–13.941
800	63.511	254.331	219.418	27.931	225.436	181.267	–11.835
900	65.831	261.947	223.726	34.399	224.873	175.779	–10.202
1000	67.960	268.995	227.905	41.090	224.300	170.355	–8.898
1100	69.909	275.565	231.942	47.985	223.734	164.988	–7.835
1200	71.686	281.725	235.837	55.067	223.189	159.672	–6.950
1300	73.299	287.528	239.592	62.317	222.676	154.400	–6.204
1400	74.758	293.014	243.214	69.721	222.203	149.166	–5.565
1500	76.077	298.218	246.709	77.264	221.774	143.964	–5.013
13. ETHYLENE C_2H_4 (g)							
298.15	42.883	219.316	219.316	0.000	52.400	68.358	–11.976
300	43.059	219.582	219.317	0.079	52.341	68.457	–11.919
400	53.045	233.327	221.124	4.881	49.254	74.302	–9.703
500	62.479	246.198	224.864	10.667	46.533	80.887	–8.450
600	70.673	258.332	229.441	17.335	44.221	87.982	–7.659
700	77.733	269.770	234.393	24.764	42.278	95.434	–7.121
800	83.868	280.559	239.496	32.851	40.655	103.142	–6.734
900	89.234	290.754	244.630	41.512	39.310	111.036	–6.444
1000	93.939	300.405	249.730	50.675	38.205	119.067	–6.219
1100	98.061	309.556	254.756	60.280	37.310	127.198	–6.040
1200	101.670	318.247	259.688	70.271	36.596	135.402	–5.894
1300	104.829	326.512	264.513	80.599	36.041	143.660	–5.772
1400	107.594	334.384	269.225	91.223	35.623	151.955	–5.669
1500	110.018	341.892	273.821	102.107	35.327	160.275	–5.581
14. ETHANE C_2H_6 (g)							
298.15	52.487	229.161	229.161	0.000	–84.000	–32.015	5.609
300	52.711	229.487	229.162	0.097	–84.094	–31.692	5.518
400	65.459	246.378	231.379	5.999	–88.988	–13.473	1.759
500	77.941	262.344	235.989	13.177	–93.238	5.912	–0.618
600	89.188	277.568	241.660	21.545	–96.779	26.086	–2.271
700	99.136	292.080	247.835	30.972	–99.663	46.800	–3.492
800	107.936	305.904	254.236	41.334	–101.963	67.887	–4.433
900	115.709	319.075	260.715	52.525	–103.754	89.231	–5.179
1000	122.552	331.628	267.183	64.445	–105.105	110.750	–5.785
1100	128.553	343.597	273.590	77.007	–106.082	132.385	–6.286
1200	133.804	355.012	279.904	90.131	–106.741	154.096	–6.708
1300	138.391	365.908	286.103	103.746	–107.131	175.850	–7.066
1400	142.399	376.314	292.178	117.790	–107.292	197.625	–7.373
1500	145.905	386.260	298.121	132.209	–107.260	219.404	–7.640

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
15. CYCLOPROPANE C_3H_6 (g)							
298.15	55.571	237.488	237.488	0.000	53.300	104.514	–18.310
300	55.941	237.832	237.489	0.103	53.195	104.832	–18.253
400	76.052	256.695	239.924	6.708	47.967	122.857	–16.043
500	93.859	275.637	245.177	15.230	43.730	142.091	–14.844
600	108.542	294.092	251.801	25.374	40.405	162.089	–14.111
700	120.682	311.763	259.115	36.854	37.825	182.583	–13.624
800	130.910	328.564	266.755	49.447	35.854	203.404	–13.281
900	139.658	344.501	274.516	62.987	34.384	224.441	–13.026
1000	147.207	359.616	282.277	77.339	33.334	245.618	–12.830
1100	153.749	373.961	289.965	92.395	32.640	266.883	–12.673
1200	159.432	387.588	297.538	108.060	32.249	288.197	–12.545
1300	164.378	400.549	304.967	124.257	32.119	309.533	–12.437
1400	168.689	412.892	312.239	140.915	32.215	330.870	–12.345
1500	172.453	424.662	319.344	157.976	32.507	352.193	–12.264
16. PROPANE C_3H_8 (g)							
298.15	73.597	270.313	270.313	0.000	–103.847	–23.458	4.110
300	73.931	270.769	270.314	0.136	–103.972	–22.959	3.997
400	94.014	294.739	273.447	8.517	–110.33	15.029	–0.657
500	112.591	317.768	280.025	18.872	–115.658	34.507	–3.605
600	128.700	339.753	288.162	30.955	–119.973	64.961	–5.655
700	142.674	360.668	297.039	44.540	–123.384	96.065	–7.168
800	154.766	380.528	306.245	59.427	–126.016	127.603	–8.331
900	165.352	399.381	315.555	75.444	–127.982	159.430	–9.253
1000	174.598	417.293	324.841	92.452	–129.380	191.444	–10.000
1100	182.673	434.321	334.026	110.325	–130.296	223.574	–10.617
1200	189.745	450.526	343.064	128.954	–130.802	255.770	–11.133
1300	195.853	465.961	351.929	148.241	–130.961	287.993	–11.572
1400	201.209	480.675	360.604	168.100	–130.829	320.217	–11.947
1500	205.895	494.721	369.080	188.460	–130.445	352.422	–12.272
17. BENZENE C_6H_6 (l)							
298.15	135.950	173.450	173.450	0.000	49.080	124.521	–21.815
300	136.312	174.292	173.453	.252	49.077	124.989	–21.762
400	161.793	216.837	179.082	15.102	48.978	150.320	–19.630
500	207.599	257.048	190.639	33.204	50.330	175.559	–18.340
18. BENZENE C_6H_6 (g)							
298.15	82.430	269.190	269.190	0.000	82.880	129.750	–22.731
300	83.020	269.700	269.190	0.153	82.780	130.040	–22.641
400	113.510	297.840	272.823	10.007	77.780	146.570	–19.140
500	139.340	326.050	280.658	22.696	73.740	164.260	–17.160
600	160.090	353.360	290.517	37.706	70.490	182.680	–15.903
700	176.790	379.330	301.360	54.579	67.910	201.590	–15.042
800	190.460	403.860	312.658	72.962	65.910	220.820	–14.418
900	201.840	426.970	324.084	92.597	64.410	240.280	–13.945
1000	211.430	448.740	335.473	113.267	63.340	259.890	–13.575
1100	219.580	469.280	346.710	134.827	62.620	277.640	–13.184
1200	226.540	488.690	357.743	157.137	62.200	299.320	–13.029
1300	232.520	507.070	368.534	180.097	62.000	319.090	–12.821
1400	237.680	524.490	379.056	203.607	61.990	338.870	–12.643
1500	242.140	541.040	389.302	227.607	62.110	358.640	–12.489

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
19. NAPHTHALENE $C_{10}H_8$ (cr, l)							
298.15	165.720	167.390	167.390	0.000	78.530	201.585	–35.316
300	167.001	168.419	167.393	0.308	78.466	202.349	–35.232
353.43	208.722	198.948	169.833	10.290	96.099	224.543	–33.186
PHASE TRANSITION: $\Delta_{trs}H$ = 18.980 kJ/mol, $\Delta_{trs}S$ = 53.702 J/K·mol, cr–l							
353.43	217.200	252.650	169.833	29.270	96.099	224.543	–33.186
400	241.577	280.916	181.124	39.917	96.067	241.475	–31.533
470	276.409	322.712	199.114	58.091	97.012	266.859	–29.658
20. NAPHTHALENE $C_{10}H_8$ (g)							
298.15	131.920	333.150	333.150	0.000	150.580	224.100	–39.260
300	132.840	333.970	333.157	0.244	150.450	224.560	–39.098
400	180.070	378.800	338.950	15.940	144.190	250.270	–32.681
500	219.740	423.400	351.400	36.000	139.220	277.340	–28.973
600	251.530	466.380	367.007	59.624	135.350	305.330	–26.581
700	277.010	507.140	384.146	86.096	132.330	333.950	–24.919
800	297.730	545.520	401.935	114.868	130.050	362.920	–23.696
900	314.850	581.610	419.918	145.523	128.430	392.150	–22.759
1000	329.170	615.550	437.806	177.744	127.510	421.700	–22.027
1100	341.240	647.500	455.426	211.281	127.100	450.630	–21.398
1200	351.500	677.650	472.707	245.932	126.960	480.450	–20.913
1300	360.260	706.130	489.568	281.531	127.060	509.770	–20.482
1400	367.780	733.110	506.009	317.941	127.390	539.740	–20.137
1500	374.270	758.720	522.019	355.051	127.920	568.940	–19.812
21. FORMALDEHYDE H_2CO (g)							
298.15	35.387	218.760	218.760	0.000	–108.700	–102.667	17.987
300	35.443	218.979	218.761	0.066	–108.731	–102.630	17.869
400	39.240	229.665	220.192	3.789	–110.438	–100.340	13.103
500	43.736	238.900	223.028	7.936	–112.073	–97.623	10.198
600	48.181	247.270	226.381	12.534	–113.545	–94.592	8.235
700	52.280	255.011	229.924	17.560	–114.833	–91.328	6.815
800	55.941	262.236	233.517	22.975	–115.942	–87.893	5.739
900	59.156	269.014	237.088	28.734	–116.889	–84.328	4.894
1000	61.951	275.395	240.603	34.792	–117.696	–80.666	4.213
1100	64.368	281.416	244.042	41.111	–118.382	–76.929	3.653
1200	66.453	287.108	247.396	47.655	–118.966	–73.134	3.183
1300	68.251	292.500	250.660	54.392	–119.463	–69.294	2.784
1400	69.803	297.616	253.833	61.297	–119.887	–65.418	2.441
1500	71.146	302.479	256.915	68.346	–120.249	–61.514	2.142
22. METHANOL CH_3OH (g)							
298.15	44.101	239.865	239.865	0.000	–201.000	–162.298	28.434
300	44.219	240.139	239.866	0.082	–201.068	–162.057	28.216
400	51.713	253.845	241.685	4.864	–204.622	–148.509	19.393
500	59.800	266.257	245.374	10.442	–207.750	–134.109	14.010
600	67.294	277.835	249.830	16.803	–210.387	–119.125	10.371
700	73.958	288.719	254.616	23.873	–212.570	–103.737	7.741
800	79.838	298.987	259.526	31.569	–214.350	–88.063	5.750
900	85.025	308.696	264.455	39.817	–215.782	–72.188	4.190
1000	89.597	317.896	269.343	48.553	–216.916	–56.170	2.934
1100	93.624	326.629	274.158	57.718	–217.794	–40.050	1.902
1200	97.165	334.930	278.879	67.262	–218.457	–23.861	1.039
1300	100.277	342.833	283.497	77.137	–218.936	–7.624	0.306
1400	103.014	350.367	288.007	87.304	–219.261	8.644	–0.322
1500	105.422	357.558	292.405	97.729	–219.456	24.930	–0.868

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
23. ACETALDEHYDE C_2H_4O (g)							
298.15	55.318	263.840	263.840	0.000	–166.190	–133.010	23.302
300	55.510	264.180	263.837	0.103	–166.250	–132.800	23.122
400	66.282	281.620	266.147	6.189	–169.530	–121.130	15.818
500	76.675	297.540	270.850	13.345	–172.420	–108.700	11.356
600	85.942	312.360	276.550	21.486	–174.870	–95.720	8.334
700	94.035	326.230	282.667	30.494	–176.910	–82.350	6.145
800	101.070	339.260	288.938	40.258	–178.570	–68.730	4.487
900	107.190	351.520	295.189	50.698	–179.880	–54.920	3.187
1000	112.490	363.100	301.431	61.669	–180.850	–40.930	2.138
1100	117.080	374.040	307.537	73.153	–181.560	–27.010	1.283
1200	121.060	384.400	313.512	85.065	–182.070	–12.860	0.560
1300	124.500	394.230	319.350	97.344	–182.420	1.240	–0.050
1400	127.490	403.570	325.031	109.954	–182.640	15.470	–0.577
1500	130.090	412.460	330.571	122.834	–182.750	29.580	–1.030
24. ETHANOL C_2H_5OH (g)							
298.15	65.652	281.622	281.622	0.000	–234.800	–167.874	29.410
300	65.926	282.029	281.623	0.122	–234.897	–167.458	29.157
400	81.169	303.076	284.390	7.474	–239.826	–144.216	18.832
500	95.400	322.750	290.115	16.318	–243.940	–119.820	12.517
600	107.656	341.257	297.112	26.487	–247.260	–94.672	8.242
700	118.129	358.659	304.674	37.790	–249.895	–69.023	5.151
800	127.171	375.038	312.456	50.065	–251.951	–43.038	2.810
900	135.049	390.482	320.276	63.185	–253.515	–16.825	0.976
1000	141.934	405.075	328.033	77.042	–254.662	9.539	–0.498
1100	147.958	418.892	335.670	91.543	–255.454	36.000	–1.709
1200	153.232	431.997	343.156	106.609	–255.947	62.520	–2.721
1300	157.849	444.448	350.473	122.168	–256.184	89.070	–3.579
1400	161.896	456.298	357.612	138.160	–256.206	115.630	–4.314
1500	165.447	467.591	364.571	154.531	–256.044	142.185	–4.951
25. ACETIC ACID $C_2H_4O_2$ (g)							
298.15	63.438	283.470	283.470	0.000	–432.249	–374.254	65.567
300	63.739	283.863	283.471	0.118	–432.324	–373.893	65.100
400	79.665	304.404	286.164	7.296	–436.006	–353.840	46.206
500	93.926	323.751	291.765	15.993	–438.875	–332.950	34.783
600	106.181	341.988	298.631	26.014	–440.993	–311.554	27.123
700	116.627	359.162	306.064	37.169	–442.466	–289.856	21.629
800	125.501	375.331	313.722	49.287	–443.395	–267.985	17.497
900	132.989	390.558	321.422	62.223	–443.873	–246.026	14.279
1000	139.257	404.904	329.060	75.844	–443.982	–224.034	11.702
1100	144.462	418.429	336.576	90.039	–443.798	–202.046	9.594
1200	148.760	431.189	343.933	104.707	–443.385	–180.086	7.839
1300	152.302	443.240	351.113	119.765	–442.795	–158.167	6.355
1400	155.220	454.637	358.105	135.146	–442.071	–136.299	5.085
1500	157.631	465.432	364.903	150.793	–441.247	–114.486	3.987
26. ACETONE C_3H_6O (g)							
298.15	74.517	295.349	295.349	0.000	–217.150	–152.716	26.757
300	74.810	295.809	295.349	0.138	–217.233	–152.339	26.521
400	91.755	319.658	298.498	8.464	–222.212	–129.913	16.962
500	107.864	341.916	304.988	18.464	–226.522	–106.315	11.107
600	122.047	362.836	312.873	29.978	–230.120	–81.923	7.133
700	134.306	382.627	321.470	42.810	–233.049	–56.986	4.252
800	144.934	401.246	330.265	56.785	–235.350	–31.673	2.068

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
26. ACETONE C_3H_6O (g) (continued)							
900	154.097	418.860	339.141	71.747	–237.149	–6.109	0.353
1000	162.046	435.513	347.950	87.563	–238.404	19.707	–1.030
1100	168.908	451.286	356.617	104.136	–239.283	45.396	–2.157
1200	174.891	466.265	365.155	121.332	–239.827	71.463	–3.110
1300	180.079	480.491	373.513	139.072	–240.120	97.362	–3.912
1400	184.556	493.963	381.596	157.314	–240.203	123.470	–4.607
1500	188.447	506.850	389.533	175.975	–240.120	149.369	–5.202
27. PHENOL C_6H_6O (g)							
298.15	103.220	314.810	314.810	0.000	–96.400	–32.630	5.720
300	103.860	315.450	314.810	0.192	–96.490	–32.230	5.610
400	135.790	349.820	319.278	12.217	–100.870	–10.180	1.330
500	161.910	383.040	328.736	27.152	–104.240	12.970	–1.360
600	182.480	414.450	340.430	44.412	–106.810	36.650	–3.190
700	198.840	443.860	353.134	63.508	–108.800	60.750	–4.530
800	212.140	471.310	366.211	84.079	–110.300	85.020	–5.550
900	223.190	496.950	379.327	105.861	–111.370	109.590	–6.360
1000	232.490	520.960	392.302	128.658	–111.990	134.280	–7.010
1100	240.410	543.500	405.033	152.314	–112.280	158.620	–7.530
1200	247.200	564.720	417.468	176.703	–112.390	183.350	–7.980
1300	253.060	584.740	429.568	201.723	–112.330	208.070	–8.360
1400	258.120	603.680	441.331	227.288	–112.120	233.050	–8.700
1500	262.520	621.650	452.767	253.325	–111.780	257.540	–8.970
28. CARBON TETRAFLUORIDE CF_4 (g)							
298.15	61.050	261.455	261.455	0.000	–933.200	–888.518	155.663
300	61.284	261.833	261.456	0.113	–933.219	–888.240	154.654
400	72.399	281.057	264.001	6.822	–933.986	–873.120	114.016
500	80.713	298.153	269.155	14.499	–934.372	–857.852	89.618
600	86.783	313.434	275.284	22.890	–934.490	–842.533	73.348
700	91.212	327.162	281.732	31.801	–934.431	–827.210	61.726
800	94.479	339.566	288.199	41.094	–934.261	–811.903	53.011
900	96.929	350.842	294.542	50.670	–934.024	–796.622	46.234
1000	98.798	361.156	300.695	60.460	–933.745	–781.369	40.814
1100	100.250	370.643	306.629	70.416	–933.442	–766.146	36.381
1200	101.396	379.417	312.334	80.500	–933.125	–750.952	32.688
1300	102.314	387.571	317.811	90.687	–932.800	–735.784	29.564
1400	103.059	395.181	323.069	100.957	–932.470	–720.641	26.887
1500	103.671	402.313	328.116	111.295	–932.137	–705.522	24.568
29. TRIFLUOROMETHANE CHF_3 (g)							
298.15	51.069	259.675	259.675	0.000	–696.700	–662.237	116.020
300	51.258	259.991	259.676	0.095	–696.735	–662.023	115.267
400	61.148	276.113	261.807	5.722	–698.427	–650.186	84.905
500	69.631	290.700	266.149	12.275	–699.715	–637.969	66.647
600	76.453	304.022	271.368	19.593	–700.634	–625.528	54.456
700	81.868	316.230	276.917	27.519	–701.253	–612.957	45.739
800	86.201	327.455	282.542	35.930	–701.636	–600.315	39.196
900	89.719	337.818	288.116	44.732	–701.832	–587.636	34.105
1000	92.617	347.426	293.572	53.854	–701.879	–574.944	30.032
1100	95.038	356.370	298.879	63.240	–701.805	–562.253	26.699
1200	97.084	364.730	304.022	72.849	–701.629	–549.574	23.922
1300	98.833	372.571	308.997	82.647	–701.368	–536.913	21.573
1400	100.344	379.952	313.804	92.607	–701.033	–524.274	19.561
1500	101.660	386.921	318.449	102.709	–700.635	–511.662	17.817

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
30. CHLOROTRIFLUOROMETHANE $CClF_3$ (g)							
298.15	66.886	285.419	285.419	0.000	–707.800	–667.238	116.896
300	67.111	285.834	285.421	0.124	–707.810	–666.986	116.131
400	77.528	306.646	288.187	7.383	–708.153	–653.316	85.313
500	85.013	324.797	293.734	15.532	–708.170	–639.599	66.818
600	90.329	340.794	300.271	24.314	–707.975	–625.901	54.489
700	94.132	355.020	307.096	33.547	–707.654	–612.246	45.686
800	96.899	367.780	313.897	43.106	–707.264	–598.642	39.087
900	98.951	379.317	320.536	52.903	–706.837	–585.090	33.957
1000	100.507	389.827	326.947	62.880	–706.396	–571.586	29.856
1100	101.708	399.465	333.108	72.993	–705.950	–558.126	26.503
1200	102.651	408.357	339.013	83.213	–705.505	–544.707	23.710
1300	103.404	416.604	344.668	93.517	–705.064	–531.326	21.349
1400	104.012	424.290	350.084	103.889	–704.628	–517.977	19.326
1500	104.512	431.484	355.273	114.316	–704.196	–504.660	17.574
31. DICHLORODIFLUOROMETHANE CCl_2F_2 (g)							
298.15	72.476	300.903	300.903	0.000	–486.000	–447.030	78.317
300	72.691	301.352	300.905	0.134	–486.002	–446.788	77.792
400	82.408	323.682	303.883	7.919	–485.945	–433.716	56.637
500	89.063	342.833	309.804	16.514	–485.618	–420.692	43.949
600	93.635	359.500	316.729	25.663	–485.136	–407.751	35.497
700	96.832	374.189	323.909	35.196	–484.576	–394.897	29.467
800	99.121	387.276	331.027	44.999	–483.984	–382.126	24.950
900	100.801	399.053	337.942	55.000	–483.388	–369.429	21.441
1000	102.062	409.742	344.596	65.146	–482.800	–356.799	18.637
1100	103.030	419.517	350.969	75.402	–482.226	–344.227	16.346
1200	103.786	428.515	357.061	85.745	–481.667	–331.706	14.439
1300	104.388	436.847	362.882	96.154	–481.121	–319.232	12.827
1400	104.874	444.602	368.445	106.618	–480.588	–306.799	11.447
1500	105.270	451.851	373.767	117.126	–480.065	–294.404	10.252
32. CHLORODIFLUOROMETHANE $CHClF_2$ (g)							
298.15	55.853	280.915	280.915	0.000	–475.000	–443.845	77.759
300	56.039	281.261	280.916	0.104	–475.028	–443.652	77.246
400	65.395	298.701	283.231	6.188	–476.390	–432.978	56.540
500	73.008	314.145	287.898	13.123	–477.398	–422.001	44.086
600	78.940	328.003	293.448	20.733	–478.103	–410.851	35.767
700	83.551	340.533	299.294	28.867	–478.574	–399.603	29.818
800	87.185	351.936	305.172	37.411	–478.870	–388.299	25.353
900	90.100	362.379	310.956	46.280	–479.031	–376.967	21.878
1000	92.475	371.999	316.586	55.413	–479.090	–365.622	19.098
1100	94.433	380.908	322.033	64.761	–479.068	–354.276	16.823
1200	96.066	389.196	327.289	74.289	–478.982	–342.935	14.927
1300	97.438	396.941	332.352	83.966	–478.843	–331.603	13.324
1400	98.601	404.206	337.228	93.769	–478.661	–320.283	11.950
1500	99.593	411.044	341.923	103.681	–478.443	–308.978	10.759
33. METHYLAMINE CH_5N (g)							
298.15	50.053	242.881	242.881	0.000	–22.529	32.734	–5.735
300	50.227	243.196	242.893	0.091	–22.614	33.077	–5.759
400	60.171	258.986	244.975	5.604	–26.846	52.294	–6.829
500	70.057	273.486	249.244	12.121	–30.431	72.510	–7.575
600	78.929	287.063	254.431	19.579	–33.364	93.382	–8.129
700	86.711	299.826	260.008	27.873	–35.712	114.702	–8.559
800	93.545	311.865	265.749	36.893	–37.548	136.316	–8.900

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
33. METHYLAMINE CH_5N (g) (continued)							
900	99.573	323.239	271.511	46.555	–38.949	158.138	–9.178
1000	104.886	334.006	277.220	56.786	–39.967	180.098	–9.407
1100	109.576	344.233	282.861	67.509	–40.681	201.822	–9.584
1200	113.708	353.944	288.374	78.685	–41.136	224.240	–9.761
1300	117.341	363.190	293.775	90.239	–41.376	246.364	–9.899
1400	120.542	372.012	299.061	102.131	–41.451	268.504	–10.018
1500	123.353	380.426	304.209	114.326	–41.381	290.639	–10.121
34. CHLORINE Cl (g)							
298.15	21.838	165.190	165.190	0.000	121.302	105.306	–18.449
300	21.852	165.325	165.190	0.040	121.311	105.207	–18.318
400	22.467	171.703	166.055	2.259	121.795	99.766	–13.028
500	22.744	176.752	167.708	4.522	122.272	94.203	–9.841
600	22.781	180.905	169.571	6.800	122.734	88.546	–7.709
700	22.692	184.411	171.448	9.074	123.172	82.813	–6.179
800	22.549	187.432	173.261	11.337	123.585	77.019	–5.029
900	22.389	190.079	174.986	13.584	123.971	71.175	–4.131
1000	22.233	192.430	176.615	15.815	124.334	65.289	–3.410
1100	22.089	194.542	178.150	18.031	124.675	59.368	–2.819
1200	21.959	196.458	179.597	20.233	124.996	53.416	–2.325
1300	21.843	198.211	180.963	22.423	125.299	47.439	–1.906
1400	21.742	199.826	182.253	24.602	125.587	41.439	–1.546
1500	21.652	201.323	183.475	26.772	125.861	35.418	–1.233
35. DICHLORINE Cl_2 (g)							
298.15	33.949	223.079	223.079	0.000	0.000	0.000	0.000
300	33.981	223.290	223.080	0.063	0.000	0.000	0.000
400	35.296	233.263	224.431	3.533	0.000	0.000	0.000
500	36.064	241.229	227.021	7.104	0.000	0.000	0.000
600	36.547	247.850	229.956	10.736	0.000	0.000	0.000
700	36.874	253.510	232.926	14.408	0.000	0.000	0.000
800	37.111	258.450	235.815	18.108	0.000	0.000	0.000
900	37.294	262.832	238.578	21.829	0.000	0.000	0.000
1000	37.442	266.769	241.203	25.566	0.000	0.000	0.000
1100	37.567	270.343	243.692	29.316	0.000	0.000	0.000
1200	37.678	273.617	246.052	33.079	0.000	0.000	0.000
1300	37.778	276.637	248.290	36.851	0.000	0.000	0.000
1400	37.872	279.440	250.416	40.634	0.000	0.000	0.000
1500	37.961	282.056	252.439	44.426	0.000	0.000	0.000
36. HYDROGEN CHLORIDE HCl (g)							
298.15	29.136	186.902	186.902	0.000	–92.310	–95.298	16.696
300	29.137	187.082	186.902	0.054	–92.314	–95.317	16.596
400	29.175	195.468	188.045	2.969	–92.587	–96.278	12.573
500	29.304	201.990	190.206	5.892	–92.911	–97.164	10.151
600	29.576	207.354	192.630	8.835	–93.249	–97.983	8.530
700	29.988	211.943	195.069	11.812	–93.577	–98.746	7.368
800	30.500	215.980	197.435	14.836	–93.879	–99.464	6.494
900	31.063	219.604	199.700	17.913	–94.149	–100.145	5.812
1000	31.639	222.907	201.858	21.049	–94.384	–100.798	5.265
1100	32.201	225.949	203.912	24.241	–94.587	–101.430	4.816
1200	32.734	228.774	205.867	27.488	–94.760	–102.044	4.442
1300	33.229	231.414	207.732	30.786	–94.908	–102.645	4.124
1400	33.684	233.893	209.513	34.132	–95.035	–103.235	3.852
1500	34.100	236.232	211.217	37.522	–95.146	–103.817	3.615

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
37. COPPER Cu (cr, l)							
298.15	24.440	33.150	33.150	0.000	0.000	0.000	0.000
300	24.460	33.301	33.150	0.045	0.000	0.000	0.000
400	25.339	40.467	34.122	2.538	0.000	0.000	0.000
500	25.966	46.192	35.982	5.105	0.000	0.000	0.000
600	26.479	50.973	38.093	7.728	0.000	0.000	0.000
700	26.953	55.090	40.234	10.399	0.000	0.000	0.000
800	27.448	58.721	42.322	13.119	0.000	0.000	0.000
900	28.014	61.986	44.328	15.891	0.000	0.000	0.000
1000	28.700	64.971	46.245	18.726	0.000	0.000	0.000
1100	29.553	67.745	48.075	21.637	0.000	0.000	0.000
1200	30.617	70.361	49.824	24.644	0.000	0.000	0.000
1300	31.940	72.862	51.501	27.769	0.000	0.000	0.000
1358	32.844	74.275	52.443	29.647	0.000	0.000	0.000
PHASE TRANSITION: $\Delta_{trs} H$ = 13.141 kJ/mol, $\Delta_{trs} S$ = 9.676 J/K·mol, cr–l							
1358	32.800	83.951	52.443	42.788	0.000	0.000	0.000
1400	32.800	84.950	53.403	44.166	0.000	0.000	0.000
1500	32.800	87.213	55.583	47.446	0.000	0.000	0.000
38. COPPER Cu (g)							
298.15	20.786	166.397	166.397	0.000	337.600	297.873	–52.185
300	20.786	166.525	166.397	0.038	337.594	297.626	–51.821
400	20.786	172.505	167.213	2.117	337.179	284.364	–37.134
500	20.786	177.143	168.752	4.196	336.691	271.215	–28.333
600	20.786	180.933	170.476	6.274	336.147	258.170	–22.475
700	20.786	184.137	172.205	8.353	335.554	245.221	–18.298
800	20.786	186.913	173.874	10.431	334.913	232.359	–15.171
900	20.786	189.361	175.461	12.510	334.219	219.581	–12.744
1000	20.786	191.551	176.963	14.589	333.463	206.883	–10.806
1100	20.788	193.532	178.380	16.667	332.631	194.265	–9.225
1200	20.793	195.341	179.719	18.746	331.703	181.726	–7.910
1300	20.803	197.006	180.986	20.826	330.657	169.270	–6.801
1400	20.823	198.548	182.186	22.907	316.342	157.305	–5.869
1500	20.856	199.986	183.325	24.991	315.146	145.987	–5.084
39. COPPER OXIDE CuO (cr)							
298.15	42.300	42.740	42.740	0.000	–162.000	–134.277	23.524
300	42.417	43.002	42.741	0.078	–161.994	–134.105	23.349
400	46.783	55.878	44.467	4.564	–161.487	–124.876	16.307
500	49.190	66.596	47.852	9.372	–160.775	–115.803	12.098
600	50.827	75.717	51.755	14.377	–159.973	–106.883	9.305
700	52.099	83.651	55.757	19.526	–159.124	–98.102	7.320
800	53.178	90.680	59.691	24.791	–158.247	–89.444	5.840
900	54.144	97.000	63.491	30.158	–157.356	–80.897	4.695
1000	55.040	102.751	67.134	35.617	–156.462	–72.450	3.784
1100	55.890	108.037	70.615	41.164	–155.582	–64.091	3.043
1200	56.709	112.936	73.941	46.794	–154.733	–55.812	2.429
1300	57.507	117.507	77.118	52.505	–153.940	–47.601	1.913
1400	58.288	121.797	80.158	58.295	–166.354	–39.043	1.457
1500	59.057	125.845	83.070	64.163	–165.589	–29.975	1.044
40. DICOPPER OXIDE Cu_2O (cr)							
298.15	62.600	92.550	92.550	0.000	–173.100	–150.344	26.339
300	62.721	92.938	92.551	0.116	–173.102	–150.203	26.152
400	67.587	111.712	95.078	6.654	–173.036	–142.572	18.618
500	70.784	127.155	99.995	13.580	–172.772	–134.984	14.101

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f

40. DICOPPER OXIDE Cu_2O (cr) (continued)

T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
600	73.323	140.291	105.643	20.789	–172.389	–127.460	11.096
700	75.552	151.764	111.429	28.235	–171.914	–120.009	8.955
800	77.616	161.989	117.121	35.894	–171.363	–112.631	7.354
900	79.584	171.245	122.629	43.755	–170.750	–105.325	6.113
1000	81.492	179.729	127.920	51.809	–170.097	–98.091	5.124
1100	83.360	187.584	132.992	60.052	–169.431	–90.922	4.317
1200	85.202	194.917	137.850	68.480	–168.791	–83.814	3.648
1300	87.026	201.808	142.507	77.092	–168.223	–76.756	3.084
1400	88.836	208.324	146.978	85.885	–194.030	–68.926	2.572
1500	90.636	214.515	151.276	94.858	–193.438	–60.010	2.090

41. COPPER DICHLORIDE $CuCl_2$ (cr, l)

T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	71.880	108.070	108.070	0.000	–218.000	–173.826	30.453
300	71.998	108.515	108.071	0.133	–217.975	–173.552	30.218
400	76.338	129.899	110.957	7.577	–216.494	–158.962	20.758
500	78.654	147.204	116.532	15.336	–214.873	–144.765	15.123
600	80.175	161.687	122.884	23.282	–213.182	–130.901	11.396
675	81.056	171.183	127.732	29.329	–211.185	–120.693	9.340
PHASE TRANSITION: $\Delta_{trs}H$ = 0.700 kJ/mol, $\Delta_{trs}S$ = 1.037 J/K·mol, crII–crI							
675	82.400	172.220	127.732	30.029	–211.185	–120.693	9.340
700	82.400	175.216	129.375	32.089	–210.719	–117.350	8.757
800	82.400	186.219	135.808	40.329	–208.898	–104.137	6.799
871	82.400	193.226	140.207	46.179	–192.649	–94.893	5.691
PHASE TRANSITION: $\Delta_{trs}H$ = 15.001 kJ/mol, $\Delta_{trs}S$ = 17.221 J/K·mol, crI–l							
871	100.000	210.447	140.207	61.180	–192.649	–94.893	5.691
900	100.000	213.723	142.523	64.080	–191.640	–91.655	5.319
1000	100.000	224.259	150.179	74.080	–188.212	–80.730	4.217
1100	100.000	233.790	157.353	84.080	–184.873	–70.144	3.331
1130.75	100.000	236.547	159.470	87.155	–183.867	–66.951	3.093

42. COPPER DICHLORIDE $CuCl_2$ (g)

T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	56.814	278.418	278.418	0.000	–43.268	–49.883	8.739
300	56.869	278.769	278.419	0.105	–43.271	–49.924	8.692
400	58.992	295.456	280.679	5.911	–43.428	–52.119	6.806
500	60.111	308.752	285.010	11.871	–43.606	–54.271	5.670
600	60.761	319.774	289.911	17.918	–43.814	–56.385	4.909
700	61.168	329.173	294.865	24.015	–44.060	–58.462	4.362
800	61.439	337.360	299.677	30.147	–44.349	–60.500	3.950
900	61.630	344.608	304.274	36.301	–44.688	–62.499	3.627
1000	61.776	351.109	308.638	42.471	–45.088	–64.457	3.367
1100	61.900	357.003	312.771	48.655	–45.566	–66.372	3.152
1200	62.022	362.394	316.685	54.851	–46.139	–68.239	2.970
1300	62.159	367.364	320.395	61.060	–46.829	–70.053	2.815
1400	62.325	371.976	323.916	67.284	–60.784	–71.404	2.664
1500	62.531	376.283	327.265	73.526	–61.613	–72.133	2.512

43. FLUORINE F (g)

T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	22.746	158.750	158.750	0.000	79.380	62.280	–10.911
300	22.742	158.891	158.750	0.042	79.393	62.173	–10.825
400	22.432	165.394	159.639	2.302	80.043	56.332	–7.356
500	22.100	170.363	161.307	4.528	80.587	50.340	–5.259
600	21.832	174.368	163.161	6.724	81.046	44.246	–3.852
700	21.629	177.717	165.008	8.897	81.442	38.081	–2.842
800	21.475	180.595	166.780	11.052	81.792	31.862	–2.080
900	21.357	183.117	168.458	13.193	82.106	25.601	–1.486

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
43. FLUORINE F (g) (continued)							
1000	21.266	185.362	170.039	15.324	82.391	19.308	–1.009
1100	21.194	187.386	171.525	17.447	82.654	12.986	–0.617
1200	21.137	189.227	172.925	19.563	82.897	6.642	–0.289
1300	21.091	190.917	174.245	21.675	83.123	0.278	–0.011
1400	21.054	192.479	175.492	23.782	83.335	–6.103	0.228
1500	21.022	193.930	176.673	25.886	83.533	–12.498	0.435
44. DIFLUORINE F_2 (g)							
298.15	31.304	202.790	202.790	0.000	0.000	0.000	0.000
300	31.337	202.984	202.790	0.058	0.000	0.000	0.000
400	32.995	212.233	204.040	3.277	0.000	0.000	0.000
500	34.258	219.739	206.453	6.643	0.000	0.000	0.000
600	35.171	226.070	209.208	10.117	0.000	0.000	0.000
700	35.839	231.545	212.017	13.669	0.000	0.000	0.000
800	36.343	236.365	214.765	17.279	0.000	0.000	0.000
900	36.740	240.669	217.409	20.934	0.000	0.000	0.000
1000	37.065	244.557	219.932	24.625	0.000	0.000	0.000
1100	37.342	248.103	222.334	28.346	0.000	0.000	0.000
1200	37.588	251.363	224.619	32.093	0.000	0.000	0.000
1300	37.811	254.381	226.794	35.863	0.000	0.000	0.000
1400	38.019	257.191	228.866	39.654	0.000	0.000	0.000
1500	38.214	259.820	230.843	43.466	0.000	0.000	0.000
45. HYDROGEN FLUORIDE HF (g)							
298.15	29.137	173.776	173.776	0.000	–273.300	–275.399	48.248
300	29.137	173.956	173.776	0.054	–273.302	–275.412	47.953
400	29.149	182.340	174.919	2.968	–273.450	–276.096	36.054
500	29.172	188.846	177.078	5.884	–273.679	–276.733	28.910
600	29.230	194.169	179.496	8.804	–273.961	–277.318	24.142
700	29.350	198.683	181.923	11.732	–274.277	–277.852	20.733
800	29.549	202.614	184.269	14.676	–274.614	–278.340	18.174
900	29.827	206.110	186.505	17.645	–274.961	–278.785	16.180
1000	30.169	209.270	188.626	20.644	–275.309	–279.191	14.583
1100	30.558	212.163	190.636	23.680	–275.652	–279.563	13.275
1200	30.974	214.840	192.543	26.756	–275.988	–279.904	12.184
1300	31.403	217.336	194.355	29.875	–276.315	–280.217	11.259
1400	31.831	219.679	196.081	33.037	–276.631	–280.505	10.466
1500	32.250	221.889	197.729	36.241	–276.937	–280.771	9.777
46. GERMANIUM Ge (cr, l)							
298.15	23.222	31.090	31.090	0.000	0.000	0.000	0.000
300	23.249	31.234	31.090	0.043	0.000	0.000	0.000
400	24.310	38.083	32.017	2.426	0.000	0.000	0.000
500	24.962	43.582	33.798	4.892	0.000	0.000	0.000
600	25.452	48.178	35.822	7.414	0.000	0.000	0.000
700	25.867	52.133	37.876	9.980	0.000	0.000	0.000
800	26.240	55.612	39.880	12.586	0.000	0.000	0.000
900	26.591	58.723	41.804	15.227	0.000	0.000	0.000
1000	26.926	61.542	43.639	17.903	0.000	0.000	0.000
1100	27.252	64.124	45.386	20.612	0.000	0.000	0.000
1200	27.571	66.509	47.048	23.353	0.000	0.000	0.000
1211.4	27.608	66.770	47.232	23.668	0.000	0.000	0.000
PHASE TRANSITION: $\Delta_{trs} H$ = 37.030 kJ/mol, $\Delta_{trs} S$ = 30.568 J/K·mol, cr–l							
1211.4	27.600	97.338	47.232	60.698	0.000	0.000	0.000
1300	27.600	99.286	50.714	63.143	0.000	0.000	0.000

T/K	C_p° (J/K·mol)	S° (J/K·mol)	$-(G^\circ-H^\circ(T_r))/T$ (J/K·mol)	$H^\circ-H^\circ(T_r)$ (kJ/mol)	$\Delta_f H^\circ$ (kJ/mol)	$\Delta_f G^\circ$ (kJ/mol)	Log K_f
46. GERMANIUM Ge (cr, l) (continued)							
1400	27.600	101.331	54.258	65.903	0.000	0.000	0.000
1500	27.600	103.236	57.460	68.663	0.000	0.000	0.000
47. GERMANIUM Ge (g)							
298.15	30.733	167.903	167.903	0.000	367.800	327.009	–57.290
300	30.757	168.094	167.904	0.057	367.814	326.756	–56.893
400	31.071	177.025	169.119	3.162	368.536	312.959	–40.868
500	30.360	183.893	171.415	6.239	369.147	298.991	–31.235
600	29.265	189.334	173.965	9.222	369.608	284.914	–24.804
700	28.102	193.758	176.487	12.090	369.910	270.773	–20.205
800	27.029	197.439	178.882	14.845	370.060	256.598	–16.754
900	26.108	200.567	181.122	17.501	370.073	242.414	–14.069
1000	25.349	203.277	183.205	20.072	369.969	228.234	–11.922
1100	24.741	205.664	185.141	22.575	369.763	214.069	–10.165
1200	24.264	207.795	186.941	25.025	369.471	199.928	–8.703
1300	23.898	209.722	188.621	27.432	332.088	188.521	–7.575
1400	23.624	211.483	190.192	29.807	331.704	177.492	–6.622
1500	23.426	213.105	191.666	32.159	331.296	166.491	–5.798
48. GERMANIUM DIOXIDE GeO_2 (cr, l)							
298.15	50.166	39.710	39.710	0.000	–580.200	–521.605	91.382
300	50.475	40.021	39.711	0.093	–580.204	–521.242	90.755
400	61.281	56.248	41.850	5.759	–579.893	–501.610	65.503
500	66.273	70.519	46.191	12.164	–579.013	–482.134	50.368
600	69.089	82.872	51.299	18.943	–577.915	–462.859	40.295
700	70.974	93.671	56.597	25.952	–576.729	–443.776	33.115
800	72.449	103.247	61.841	33.125	–575.498	–424.866	27.741
900	73.764	111.857	66.928	40.436	–574.235	–406.113	23.570
1000	75.049	119.696	71.819	47.877	–572.934	–387.502	20.241
1100	76.378	126.910	76.504	55.447	–571.582	–369.024	17.523
1200	77.796	133.616	80.987	63.155	–570.166	–350.671	15.264
1300	79.332	139.903	85.279	71.010	–605.685	–329.732	13.249
1308	79.460	140.390	85.615	71.646	–584.059	–328.034	13.100
PHASE TRANSITION: $\Delta_{trs} H$ = 21.500 kJ/mol, $\Delta_{trs} S$ = 16.437 J/K·mol, crII–crI							
1308	80.075	156.827	85.615	93.146	–584.059	–328.034	13.100
1388	81.297	161.617	89.858	99.601	–565.504	–312.415	11.757
PHASE TRANSITION: $\Delta_{trs} H$ = 17.200 kJ/mol, $\Delta_{trs} S$ = 12.392 J/K·mol, crI–l							
1388	78.500	174.009	89.858	116.801	–565.504	–312.415	11.757
1400	78.500	174.685	90.582	117.743	–565.328	–310.228	11.575
1500	78.500	180.100	96.372	125.593	–563.882	–292.057	10.170
49. GERMANIUM TETRACHLORIDE $GeCl_4$ (g)							
298.15	95.918	348.393	348.393	0.000	–500.000	–461.582	80.866
300	96.041	348.987	348.395	0.178	–499.991	–461.343	80.326
400	100.750	377.342	352.229	10.045	–499.447	–448.540	58.573
500	103.206	400.114	359.604	20.255	–498.845	–435.882	45.536
600	104.624	419.067	367.980	30.652	–498.234	–423.347	36.855
700	105.509	435.266	376.463	41.162	–497.634	–410.914	30.662
800	106.096	449.396	384.715	51.744	–497.057	–398.565	26.023
900	106.504	461.917	392.611	62.375	–496.509	–386.287	22.419
1000	106.799	473.155	400.113	73.041	–495.993	–374.068	19.539
1100	107.020	483.344	407.224	83.733	–495.512	–361.899	17.185
1200	107.189	492.664	413.961	94.444	–495.067	–349.772	15.225
1300	107.320	501.249	420.349	105.169	–531.677	–334.973	13.459
1400	107.425	509.206	426.416	115.907	–531.265	–319.857	11.934
1500	107.509	516.621	432.185	126.654	–530.861	–304.771	10.613

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
50. HYDROGEN H (g)							
298.15	20.786	114.716	114.716	0.000	217.998	203.276	–35.613
300	20.786	114.845	114.716	0.038	218.010	203.185	–35.377
400	20.786	120.824	115.532	2.117	218.635	198.149	–25.875
500	20.786	125.463	117.071	4.196	219.253	192.956	–20.158
600	20.786	129.252	118.795	6.274	219.867	187.639	–16.335
700	20.786	132.457	120.524	8.353	220.476	182.219	–13.597
800	20.786	135.232	122.193	10.431	221.079	176.712	–11.538
900	20.786	137.680	123.780	12.510	221.670	171.131	–9.932
1000	20.786	139.870	125.282	14.589	222.247	165.485	–8.644
1100	20.786	141.852	126.700	16.667	222.806	159.781	–7.587
1200	20.786	143.660	128.039	18.746	223.345	154.028	–6.705
1300	20.786	145.324	129.305	20.824	223.864	148.230	–5.956
1400	20.786	146.864	130.505	22.903	224.360	142.393	–5.313
1500	20.786	148.298	131.644	24.982	224.835	136.522	–4.754
51. DIHYDROGEN H_2 (g)							
298.15	28.836	130.680	130.680	0.000	0.000	0.000	0.000
300	28.849	130.858	130.680	0.053	0.000	0.000	0.000
400	29.181	139.217	131.818	2.960	0.000	0.000	0.000
500	29.260	145.738	133.974	5.882	0.000	0.000	0.000
600	29.327	151.078	136.393	8.811	0.000	0.000	0.000
700	29.440	155.607	138.822	11.749	0.000	0.000	0.000
800	29.623	159.549	141.172	14.702	0.000	0.000	0.000
900	29.880	163.052	143.412	17.676	0.000	0.000	0.000
1000	30.204	166.217	145.537	20.680	0.000	0.000	0.000
1100	30.580	169.113	147.550	23.719	0.000	0.000	0.000
1200	30.991	171.791	149.460	26.797	0.000	0.000	0.000
1300	31.422	174.288	151.275	29.918	0.000	0.000	0.000
1400	31.860	176.633	153.003	33.082	0.000	0.000	0.000
1500	32.296	178.846	154.653	36.290	0.000	0.000	0.000
52. HYDROXYL OH (g)							
298.15	29.886	183.737	183.737	0.000	39.349	34.631	–6.067
300	29.879	183.922	183.738	0.055	39.350	34.602	–6.025
400	29.604	192.476	184.906	3.028	39.384	33.012	–4.311
500	29.495	199.067	187.104	5.982	39.347	31.422	–3.283
600	29.513	204.445	189.560	8.931	39.252	29.845	–2.598
700	29.655	209.003	192.020	11.888	39.113	28.287	–2.111
800	29.914	212.979	194.396	14.866	38.945	26.752	–1.747
900	30.265	216.522	196.661	17.874	38.763	25.239	–1.465
1000	30.682	219.731	198.810	20.921	38.577	23.746	–1.240
1100	31.135	222.677	200.848	24.012	38.393	22.272	–1.058
1200	31.603	225.406	202.782	27.149	38.215	20.814	–0.906
1300	32.069	227.954	204.621	30.332	38.046	19.371	–0.778
1400	32.522	230.347	206.374	33.562	37.886	17.941	–0.669
1500	32.956	232.606	208.048	36.836	37.735	16.521	–0.575
53. WATER H_2O (l)							
298.15	75.300	69.950	69.950	0.000	–285.830	–237.141	41.546
300	75.281	70.416	69.951	0.139	–285.771	–236.839	41.237
373.21	76.079	86.896	71.715	5.666	–283.454	–225.160	31.513
54. WATER H_2O (g)							
298.15	33.598	188.832	188.832	0.000	–241.826	–228.582	40.046

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
54. WATER H_2O (g) (continued)							
300	33.606	189.040	188.833	0.062	–241.844	–228.500	39.785
400	34.283	198.791	190.158	3.453	–242.845	–223.900	29.238
500	35.259	206.542	192.685	6.929	–243.822	–219.050	22.884
600	36.371	213.067	195.552	10.509	–244.751	–214.008	18.631
700	37.557	218.762	198.469	14.205	–245.620	–208.814	15.582
800	38.800	223.858	201.329	18.023	–246.424	–203.501	13.287
900	40.084	228.501	204.094	21.966	–247.158	–198.091	11.497
1000	41.385	232.792	206.752	26.040	–247.820	–192.603	10.060
1100	42.675	236.797	209.303	30.243	–248.410	–187.052	8.882
1200	43.932	240.565	211.753	34.574	–248.933	–181.450	7.898
1300	45.138	244.129	214.108	39.028	–249.392	–175.807	7.064
1400	46.281	247.516	216.374	43.599	–249.792	–170.132	6.348
1500	47.356	250.746	218.559	48.282	–250.139	–164.429	5.726
55. IODINE I (g)							
298.15	20.786	180.787	180.787	0.000	106.760	70.172	–12.294
300	20.786	180.915	180.787	0.038	106.748	69.945	–12.178
400	20.786	186.895	181.602	2.117	97.974	58.060	–7.582
500	20.786	191.533	183.142	4.196	75.988	50.202	–5.244
600	20.786	195.323	184.866	6.274	76.190	45.025	–3.920
700	20.786	198.527	186.594	8.353	76.385	39.816	–2.971
800	20.787	201.303	188.263	10.432	76.574	34.579	–2.258
900	20.789	203.751	189.851	12.510	76.757	29.319	–1.702
1000	20.795	205.942	191.352	14.589	76.936	24.038	–1.256
1100	20.806	207.924	192.770	16.669	77.109	18.740	–0.890
1200	20.824	209.735	194.110	18.751	77.277	13.426	–0.584
1300	20.851	211.403	195.377	20.835	77.440	8.098	–0.325
1400	20.889	212.950	196.577	22.921	77.596	2.758	–0.103
1500	20.936	214.392	197.717	25.013	77.745	–2.592	0.090
56. DIIODINE I_2 (cr, l)							
298.15	54.440	116.139	116.139	0.000	0.000	0.000	0.000
300	54.518	116.476	116.140	0.101	0.000	0.000	0.000
386.75	61.531	131.039	117.884	5.088	0.000	0.000	0.000
		PHASE TRANSITION: $\Delta_{trs} H$ = 15.665 kJ/mol, $\Delta_{trs} S$ = 40.504 J/K·mol, cr–l					
386.75	79.555	171.543	117.884	20.753	0.000	0.000	0.000
400	79.555	174.223	119.706	21.807	0.000	0.000	0.000
457.67	79.555	184.938	127.266	26.395	0.000	0.000	0.000
57. DIIODINE I_2 (g)							
298.15	36.887	260.685	260.685	0.000	62.420	19.324	–3.385
300	36.897	260.913	260.685	0.068	62.387	19.056	–3.318
400	37.256	271.584	262.138	3.778	44.391	5.447	–0.711
457.67	37.385	276.610	263.652	5.931		pressure = 1 bar	
500	37.464	279.921	264.891	7.515	0.000	0.000	0.000
600	37.613	286.765	267.983	11.269	0.000	0.000	0.000
700	37.735	292.573	271.092	15.037	0.000	0.000	0.000
800	37.847	297.619	274.099	18.816	0.000	0.000	0.000
900	37.956	302.083	276.965	22.606	0.000	0.000	0.000
1000	38.070	306.088	279.681	26.407	0.000	0.000	0.000
1100	38.196	309.722	282.249	30.220	0.000	0.000	0.000
1200	38.341	313.052	284.679	34.047	0.000	0.000	0.000
1300	38.514	316.127	286.981	37.890	0.000	0.000	0.000
1400	38.719	318.989	289.166	41.751	0.000	0.000	0.000
1500	38.959	321.668	291.245	45.635	0.000	0.000	0.000

	J/K·mol			kJ/mol			
***T*/K**	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
58. HYDROGEN IODIDE HI (g)							
298.15	29.157	206.589	206.589	0.000	26.500	1.700	–0.298
300	29.158	206.769	206.589	0.054	26.477	1.546	–0.269
400	29.329	215.176	207.734	2.977	17.093	–6.289	0.821
500	29.738	221.760	209.904	5.928	–5.481	–9.946	1.039
600	30.351	227.233	212.348	8.931	–5.819	–10.806	0.941
700	31.070	231.965	214.820	12.002	–6.101	–11.614	0.867
800	31.807	236.162	217.230	15.145	–6.323	–12.386	0.809
900	32.511	239.950	219.548	18.362	–6.489	–13.133	0.762
1000	33.156	243.409	221.763	21.646	–6.608	–13.865	0.724
1100	33.735	246.597	223.878	24.991	–6.689	–14.586	0.693
1200	34.249	249.555	225.896	28.391	–6.741	–15.302	0.666
1300	34.703	252.314	227.823	31.839	–6.775	–16.014	0.643
1400	35.106	254.901	229.666	35.330	–6.797	–16.723	0.624
1500	35.463	257.336	231.430	38.858	–6.814	–17.432	0.607
59. POTASSIUM K (cr, l)							
298.15	29.600	64.680	64.680	0.000	0.000	0.000	0.000
300	29.671	64.863	64.681	0.055	0.000	0.000	0.000
336.86	32.130	68.422	64.896	1.188	0.000	0.000	0.000
PHASE TRANSITION: $\Delta_{trs} H$ = 2.321 kJ/mol, $\Delta_{trs} S$ = 6.891 J/K·mol, cr–l							
336.86	32.129	75.313	64.896	3.509	0.000	0.000	0.000
400	31.552	80.784	66.986	5.519	0.000	0.000	0.000
500	30.741	87.734	70.469	8.632	0.000	0.000	0.000
600	30.158	93.283	73.824	11.675	0.000	0.000	0.000
700	29.851	97.905	76.943	14.673	0.000	0.000	0.000
800	29.838	101.887	79.818	17.655	0.000	0.000	0.000
900	30.130	105.415	82.470	20.651	0.000	0.000	0.000
1000	30.730	108.618	84.927	23.691	0.000	0.000	0.000
1039.4	31.053	109.812	85.847	24.908	0.000	0.000	0.000
60. POTASSIUM K (g)							
298.15	20.786	160.340	160.340	0.000	89.000	60.479	–10.596
300	20.786	160.468	160.340	0.038	88.984	60.302	–10.499
400	20.786	166.448	161.155	2.117	85.598	51.332	–6.703
500	20.786	171.086	162.695	4.196	84.563	42.887	–4.480
600	20.786	174.876	164.419	6.274	83.599	34.643	–3.016
700	20.786	178.080	166.148	8.353	82.680	26.557	–1.982
800	20.786	180.856	167.817	10.431	81.776	18.601	–1.215
900	20.786	183.304	169.404	12.510	80.859	10.759	–0.624
1000	20.786	185.494	170.905	14.589	79.897	3.021	–0.158
1039.4	20.786	186.297	171.474	15.408		pressure = 1 bar	
1100	20.786	187.475	172.323	16.667	0.000	0.000	0.000
1200	20.786	189.284	173.662	18.746	0.000	0.000	0.000
1300	20.789	190.948	174.929	20.825	0.000	0.000	0.000
1400	20.793	192.489	176.129	22.904	0.000	0.000	0.000
1500	20.801	193.923	177.268	24.983	0.000	0.000	0.000
61. DIPOTASSIUM OXIDE K_2O (cr, l)							
298.15	72.000	96.000	96.000	0.000	–361.700	–321.171	56.267
300	72.130	96.446	96.001	0.133	–361.704	–320.920	55.876
400	79.154	118.158	98.914	7.698	–366.554	–306.416	40.013
500	86.178	136.575	104.647	15.964	–366.043	–291.423	30.444
590	92.500	151.348	110.662	24.005	–364.204	–278.079	24.619
PHASE TRANSITION: $\Delta_{trs} H$ = 0.700 kJ/mol, $\Delta_{trs} S$ = 1.186 J/K·mol, crIII–crII							

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f

61. DIPOTASSIUM OXIDE K_2O (cr, l) (continued)

T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
590	100.000	152.534	110.662	24.705	–364.204	–278.079	24.619
600	100.000	154.215	111.374	25.705	–363.968	–276.621	24.082
645	100.000	161.447	114.618	30.205	–358.901	–270.109	21.874
PHASE TRANSITION: $\Delta_{trs} H$ = 4.000 kJ/mol, $\Delta_{trs} S$ = 6.202 J/K·mol, crII–crI							
645	100.000	167.649	114.618	34.205	–358.901	–270.109	21.874
700	100.000	175.832	119.111	39.705	–357.592	–262.592	19.595
800	100.000	189.185	127.054	49.705	–355.224	–249.183	16.270
900	100.000	200.963	134.625	59.705	–352.919	–236.067	13.701
1000	100.000	211.499	141.794	69.705	–350.732	–223.202	11.659
1013	100.000	212.791	142.697	71.005	–323.459	–221.546	11.424
PHASE TRANSITION: $\Delta_{trs} H$ = 27.000 kJ/mol, $\Delta_{trs} S$ =26.654 J/K·mol, crI–l							
1013	100.000	239.444	142.697	98.005	–323.459	–221.546	11.424
1100	100.000	247.684	150.679	106.705	–479.439	–203.633	9.670
1200	100.000	256.385	159.131	116.705	–475.371	–178.740	7.780
1300	100.000	264.389	166.924	126.705	–471.321	–154.185	6.195
1400	100.000	271.800	174.154	136.705	–467.287	–129.941	4.848
1500	100.000	278.699	180.896	146.705	–463.268	–105.986	3.691

62. POTASSIUM HYDROXIDE KOH (cr, l)

T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	64.900	78.870	78.870	0.000	–424.580	–378.747	66.354
300	65.038	79.272	78.871	0.120	–424.569	–378.463	65.895
400	72.519	99.007	81.512	6.998	–426.094	–362.765	47.372
500	80.000	115.993	86.745	14.624	–424.572	–347.093	36.260
520	81.496	119.159	87.931	16.239	–417.725	–344.002	34.555
PHASE TRANSITION: $\Delta_{trs} H$ = 6.450 kJ/mol, $\Delta_{trs} S$ = 12.404 J/K·mol, crII–crI							
520	79.000	131.563	87.931	22.689	–417.725	–344.002	34.555
600	79.000	142.868	94.520	29.009	–416.274	–332.766	28.969
678	79.000	152.523	100.649	35.171	–405.464	–321.998	24.807
PHASE TRANSITION: $\Delta_{trs} H$ = 9.400 kJ/mol, $\Delta_{trs} S$ = 13.865 J/K·mol, crI–l							
678	83.000	166.388	100.649	44.571	–405.464	–321.998	24.807
700	83.000	169.038	102.757	46.397	–404.981	–319.297	23.826
800	83.000	180.121	111.750	54.697	–402.808	–307.206	20.058
900	83.000	189.897	119.901	62.997	–400.694	–295.383	17.143
1000	83.000	198.642	127.345	71.297	–398.668	–283.791	14.824
1100	83.000	206.553	134.192	79.597	–475.618	–267.780	12.716
1200	83.000	213.775	140.527	87.897	–472.711	–249.014	10.839
1300	83.000	220.418	146.421	96.197	–469.843	–230.490	9.261
1400	83.000	226.569	151.929	104.497	–467.011	–212.184	7.917
1500	83.000	232.296	157.098	112.797	–464.217	–194.080	6.758

63. POTASSIUM HYDROXIDE KOH (g)

T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	49.184	238.283	238.283	0.000	–227.989	–229.685	40.239
300	49.236	238.588	238.284	0.091	–228.007	–229.696	39.993
400	51.178	253.053	240.243	5.124	–231.377	–229.667	29.991
500	52.178	264.591	243.998	10.296	–232.309	–229.129	23.937
600	52.804	274.163	248.251	15.547	–233.145	–228.413	19.885
700	53.296	282.340	252.551	20.853	–233.934	–227.562	16.981
800	53.758	289.487	256.730	26.206	–234.708	–226.599	14.795
900	54.229	295.846	260.730	31.605	–235.495	–225.538	13.090
1000	54.713	301.585	264.533	37.052	–236.322	–224.388	11.721
1100	55.203	306.823	268.143	42.548	–316.077	–218.535	10.377
1200	55.686	311.647	271.570	48.092	–315.925	–209.674	9.127
1300	56.153	316.122	274.827	53.684	–315.764	–200.826	8.069
1400	56.598	320.300	277.927	59.322	–315.595	–191.991	7.163
1500	57.016	324.220	280.884	65.003	–315.420	–183.169	6.378

64. POTASSIUM CHLORIDE KCl (cr, l)

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	51.300	82.570	82.570	0.000	–436.490	–408.568	71.579
300	51.333	82.887	82.571	0.095	–436.481	–408.395	71.107
400	52.977	97.886	84.605	5.312	–438.463	–398.651	52.058
500	54.448	109.867	88.498	10.685	–437.990	–388.749	40.612
600	55.885	119.921	92.919	16.201	–437.332	–378.960	32.991
700	57.425	128.649	97.413	21.865	–436.502	–369.295	27.557
800	59.205	136.430	101.812	27.694	–435.505	–359.760	23.490
900	61.361	143.523	106.058	33.719	–434.337	–350.360	20.334
1000	64.032	150.121	110.138	39.983	–432.981	–341.100	17.817
1044	65.405	152.908	111.882	42.830	–485.450	–336.720	16.847
PHASE TRANSITION: $\Delta_{trs} H$ = 26.320 kJ/mol, $\Delta_{trs} S$ = 25.210 J/K·mol, cr–l							
1044	72.000	178.118	111.882	69.150	–485.450	–336.720	16.847
1100	72.000	181.880	115.351	73.182	–483.633	–328.790	15.613
1200	72.000	188.145	121.160	80.382	–480.393	–314.856	13.705
1300	72.000	193.908	126.537	87.582	–477.158	–301.192	12.102
1400	72.000	199.244	131.542	94.782	–473.928	–287.778	10.737
1500	72.000	204.211	136.223	101.982	–470.704	–274.594	9.562

65. POTASSIUM CHLORIDE KCl (g)

T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	36.505	239.091	239.091	0.000	–214.575	–233.320	40.876
300	36.518	239.317	239.092	0.068	–214.594	–233.436	40.644
400	37.066	249.904	240.532	3.749	–218.112	–239.107	31.224
500	37.384	258.212	243.267	7.473	–219.287	–244.219	25.513
600	37.597	265.048	246.344	11.222	–220.396	–249.100	21.686
700	37.769	270.857	249.441	14.991	–221.461	–253.799	18.938
800	37.907	275.910	252.441	18.775	–222.509	–258.347	16.868
900	38.041	280.382	255.302	22.572	–223.568	–262.764	15.250
1000	38.162	284.397	258.014	26.383	–224.667	–267.061	13.950
1100	38.279	288.039	260.581	30.205	–304.696	–266.627	12.661
1200	38.401	291.375	263.010	34.039	–304.821	–263.161	11.455
1300	38.518	294.454	265.312	37.885	–304.941	–259.684	10.434
1400	38.639	297.313	267.496	41.743	–305.053	–256.199	9.559
1500	38.761	299.983	269.574	45.613	–305.159	–252.706	8.800

66. DINITROGEN N_2 (g)

T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	29.124	191.608	191.608	0.000	0.000	0.000	0.000
300	29.125	191.788	191.608	0.054	0.000	0.000	0.000
400	29.249	200.180	192.752	2.971	0.000	0.000	0.000
500	29.580	206.738	194.916	5.911	0.000	0.000	0.000
600	30.109	212.175	197.352	8.894	0.000	0.000	0.000
700	30.754	216.864	199.812	11.936	0.000	0.000	0.000
800	31.433	221.015	202.208	15.046	0.000	0.000	0.000
900	32.090	224.756	204.509	18.222	0.000	0.000	0.000
1000	32.696	228.169	206.706	21.462	0.000	0.000	0.000
1100	33.241	231.311	208.802	24.759	0.000	0.000	0.000
1200	33.723	234.224	210.801	28.108	0.000	0.000	0.000
1300	34.147	236.941	212.708	31.502	0.000	0.000	0.000
1400	34.517	239.485	214.531	34.936	0.000	0.000	0.000
1500	34.842	241.878	216.275	38.404	0.000	0.000	0.000

67. NITRIC OXIDE NO (g)

T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
298.15	29.862	210.745	210.745	0.000	91.277	87.590	–15.345
300	29.858	210.930	210.746	0.055	91.278	87.567	–15.247
400	29.954	219.519	211.916	3.041	91.320	86.323	–11.272
500	30.493	226.255	214.133	6.061	91.340	85.071	–8.887

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
67. NITRIC OXIDE NO (g) (continued)							
600	31.243	231.879	216.635	9.147	91.354	83.816	–7.297
700	32.031	236.754	219.168	12.310	91.369	82.558	–6.160
800	32.770	241.081	221.642	15.551	91.386	81.298	–5.308
900	33.425	244.979	224.022	18.862	91.405	80.036	–4.645
1000	33.990	248.531	226.298	22.233	91.426	78.772	–4.115
1100	34.473	251.794	228.469	25.657	91.445	77.505	–3.680
1200	34.883	254.811	230.540	29.125	91.464	76.237	–3.318
1300	35.234	257.618	232.516	32.632	91.481	74.967	–3.012
1400	35.533	260.240	234.404	36.170	91.495	73.697	–2.750
1500	35.792	262.700	236.209	39.737	91.506	72.425	–2.522
68. NITROGEN DIOXIDE NO_2 (g)							
298.15	37.178	240.166	240.166	0.000	34.193	52.316	–9.165
300	37.236	240.397	240.167	0.069	34.181	52.429	–9.129
400	40.513	251.554	241.666	3.955	33.637	58.600	–7.652
500	43.664	260.939	244.605	8.167	33.319	64.882	–6.778
600	46.383	269.147	248.026	12.673	33.174	71.211	–6.199
700	48.612	276.471	251.575	17.427	33.151	77.553	–5.787
800	50.405	283.083	255.107	22.381	33.213	83.893	–5.478
900	51.844	289.106	258.555	27.496	33.334	90.221	–5.236
1000	53.007	294.631	261.891	32.741	33.495	96.534	–5.042
1100	53.956	299.729	265.102	38.090	33.686	102.828	–4.883
1200	54.741	304.459	268.187	43.526	33.898	109.105	–4.749
1300	55.399	308.867	271.148	49.034	34.124	115.363	–4.635
1400	55.960	312.994	273.992	54.603	34.360	121.603	–4.537
1500	56.446	316.871	276.722	60.224	34.604	127.827	–4.451
69. AMMONIA NH_3 (g)							
298.15	35.630	192.768	192.768	0.000	–45.940	–16.407	2.874
300	35.678	192.989	192.769	0.066	–45.981	–16.223	2.825
400	38.674	203.647	194.202	3.778	–48.087	–5.980	0.781
500	41.994	212.633	197.011	7.811	–49.908	4.764	–0.498
600	45.229	220.578	200.289	12.174	–51.430	15.846	–1.379
700	48.269	227.781	203.709	16.850	–52.682	27.161	–2.027
800	51.112	234.414	207.138	21.821	–53.695	38.639	–2.523
900	53.769	240.589	210.516	27.066	–54.499	50.231	–2.915
1000	56.244	246.384	213.816	32.569	–55.122	61.903	–3.233
1100	58.535	251.854	217.027	38.309	–55.589	73.629	–3.496
1200	60.644	257.039	220.147	44.270	–55.920	85.392	–3.717
1300	62.576	261.970	223.176	50.432	–56.136	97.177	–3.905
1400	64.339	266.673	226.117	56.779	–56.251	108.975	–4.066
1500	65.945	271.168	228.971	63.295	–56.282	120.779	–4.206
70. OXYGEN O (g)							
298.15	21.911	161.058	161.058	0.000	249.180	231.743	–40.600
300	21.901	161.194	161.059	0.041	249.193	231.635	–40.331
400	21.482	167.430	161.912	2.207	249.874	225.677	–29.470
500	21.257	172.197	163.511	4.343	250.481	219.556	–22.937
600	21.124	176.060	165.290	6.462	251.019	213.319	–18.571
700	21.040	179.310	167.067	8.570	251.500	206.997	–15.446
800	20.984	182.115	168.777	10.671	251.932	200.610	–13.098
900	20.944	184.584	170.399	12.767	252.325	194.171	–11.269
1000	20.915	186.789	171.930	14.860	252.686	187.689	–9.804
1100	20.893	188.782	173.372	16.950	253.022	181.173	–8.603
1200	20.877	190.599	174.733	19.039	253.335	174.628	–7.601
1300	20.864	192.270	176.019	21.126	253.630	168.057	–6.753

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
70. OXYGEN O (g) (continued)							
1400	20.853	193.815	177.236	23.212	253.908	161.463	–6.024
1500	20.845	195.254	178.389	25.296	254.171	154.851	–5.392
71. DIOXYGEN O_2 (g)							
298.15	29.378	205.148	205.148	0.000	0.000	0.000	0.000
300	29.387	205.330	205.148	0.054	0.000	0.000	0.000
400	30.109	213.873	206.308	3.026	0.000	0.000	0.000
500	31.094	220.695	208.525	6.085	0.000	0.000	0.000
600	32.095	226.454	211.045	9.245	0.000	0.000	0.000
700	32.987	231.470	213.612	12.500	0.000	0.000	0.000
800	33.741	235.925	216.128	15.838	0.000	0.000	0.000
900	34.365	239.937	218.554	19.244	0.000	0.000	0.000
1000	34.881	243.585	220.878	22.707	0.000	0.000	0.000
1100	35.314	246.930	223.096	26.217	0.000	0.000	0.000
1200	35.683	250.019	225.213	29.768	0.000	0.000	0.000
1300	36.006	252.888	227.233	33.352	0.000	0.000	0.000
1400	36.297	255.568	229.162	36.968	0.000	0.000	0.000
1500	36.567	258.081	231.007	40.611	0.000	0.000	0.000
72. SULFUR S (cr, l)							
298.15	22.690	32.070	32.070	0.000	0.000	0.000	0.000
300	22.737	32.210	32.070	0.042	0.000	0.000	0.000
368.3	24.237	37.030	32.554	1.649	0.000	0.000	0.000
PHASE TRANSITION: $\Delta_{trs} H$ = 0.401 kJ/mol, $\Delta_{trs} S$ = 1.089 J/K·mol, crII–crI							
368.3	24.773	38.119	32.553	2.050	0.000	0.000	0.000
388.36	25.180	39.444	32.875	2.551	0.000	0.000	0.000
PHASE TRANSITION: $\Delta_{trs} H$ = 1.722 kJ/mol, $\Delta_{trs} S$ = 4.431 J/K·mol, crI–l							
388.36	31.710	43.875	32.872	4.273	0.000	0.000	0.000
400	32.369	44.824	33.206	4.647	0.000	0.000	0.000
500	38.026	53.578	36.411	8.584	0.000	0.000	0.000
600	34.371	60.116	39.842	12.164	0.000	0.000	0.000
700	32.451	65.278	43.120	15.511	0.000	0.000	0.000
800	32.000	69.557	46.163	18.715	0.000	0.000	0.000
882.38	32.000	72.693	48.496	21.351	0.000	0.000	0.000
73. SULFUR S (g)							
298.15	23.673	167.828	167.828	0.000	277.180	236.704	–41.469
300	23.669	167.974	167.828	0.044	277.182	236.453	–41.170
400	23.233	174.730	168.752	2.391	274.924	222.962	–29.115
500	22.741	179.860	170.482	4.689	273.286	210.145	–21.953
600	22.338	183.969	172.398	6.942	271.958	197.646	–17.206
700	22.031	187.388	174.302	9.160	270.829	185.352	–13.831
800	21.800	190.314	176.125	11.351	269.816	173.210	–11.309
900	21.624	192.871	177.847	13.522	215.723	162.258	–9.417
1000	21.489	195.142	179.465	15.677	216.018	156.301	–8.164
1100	21.386	197.185	180.985	17.821	216.284	150.317	–7.138
1200	21.307	199.043	182.413	19.955	216.525	144.309	–6.282
1300	21.249	200.746	183.759	22.083	216.743	138.282	–5.556
1400	21.209	202.319	185.029	24.206	216.940	132.239	–4.934
1500	21.186	203.781	186.231	26.325	217.119	126.182	–4.394
74. DISULFUR S_2 (g)							
298.15	32.505	228.165	228.165	0.000	128.600	79.696	–13.962
300	32.540	228.366	228.165	0.060	128.576	79.393	–13.823
400	34.108	237.956	229.462	3.398	122.703	63.380	–8.276
500	35.133	245.686	231.959	6.863	118.296	49.031	–5.122

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ - H^\circ(T_r))/T$	$H^\circ - H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
74. DISULFUR S_2 (g) (continued)							
600	35.815	252.156	234.800	10.413	114.685	35.530	–3.093
700	36.305	257.715	237.686	14.020	111.599	22.588	–1.685
800	36.697	262.589	240.501	17.671	108.841	10.060	–0.657
882.38	36.985	266.200	242.734	20.706		pressure = 1 bar	
900	37.045	266.932	243.201	21.358	0.000	0.000	0.000
1000	37.377	270.852	245.773	25.079	0.000	0.000	0.000
1100	37.704	274.430	248.218	28.833	0.000	0.000	0.000
1200	38.030	277.725	250.541	32.620	0.000	0.000	0.000
1300	38.353	280.781	252.751	36.439	0.000	0.000	0.000
1400	38.669	283.635	254.856	40.290	0.000	0.000	0.000
1500	38.976	286.314	256.865	44.173	0.000	0.000	0.000
75. OCTASULFUR S_8 (g)							
298.15	156.500	432.536	432.536	0.000	101.277	48.810	–8.551
300	156.768	433.505	432.539	0.290	101.231	48.484	–8.442
400	167.125	480.190	438.834	16.542	80.642	32.003	–4.179
500	173.181	518.176	451.022	33.577	66.185	21.409	–2.237
600	177.936	550.180	464.951	51.137	55.101	13.549	–1.180
700	182.441	577.948	479.152	69.157	46.349	7.343	–0.548
800	186.764	602.596	493.071	87.620	39.177	2.263	–0.148
900	190.595	624.821	506.495	106.494	–392.062	6.554	–0.380
1000	193.618	645.067	519.355	125.712	–387.728	50.614	–2.644
1100	195.684	663.625	531.639	145.185	–383.272	94.233	–4.475
1200	196.825	680.707	543.359	164.817	–378.786	137.444	–5.983
1300	197.195	696.480	554.539	184.524	–374.356	180.283	–7.244
1400	196.988	711.089	565.206	204.237	–370.048	222.785	–8.312
1500	196.396	724.662	575.389	223.909	–365.905	264.984	–9.227
76. SULFUR DIOXIDE SO_2 (g)							
298.15	39.842	248.219	248.219	0.000	–296.810	–300.090	52.574
300	39.909	248.466	248.220	0.074	–296.833	–300.110	52.253
400	43.427	260.435	249.828	4.243	–300.240	–300.935	39.298
500	46.490	270.465	252.978	8.744	–302.735	–300.831	31.427
600	48.938	279.167	256.634	13.520	–304.699	–300.258	26.139
700	50.829	286.859	260.413	18.513	–306.308	–299.386	22.340
800	52.282	293.746	264.157	23.671	–307.691	–298.302	19.477
900	53.407	299.971	267.796	28.958	–362.075	–295.987	17.178
1000	54.290	305.646	271.301	34.345	–362.012	–288.647	15.077
1100	54.993	310.855	274.664	39.810	–361.934	–281.314	13.358
1200	55.564	315.665	277.882	45.339	–361.849	–273.989	11.926
1300	56.033	320.131	280.963	50.920	–361.763	–266.671	10.715
1400	56.426	324.299	283.911	56.543	–361.680	–259.359	9.677
1500	56.759	328.203	286.735	62.203	–361.605	–252.053	8.777
77. SILICON Si (cr)							
298.15	19.789	18.810	18.810	0.000	0.000	0.000	0.000
300	19.855	18.933	18.810	0.037	0.000	0.000	0.000
400	22.301	25.023	19.624	2.160	0.000	0.000	0.000
500	23.610	30.152	21.231	4.461	0.000	0.000	0.000
600	24.472	34.537	23.092	6.867	0.000	0.000	0.000
700	25.124	38.361	25.006	9.348	0.000	0.000	0.000
800	25.662	41.752	26.891	11.888	0.000	0.000	0.000
900	26.135	44.802	28.715	14.478	0.000	0.000	0.000
1000	26.568	47.578	30.464	17.114	0.000	0.000	0.000
1100	26.974	50.130	32.138	19.791	0.000	0.000	0.000
1200	27.362	52.493	33.737	22.508	0.000	0.000	0.000

	J/K·mol			kJ/mol			
T/K	C_p°	S°	$-(G^\circ-H^\circ(T_r))/T$	$H^\circ-H^\circ(T_r)$	$\Delta_f H^\circ$	$\Delta_f G^\circ$	Log K_f
77. SILICON Si (cr) (continued)							
1300	27.737	54.698	35.265	25.263	0.000	0.000	0.000
1400	28.103	56.767	36.728	28.055	0.000	0.000	0.000
1500	28.462	58.719	38.130	30.883	0.000	0.000	0.000
78. SILICON Si (g)							
298.15	22.251	167.980	167.980	0.000	450.000	405.525	–71.045
300	22.234	168.117	167.980	0.041	450.004	405.249	–70.559
400	21.613	174.416	168.843	2.229	450.070	390.312	–50.969
500	21.316	179.204	170.456	4.374	449.913	375.388	–39.216
600	21.153	183.074	172.246	6.497	449.630	360.508	–31.385
700	21.057	186.327	174.032	8.607	449.259	345.682	–25.795
800	21.000	189.135	175.748	10.709	448.821	330.915	–21.606
900	20.971	191.606	177.375	12.808	448.329	316.205	–18.352
1000	20.968	193.815	178.911	14.904	447.791	301.553	–15.751
1100	20.989	195.815	180.358	17.002	447.211	286.957	–13.626
1200	21.033	197.643	181.723	19.103	446.595	272.416	–11.858
1300	21.099	199.329	183.014	21.209	445.946	257.927	–10.364
1400	21.183	200.895	184.236	23.323	445.268	243.489	–9.085
1500	21.282	202.360	185.396	25.446	444.563	229.101	–7.978
79. SILICON DIOXIDE SiO_2 (cr)							
298.15	44.602	41.460	41.460	0.000	–910.700	–856.288	150.016
300	44.712	41.736	41.461	0.083	–910.708	–855.951	149.032
400	53.477	55.744	43.311	4.973	–910.912	–837.651	109.385
500	60.533	68.505	47.094	10.705	–910.540	–819.369	85.598
600	64.452	79.919	51.633	16.971	–909.841	–801.197	69.749
700	68.234	90.114	56.414	23.590	–908.958	–783.157	58.439
800	76.224	99.674	61.226	30.758	–907.668	–765.265	49.966
848	82.967	104.298	63.533	34.569	–906.310	–756.747	46.613
PHASE TRANSITION: $\Delta_{trs} H$ = 0.411 kJ/mol, $\Delta_{trs} S$ = 0.484 J/K·mol, crII–crII′							
848	67.446	104.782	63.532	34.980	–906.310	–756.747	46.613
900	67.953	108.811	66.033	38.500	–905.922	–747.587	43.388
1000	68.941	116.021	70.676	45.345	–905.176	–730.034	38.133
1100	69.940	122.639	75.104	52.289	–904.420	–712.557	33.836
1200	70.947	128.768	79.323	59.333	–901.382	–695.148	30.259
PHASE TRANSITION: $\Delta_{trs} H$ = 2.261 kJ/mol, $\Delta_{trs} S$ = 1.883 J/K·mol, crII′–crI							
1200	71.199	130.651	79.323	61.594	–901.382	–695.148	30.259
1300	71.743	136.372	83.494	68.742	–900.574	–677.994	27.242
1400	72.249	141.707	87.463	75.941	–899.782	–660.903	24.658
1500	72.739	146.709	91.248	83.191	–899.004	–643.867	22.421
80. SILICON TETRACHLORIDE $SiCl_4$ (g)							
298.15	90.404	331.446	331.446	0.000	–662.200	–622.390	109.039
300	90.562	332.006	331.448	0.167	–662.195	–622.143	108.323
400	96.893	359.019	335.088	9.572	–661.853	–608.841	79.505
500	100.449	381.058	342.147	19.456	–661.413	–595.637	62.225
600	102.587	399.576	350.216	29.616	–660.924	–582.527	50.713
700	103.954	415.500	358.432	39.948	–660.417	–569.501	42.496
800	104.875	429.445	366.455	50.392	–659.912	–556.548	36.338
900	105.523	441.837	374.155	60.914	–659.422	–543.657	31.553
1000	105.995	452.981	381.490	71.491	–658.954	–530.819	27.727
1100	106.349	463.101	388.456	82.109	–658.515	–518.027	24.599
1200	106.620	472.366	395.068	92.758	–658.107	–505.274	21.994
1300	106.834	480.909	401.347	103.431	–657.735	–492.553	19.791
1400	107.003	488.833	407.316	114.123	–657.400	–479.860	17.904
1500	107.141	496.220	413.000	124.830	–657.104	–467.189	16.269

THERMODYNAMIC PROPERTIES OF AQUEOUS SYSTEMS

This table contains standard state thermodynamic properties of ions and neutral species in aqueous solution. It includes enthalpy and Gibbs energy of formation, entropy, and heat capacity, and thus serves as a companion to the preceding table, “Standard Thermodynamic Properties of Chemical Substances”. The standard state is the hypothetical ideal solution with molality $m = 1$ mol/kg (mean ionic molality $m_{\pm}$ in the case of a species which is assumed to dissociate at infinite dilution). Further details on conventions may be found in Reference 1.

Cations are listed by formula in the first part of the table, followed by anions and finally neutral species. All values refer to standard conditions of 25°C and 100 kPa pressure.

REFERENCES

1. Wagman, D. D., Evans, W. H., Parker, V. B., Schumm, R. H., Halow, I., Bailey, S. M., Churney, K. L., and Nuttall, R. L., *The NBS Tables of Chemical Thermodynamic Properties, J. Phys. Chem. Ref. Data*, Vol. 11, Suppl. 2, 1982.
2. Zemaitis, J. F., Clark, D. M., Rafal, M., and Scrivner, N. C., *Handbook of Aqueous Electrolyte Thermodynamics*, American Institute of Chemical Engineers, New York, 1986.

Species	$\Delta_f H°$/ kJ mol^{-1}	$\Delta_f G°$/ kJ mol^{-1}	$S°$/ J mol^{-1}K^{-1}	C_p/ J mol^{-1}K^{-1}
Cations				
Ag^{+}	105.6	77.1	72.7	21.8
Al^{+3}	-531.0	-485.0	-321.7	
$AlOH^{+2}$		-694.1		
Ba^{+2}	-537.6	-560.8	9.6	
$BaOH^{+}$		-730.5		
Be^{+2}	-382.8	-379.7	-129.7	
Bi^{+3}		82.8		
$BiOH^{+2}$		-146.4		
Ca^{+2}	-542.8	-553.6	-53.1	
$CaOH^{+}$		-718.4		
Cd^{+2}	-75.9	-77.6	-73.2	
$CdOH^{+}$		-261.1		
Ce^{+3}	-696.2	-672.0	-205.0	
Ce^{+4}	-537.2	-503.8	-301.0	
Co^{+2}	-58.2	-54.4	-113.0	
Co^{+3}	92.0	134.0	-305.0	
Cr^{+2}	-143.5			
Cs^{+}	-258.3	-292.0	133.1	-10.5
Cu^{+}	71.7	50.0	40.6	
Cu^{+2}	64.8	65.5	-99.6	
Dy^{+3}	-699.0	-665.0	-231.0	21.0
Er^{+3}	-705.4	-669.1	-244.3	21.0
Eu^{+2}	-527.0	-540.2	-8.0	
Eu^{+3}	-605.0	-574.1	-222.0	8.0
Fe^{+2}	-89.1	-78.9	-137.7	
Fe^{+3}	-48.5	-4.7	-315.9	
$FeOH^{+}$	-324.7	-277.4	-29.0	
$FeOH^{+2}$	-290.8	-229.4	-142.0	
$Fe(OH)_2^{+}$		-438.0		
Ga^{+2}		-88.0		
Ga^{+3}	-211.7	-159.0	-331.0	
$GaOH^{+2}$		-380.3		
$Ga(OH)_2^{+}$		-597.4		
Gd^{+3}	-686.0	-661.0	-205.9	
H^{+}	0	0	0	0
Hg^{+2}	171.1	164.4	-32.2	
Hg_2^{+2}	172.4	153.5	84.5	
$HgOH^{+}$	-84.5	-52.3	71.0	
Ho^{+3}	-705.0	-673.7	-226.8	17.0
In^{+}		-12.1		
In^{+2}		-50.7		
In^{+3}	-105.0	-98.0	-151.0	
$InOH^{+2}$	-370.3	-313.0	-88.0	
$In(OH)_2^{+}$	-619.0	-525.0	25.0	
K^{+}	-252.4	-283.3	102.5	21.8
La^{+3}	-707.1	-683.7	-217.6	-13.0
Li^{+}	-278.5	-293.3	13.4	68.6
Lu^{+3}	-665.0	-628.0	-264.0	25.0
LuF^{+2}		-931.4		
Mg^{+2}	-466.9	-454.8	-138.1	
$MgOH^{+}$		-626.7		
Mn^{+2}	-220.8	-228.1	-73.6	50.0
$MnOH^{+}$	-450.6	-405.0	-17.0	
NH_4^{+}	-132.5	-79.3	113.4	79.9
$N_2H_5^{+}$	-7.5	82.5	151.0	70.3
Na^{+}	-240.1	-261.9	59.0	46.4
Nd^{+3}	-696.2	-671.6	-206.7	-21.0
Ni^{+2}	-54.0	-45.6	-128.9	
$NiOH^{+}$	-287.9	-227.6	-71.0	
PH_4^{+}		92.1		
Pa^{+4}	-619.0			
Pb^{+2}	-1.7	-24.4	10.5	
$PbOH^{+}$		-226.3		
Pd^{+2}	149.0	176.5	-184.0	
Po^{+2}		71.0		
Po^{+4}		293.0		
Pr^{+3}	-704.6	-679.1	-209.0	-29.0
Pt^{+2}		254.8		
Ra^{+2}	-527.6	-561.5	54.0	
Rb^{+}	-251.2	-284.0	121.5	
Re^{+}		-33.0		
Sc^{+3}	-614.2	-586.6	-255.0	
$ScOH^{+2}$	-861.5	-801.2	-134.0	
Sm^{+2}		-497.5		
Sm^{+3}	-691.6	-666.6	-211.7	-21.0
Sn^{+2}	-8.8	-27.2	-17.0	
$SnOH^{+}$	-286.2	-254.8	50.0	
Sr^{+2}	-545.8	-559.5	-32.6	
$SrOH^{+}$		-721.3		
Tb^{+3}	-682.8	-651.9	-226.0	17.0
$Te(OH)_3^{+}$	-608.4	-496.1	111.7	
Th^{+4}	-769.0	-705.1	-422.6	
$Th(OH)^{+3}$	-1030.1	-920.5	-343.0	
$Th(OH)_2^{+2}$	-1282.4	-1140.9	-218.0	
Tl^{+}	5.4	-32.4	125.5	
Tl^{+3}	196.6	214.6	-192.0	

Species	$\Delta_f H°$/ kJ mol⁻¹	$\Delta_f G°$/ kJ mol⁻¹	$S°$/ J mol⁻¹K⁻¹	C_p/ J mol⁻¹K⁻¹
$TlOH^{+2}$		-15.9		
$Tl(OH)_2^{+}$		-244.7		
Tm^{+3}	-697.9	-662.0	-243.0	25.0
U^{+3}	-489.1	-476.2	-188.0	
U^{+4}	-591.2	-531.9	-410.0	
Y^{+3}	-723.4	-693.8	-251.0	
$Y_2(OH)_2^{+4}$		-1780.3		
Yb^{+2}		-527.0		
Yb^{+3}	-674.5	-644.0	-238.0	25.0
$Y(OH)^{+2}$		-879.1		
Zn^{+2}	-153.9	-147.1	-112.1	46.0
$ZnOH^{+}$		-330.1		
Anions				
AlO_2^{-}	-930.9	-830.9	-36.8	
$Al(OH)_4^{-}$	-1502.5	-1305.3	102.9	
AsO_2^{-}	-429.0	-350.0	40.6	
AsO_4^{-3}	-888.1	-648.4	-162.8	
BF_4^{-}	-1574.9	-1486.9	180.0	
BH_4^{-}	48.2	114.4	110.5	
BO_2^{-}	-772.4	-678.9	-37.2	
$B_4O_7^{-2}$		-2604.8		
BeO_2^{-2}	-790.8	-640.1	-159.0	
Br^{-}	-121.6	-104.0	82.4	-141.8
BrO^{-}	-94.1	-33.4	42.0	
BrO_3^{-}	-67.1	18.6	161.7	
BrO_4^{-}	13.0	118.1	199.6	
$CHOO^{-}$	-425.6	-351.0	92.0	-87.9
CH_3COO^{-}	-486.0	-369.3	86.6	-6.3
$C_2O_4^{-2}$	-825.1	-673.9	45.6	
$C_2O_4H^{-}$	-818.4	-698.3	149.4	
Cl^{-}	-167.2	-131.2	56.5	-136.4
ClO^{-}	-107.1	-36.8	42.0	
ClO_2^{-}	-66.5	17.2	101.3	
ClO_3^{-}	-104.0	-8.0	162.3	
ClO_4^{-}	-129.3	-8.5	182.0	
CN^{-}	150.6	172.4	94.1	
CO_3^{-2}	-677.1	-527.8	-56.9	
CrO_4^{-2}	-881.2	-727.8	50.2	
$Cr_2O_7^{-2}$	-1490.3	-1301.1	261.9	
F^{-}	-332.6	-278.8	-13.8	-106.7
$Fe(CN)_6^{-3}$	561.9	729.4	270.3	
$Fe(CN)_6^{-4}$	455.6	695.1	95.0	
$HB_4O_7^{-}$		-2685.1		
HCO_3^{-}	-692.0	-586.8	91.2	
HF_2^{-}	-649.9	-578.1	92.5	
HPO_3F^{-}		-1198.2		
HPO_4^{-2}	-1292.1	-1089.2	-33.5	
$HP_2O_7^{-3}$	-2274.8	-1972.2	46.0	
HS^{-}	-17.6	12.1	62.8	
HSO_3^{-}	-626.2	-527.7	139.7	
HSO_4^{-}	-887.3	-755.9	131.8	-84.0
$HS_2O_4^{-}$		-614.5		
HSe^{-}	15.9	44.0	79.0	
$HSeO_3^{-}$	-514.6	-411.5	135.1	
$HSeO_4^{-}$	-581.6	-452.2	149.4	
$H_2AsO_3^{-}$	-714.8	-587.1	110.5	
$H_2AsO_4^{-}$	-909.6	-753.2	117.0	

Species	$\Delta_f H°$/ kJ mol⁻¹	$\Delta_f G°$/ kJ mol⁻¹	$S°$/ J mol⁻¹K⁻¹	C_p/ J mol⁻¹K⁻¹
$H_2PO_4^{-}$	-1296.3	-1130.2	90.4	
$H_2P_2O_7^{-2}$	-2278.6	-2010.2	163.0	
I^{-}	-55.2	-51.6	111.3	-142.3
IO^{-}	-107.5	-38.5	-5.4	
IO_3^{-}	-221.3	-128.0	118.4	
IO_4^{-}	-151.5	-58.5	222.0	
MnO_4^{-}	-541.4	-447.2	191.2	-82.0
MnO_4^{-2}	-653.0	-500.7	59.0	
MoO_4^{-2}	-997.9	-836.3	27.2	
NO_2^{-}	-104.6	-32.2	123.0	-97.5
NO_3^{-}	-207.4	-111.3	146.4	-86.6
N_3^{-}	275.1	348.2	107.9	
OCN^{-}	-146.0	-97.4	106.7	
OH^{-}	-230.0	-157.2	-10.8	-148.5
PO_4^{-3}	-1277.4	-1018.7	-220.5	
$P_2O_7^{-4}$	-2271.1	-1919.0	-117.0	
Re^{-}	46.0	10.1	230.0	
S^{-2}	33.1	85.8	-14.6	
SCN^{-}	76.4	92.7	144.3	-40.2
SO_3^{-2}	-635.5	-486.5	-29.0	
SO_4^{-2}	-909.3	-744.5	20.1	-293.0
S_2^{-2}	30.1	79.5	28.5	
$S_2O_3^{-2}$	-652.3	-522.5	67.0	
$S_2O_4^{-2}$	-753.5	-600.3	92.0	
$S_2O_8^{-2}$	-1344.7	-1114.9	244.3	
Se^{-2}		129.3		
SeO_3^{-2}	-509.2	-369.8	13.0	
SeO_4^{-2}	-599.1	-441.3	54.0	
VO_3^{-}	-888.3	-783.6	50.0	
VO_4^{-3}		-899.0		
WO_4^{-2}	-1075.7			
Neutral species				
$AgBr$	-16.0	-26.9	155.2	-120.1
$AgCl$	-61.6	-54.1	129.3	-114.6
AgF	-227.1	-201.7	59.0	-84.9
AgI	50.4	25.5	184.1	-120.5
$AgNO_3$	-101.8	-34.2	219.2	-64.9
Ag_2SO_4	-698.1	-590.3	165.7	-251.0
$AlBr_3$	-895.0	-799.0	-74.5	
$AlCl_3$	-1033.0	-879.0	-152.3	
AlF_3	-1531.0	-1322.0	-363.2	
AlI_3	-699.0	-640.0	12.1	
$Al_2(SO_4)_3$	-3791.0	-3205.0	-583.2	
$BaBr_2$	-780.7	-768.7	174.5	
$BaCO_3$	-1214.8	-1088.6	-47.3	
$BaCl_2$	-872.0	-823.2	122.6	
BaF_2	-1202.9	-1118.4	-18.0	
$Ba(HCO_3)_2$	-1921.6	-1734.3	192.0	
BaI_2	-648.0	-663.9	232.2	
$Ba(NO_3)_2$	-952.4	-783.3	302.5	
$BaSO_4$	-1446.9	-1305.3	29.7	
$BeSO_4$	-1292.0	-1124.3	-109.6	
CCl_3COOH	-516.3			
$CHCl_2COOH$	-512.1			
$CHOOCs$	-683.8	-643.0	226.0	
$CHOOH$	-425.6	-351.0	92.0	-87.9
$CHOOK$	-677.9	-634.2	192.0	-66.1

Species	$\Delta_f H°$/ kJ mol^{-1}	$\Delta_f G°$/ kJ mol^{-1}	$S°$/ J mol^{-1}K^{-1}	C_p/ J mol^{-1}K^{-1}
$CHOONH_4$	-558.1	-430.4	205.0	-7.9
CHOONa	-665.7	-612.9	151.0	-41.4
CHOORb	-676.7	-635.1	213.0	
$CH_2ClCOOH$	-501.3			
CH_3COOCs	-744.3	-661.3	219.7	
CH_3COOH	-486.0	-369.3	86.6	-6.3
CH_3COOK	-738.4	-652.6	189.1	15.5
CH_3COONH_4	-618.5	-448.6	200.0	73.6
CH_3COONa	-726.1	-631.2	145.6	40.2
CH_3COORb	-737.2	-653.3	207.9	
$(COOH)_2$	-825.1	-673.9	45.6	
$(CH_3)_3N$	-76.0	93.1	133.5	
$CaBr_2$	-785.9	-761.5	111.7	
$CaCO_3$	-1220.0	-1081.4	-110.0	
$CaCl_2$	-877.1	-816.0	59.8	
CaF_2	-1208.1	-1111.2	-80.8	
CaI_2	-653.2	-656.7	169.5	
$Ca(NO_3)_2$	-957.6	-776.1	239.7	
$CaSO_4$	-1452.1	-1298.1	-33.1	
$CdBr_2$	-319.0	-285.5	91.6	
$CdCl_2$	-410.2	-340.1	39.7	
CdF_2	-741.2	-635.2	-100.8	
CdI_2	-186.3	-180.8	149.4	
$Cd(NO_3)_2$	-490.6	-300.1	219.7	
$CdSO_4$	-985.2	-822.1	-53.1	
$CeCl_3$	-1197.5	-1065.6	-38.0	
$CoBr_2$	-301.2	-262.3	50.0	
$CoCl_2$	-392.5	-316.7		
CoI_2	-168.6	-157.7	109.0	
$Co(NO_3)_2$	-472.8	-276.9	180.0	
$CoSO_4$	-967.3	-799.1	-92.0	
CsBr	-379.8	-396.0	215.5	
CsCl	-425.4	-423.2	189.5	-146.9
CsF	-590.9	-570.8	119.2	
$CsHCO_3$	-950.3	-878.8	224.3	
$CsHSO_4$	-1145.6	-1047.9	264.8	
CsI	-313.5	-343.6	244.3	-152.7
$CsNO_3$	-465.6	-403.3	279.5	-99.0
Cs_2CO_3	-1193.7	-1111.9	209.2	
Cs_2S	-483.7	-498.3	251.0	
Cs_2SO_4	-1425.8	-1328.6	286.2	
Cs_2Se		-454.8		
$Cu(NO_3)_2$	-350.0	-157.0	193.3	
$CuSO_4$	-844.5	-679.0	-79.5	
$DyCl_3$	-1197.0	-1059.0	-61.9	-389.0
$ErCl_3$	-1207.1	-1062.7	-75.3	-389.0
$EuCl_2$	-862.0			
$EuCl_3$	-1106.2	-967.7	-54.0	-402.0
$FeBr_2$	-332.2	-286.8	27.2	
$FeBr_3$	-413.4	-316.7	-68.6	
$FeCl_2$	-423.4	-341.3	-24.7	
$FeCl_3$	-550.2	-398.3	-146.4	
FeF_2	-754.4	-636.5	-165.3	
FeF_3	-1046.4	-840.9	-357.3	
FeI_2	-199.6	-182.1	84.9	
FeI_3	-214.2	-159.4	18.0	
$Fe(NO_3)_3$	-670.7	-338.3	123.4	
$FeSO_4$	-998.3	-823.4	-117.6	
$Fe_2(SO_4)_3$	-2825.0	-2242.8	-571.5	

Species	$\Delta_f H°$/ kJ mol^{-1}	$\Delta_f G°$/ kJ mol^{-1}	$S°$/ J mol^{-1}K^{-1}	C_p/ J mol^{-1}K^{-1}
$GdCl_3$	-1188.0	-1059.0	-36.8	-410.0
HBr	-121.6	-104.0	82.4	-141.8
HCN	150.6	172.4	94.1	
HCl	-167.2	-131.2	56.5	-136.4
HF	-332.6	-278.8	-13.8	-106.7
HI	-55.2	-51.6	111.3	-142.3
HNO_3	-207.4	-111.3	146.4	-86.6
HSCN	76.4	92.7	144.3	-40.2
H_2SO_4	-909.3	-744.5	20.1	-293.0
$HoCl_3$	-1206.7	-1067.3	-57.7	-393.0
KBr	-373.9	-387.2	184.9	-120.1
KCl	-419.5	-414.5	159.0	-114.6
KF	-585.0	-562.1	88.7	-84.9
$KHCO_3$	-944.4	-870.0	193.7	
$KHSO_4$	-1139.7	-1039.2	234.3	-63.0
KI	-307.6	-334.9	213.8	-120.5
KNO_3	-459.7	-394.5	248.9	-64.9
K_2CO_3	-1181.9	-1094.4	148.1	
K_2S	-471.5	-480.7	190.4	
K_2SO_4	-1414.0	-1311.1	225.1	-251.0
K_2Se		-437.2		
$LaCl_3$	-1208.8	-1077.3	-50.0	-423.0
LiBr	-400.0	-397.3	95.8	-73.2
LiCl	-445.6	-424.6	69.9	-67.8
LiF	-611.1	-571.9	-0.4	-38.1
LiI	-333.7	-344.8	124.7	-73.6
$LiNO_3$	-485.9	-404.5	160.2	-18.0
Li_2CO_3	-1234.1	-1114.6	-29.7	
Li_2SO_4	-1466.2	-1331.2	47.3	-155.6
$LuCl_3$	-1167.0	-1021.0	-96.0	-385.0
$MgBr_2$	-709.9	-662.7	26.8	
$MgCl_2$	-801.2	-717.1	-25.1	
MgI_2	-577.2	-558.1	84.5	
$Mg(NO_3)_2$	-881.6	-677.3	154.8	
$MgSO_4$	-1376.1	-1199.5	-118.0	
$MnBr_2$	-464.0			
$MnCl_2$	-555.1	-490.8	38.9	-222.0
MnI_2	-331.0			
$Mn(NO_3)_2$	-635.5	-450.9	218.0	-121.0
$MnSO_4$	-1130.1	-972.7	-53.6	-243.0
NH_4Br	-254.1	-183.3	195.8	-61.9
NH_4BrO_3	-199.6	-60.7	275.1	
NH_4CN	18.0	93.0	207.5	
NH_4Cl	-299.7	-210.5	169.9	-56.5
NH_4ClO_3	-236.5	-87.3	275.7	
NH_4ClO_4	-261.8	-87.8	295.4	
NH_4F	-465.1	-358.1	99.6	-26.8
NH_4HCO_3	-824.5	-666.1	204.6	
NH_4HS	-150.2	-67.2	176.1	
NH_4HSO_3	-758.7	-607.0	253.1	
NH_4HSO_4	-1019.9	-835.2	245.2	-3.8
NH_4HSeO_4	-714.2	-531.6	262.8	
$NH_4H_2AsO_3$	-847.3	-666.4	223.8	
$NH_4H_2AsO_4$	-1042.1	-832.5	230.5	
$NH_4H_2PO_4$	-1428.8	-1209.6	203.8	
$NH_4H_3P_2O_7$	-2409.1	-2102.6	326.0	
NH_4I	-187.7	-130.9	224.7	-62.3
NH_4IO_3	-354.0	-207.4	231.8	
NH_4NO_2	-237.2	-111.6	236.4	-17.6

THERMODYNAMIC PROPERTIES OF AQUEOUS SYSTEMS (continued)

Species	$\Delta_f H^\circ$/ kJ mol^{-1}	$\Delta_f G^\circ$/ kJ mol^{-1}	S°/ J mol^{-1}K^{-1}	C_p/ J mol^{-1}K^{-1}
NH_4NO_3	-339.9	-190.6	259.8	-6.7
NH_4OH	-362.5	-236.5	102.5	-68.6
NH_4SCN	-56.1	13.4	257.7	39.7
$(NH_4)_2CO_3$	-942.2	-686.4	169.9	
$(NH_4)_2CrO_4$	-1146.2	-886.4	277.0	
$(NH_4)_2Cr_2O_7$	-1755.2	-1459.5	488.7	
$(NH_4)_2HAsO_4$	-1171.4	-873.2	225.1	
$(NH_4)_2HPO_4$	-1557.2	-1247.8	193.3	
$(NH_4)_2S$	-231.8	-72.6	212.1	
$(NH_4)_2SO_3$	-900.4	-645.0	197.5	
$(NH_4)_2SO_4$	-1174.3	-903.1	246.9	-133.1
$(NH_4)_2SeO_4$	-864.0	-599.8	280.7	
$(NH_4)_3PO_4$	-1674.9	-1256.6	117.0	
NaBr	-361.7	-365.8	141.4	-95.4
NaCl	-407.3	-393.1	115.5	-90.0
NaF	-572.8	-540.7	45.2	-60.2
$NaHCO_3$	-932.1	-848.7	150.2	
$NaHSO_4$	-1127.5	-1017.8	190.8	-38.0
NaI	-295.3	-313.5	170.3	-95.8
$NaNO_3$	-447.5	-373.2	205.4	-40.2
Na_2CO_3	-1157.4	-1051.6	61.1	
Na_2S	-447.3	-438.1	103.3	
Na_2SO_4	-1389.5	-1268.4	138.1	-201.0
Na_2Se		-394.6		
$NdCl_3$	-1197.9	-1065.6	-37.7	-431.0
$NiBr_2$	-297.1	-253.6	36.0	
$NiCl_2$	-388.3	-307.9	-15.1	
NiF_2	-719.2	-603.3	-156.5	
NiI_2	-164.4	-149.0	93.7	
$Ni(NO_3)_2$	-468.6	-268.5	164.0	
$NiSO_4$	-963.2	-790.3	-108.8	
$PbBr_2$	-244.8	-232.3	175.3	
$PbCl_2$	-336.0	-286.9	123.4	
PbF_2	-666.9	-582.0	-17.2	
PbI_2	-112.1	-127.6	233.0	
$Pb(NO_3)_2$	-416.3	-246.9	303.3	
$PrCl_3$	-1206.2	-1072.7	-42.0	-439.0
$RaCl_2$	-861.9	-823.8	167.0	
$Ra(NO_3)_2$	-942.2	-784.0	347.0	
$RaSO_4$	-1436.8	-1306.2	75.0	
RbBr	-372.7	-387.9	203.9	
RbCl	-418.3	-415.2	178.0	
RbF	-583.8	-562.8	107.5	
$RbHCO_3$	-943.2	-870.8	212.7	
$RbHSO_4$	-1138.5	-1039.9	253.1	
RbI	-306.4	-335.6	232.6	
$RbNO_3$	-458.5	-395.2	267.8	
Rb_2CO_3	-1179.5	-1095.8	186.2	
Rb_2S	-469.4	-482.0	228.4	
Rb_2SO_4	-1411.6	-1312.5	263.2	
$SmCl_3$	-1193.3	-1060.2	-42.7	-431.0
$SrBr_2$	-788.9	-767.4	132.2	
$SrCO_3$	-1222.9	-1087.3	-89.5	
$SrCl_2$	-880.1	-821.9	80.3	
SrI_2	-656.2	-662.6	190.0	
$Sr(NO_3)_2$	-960.5	-782.0	260.2	
$SrSO_4$	-1455.1	-1304.0	-12.6	
$TbCl_3$	-1184.1	-1045.5	-59.0	-393.0
TlBr	-116.2	-136.4	207.9	
$TlBr_3$	-168.2	-97.1	54.0	
TlCl	-161.8	-163.6	182.0	
$TlCl_3$	-305.0	-179.0	-23.0	
TlF	-327.3	-311.2	111.7	
TlI	-49.8	-84.0	236.8	
$TlNO_3$	-202.0	-143.7	272.0	
Tl_2SO_4	-898.6	-809.3	271.1	
$TmCl_3$	-1199.1	-1055.6	-75.0	-385.0
UCl_4	-1259.8	-1056.8	-184.0	
UO_2CO_3	-1696.6	-1481.5	-154.4	
$UO_2(NO_3)_2$	-1434.3	-1176.0	195.4	
UO_2SO_4	-1928.8	-1698.2	-77.4	
$YbCl_3$	-1176.1	-1037.6	-71.0	-385.0
$ZnBr_2$	-397.0	-355.0	52.7	-238.0
$ZnCl_2$	-488.2	-409.5	0.8	-226.0
ZnF_2	-819.1	-704.6	-139.7	-167.0
ZnI_2	-264.3	-250.2	110.5	-238.0
$Zn(NO_3)_2$	-568.6	-369.6	180.7	-126.0
$ZnSO_4$	-1063.2	-891.6	-92.0	-247.0

HEAT OF COMBUSTION

The heat of combustion of a substance at 25°C can be calculated from the enthalpy of formation ($\Delta_f H°$) data in the table "Standard Thermodynamic Properties of Chemical Substances" in this Section. We can write the general combustion reaction as

$$X + O_2 \rightarrow CO_2(g) + H_2O(l) + \text{other products}$$

For a compound containing only carbon, hydrogen, and oxygen, the reaction is simply

$$C_aH_bO_c + \left(a + \frac{1}{4}b - \frac{1}{2}c\right)O_2 \rightarrow a\ \ CO_2(g) + \frac{1}{2}b\ \ H_2O(l)$$

and the standard heat of combustion $\Delta_c H°$, which is defined as the negative of the enthalpy change for the reaction (i.e., the heat released in the combustion process), is given by

$$\Delta_c H^o = -a\Delta_t H^o(CO_2, g) - \frac{1}{2}b\ \Delta_t H^o(H_2O, l) + \Delta_t H^o(C_aH_b, O_c)$$

$$= 393.51\,a + 142.915\,b + \Delta_t H^o(C_aH_b, O_c)$$

This equation applies if the reactants start in their standard states (25°C and one atmosphere pressure) and the products return to the same conditions. The same equation applies to a compound containing another element if that element ends in its standard reference state (e.g., nitrogen, if the product is N_2); in general, however, the exact products containing the other elements must be known in order to calculate the heat of combustion.

The following table gives the standard heat of combustion calculated in this manner for a few representative substances.

Molecular formula	Name	$\Delta_c H°$/kJ mol^{-1}
	Inorganic substances	
C	Carbon (graphite)	393.5
CO	Carbon monoxide (g)	283.0
H_2	Hydrogen (g)	285.8
H_3N	Ammonia (g)	382.8
H_4N_2	Hydrazine (g)	667.1
N_2O	Nitrous oxide (g)	82.1
	Hydrocarbons	
CH_4	Methane (g)	890.8
C_2H_2	Acetylene (g)	1301.1
C_2H_4	Ethylene (g)	1411.2
C_2H_6	Ethane (g)	1560.7
C_3H_6	Propylene (g)	2058.0
C_3H_6	Cyclopropane (g)	2091.3
C_3H_8	Propane (g)	2219.2
C_4H_6	1,3-Butadiene (g)	2541.5
C_4H_{10}	Butane (g)	2877.6
C_5H_{12}	Pentane (l)	3509.0
C_6H_6	Benzene (l)	3267.6
C_6H_{12}	Cyclohexane (l)	3919.6
C_6H_{14}	Hexane (l)	4163.2
C_7H_8	Toluene (l)	3910.3
C_7H_{16}	Heptane (l)	4817.0
$C_{10}H_8$	Naphthalene (s)	5156.3
	Alcohols and ethers	
CH_4O	Methanol (l)	726.1
C_2H_6O	Ethanol (l)	1366.8
C_2H_6O	Dimethyl ether (g)	1460.4
$C_2H_6O_2$	Ethylene glycol (l)	1189.2
C_3H_8O	1-Propanol (l)	2021.3
$C_3H_8O_3$	Glycerol (l)	1655.4
$C_4H_{10}O$	Diethyl ether (l)	2723.9
$C_5H_{12}O$	1-Pentanol (l)	3330.9
C_6H_6O	Phenol (s)	3053.5
	Carbonyl compounds	
CH_2O	Formaldehyde (g)	570.7
C_2H_2O	Ketene (g)	1025.4
C_2H_4O	Acetaldehyde (l)	1166.9
C_3H_6O	Acetone (l)	1789.9
C_3H_6O	Propanal (l)	1822.7
C_4H_8O	2-Butanone (l)	2444.1
	Acids and esters	
CH_2O_2	Formic acid (l)	254.6
$C_2H_4O_2$	Acetic acid (l)	874.2
$C_2H_4O_2$	Methyl formate (l)	972.6
$C_3H_6O_2$	Methyl acetate (l)	1592.2
$C_4H_8O_2$	Ethyl acetate (l)	2238.1
$C_7H_6O_2$	Benzoic acid (s)	3226.9
	Nitrogen compounds	
CHN	Hydrogen cyanide (g)	671.5
CH_3NO_2	Nitromethane (l)	709.2
CH_5N	Methylamine (g)	1085.6
C_2H_3N	Acetonitrile (l)	1247.2
C_2H_5NO	Acetamide (s)	1184.6
C_3H_9N	Trimethylamine (g)	2443.1
C_5H_5N	Pyridine (l)	2782.3
C_6H_7N	Aniline (l)	3392.8

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MOLAR CONDUCTIVITY OF AQUEOUS HF, HCl, HBr, AND HI

The molar conductivity Λ of an electrolyte solution is defined as the conductivity divided by amount-of-substance concentration. The customary unit is S $cm^2 mol^{-1}$ (i.e., Ω^{-1} $cm^2 mol^{-1}$). The first part of this table gives the molar conductivity of the hydrohalogen acids at 25°C as a function of the concentration in mol/L. The second part gives the temperature dependence of Λ for HCl and HBr. More extensive tables and mathematical representations may be found in the reference.

REFERENCE

Hamer, W.J., and DeWane, H.J., *Electrolytic Conductance and the Conductances of the Hydrohalogen Acids in Water*, Natl. Stand. Ref. Data Sys.-Natl. Bur. Standards (U.S.), No. 33, 1970.

c/mol L^{-1}	HF	HCl	HBr	HI
Inf. dil.	405.1	426.1	427.7	426.4
0.0001		424.5	425.9	424.6
0.0005		422.6	424.3	423.0
0.001		421.2	422.9	421.7
0.005	128.1	415.7	417.6	416.4
0.01	96.1	411.9	413.7	412.8
0.05	50.1	398.9	400.4	400.8
0.10	39.1	391.1	391.9	394.0
0.5	26.3	360.7	361.9	369.8
1.0	24.3	332.2	334.5	343.9
1.5		305.8	307.6	316.4
2.0		281.4	281.7	288.9
2.5		258.9	257.8	262.5
3.0		237.6	236.8	237.9
3.5		218.3	217.5	215.4
4.0		200.0	199.4	195.1
4.5		183.1	182.4	176.8
5.0		167.4	166.5	160.4
5.5		152.9	151.8	145.5
6.0		139.7	138.2	131.7
6.5		127.7	125.7	118.6
7.0		116.9	114.2	105.7
7.5		107.0	103.8	
8.0		98.2	94.4	
8.5		90.3	85.8	
9.0		83.1		
9.5		76.6		
10.0		70.7		

c/mol L^{-1}	–20°C	–10°C	0°C	10°C	20°C	30°C	40°C	50°C
HCl								
0.5			228.7	283.0	336.4	386.8	436.9	482.4
1.0			211.7	261.6	312.2	359.0	402.9	445.3
1.5			196.2	241.5	287.5	331.1	371.6	410.8
2.0			182.0	222.7	262.9	303.3	342.4	378.2
2.5		131.7	168.5	205.1	239.8	277.0	315.2	347.6
3.0		120.8	154.6	188.5	219.3	253.3	289.3	319.0
3.5	85.5	111.3	139.6	172.2	201.6	232.9	263.9	292.1
4.0	79.3	102.7	129.2	158.1	185.6	214.2	242.2	268.2
4.5	73.7	94.9	119.5	145.4	170.6	196.6	222.5	246.7
5.0	68.5	87.8	110.3	133.5	156.6	180.2	204.1	226.5
5.5	63.6	81.1	101.7	122.5	143.6	165.0	187.1	207.7
6.0	58.9	74.9	93.7	112.3	131.5	151.0	171.3	190.3
6.5	54.4	69.1	86.2	103.0	120.4	138.2	156.9	174.3
7.0	50.2	63.7	79.3	94.4	110.2	126.4	143.3	159.7
7.5	46.3	58.6	73.0	86.5	100.9	115.7	131.6	146.2
8.0	42.7	54.0	67.1	79.4	92.4	106.1	120.6	134.0
8.5	39.4	49.8	61.7	72.9	84.7	97.3	110.7	123.0
9.0	36.4	45.9	56.8	67.1	77.8	89.4	101.7	112.9
9.5	33.6	42.3	52.3	61.8	71.5	82.3	93.6	103.9
10.0	31.2	39.1	48.2	57.0	65.8	75.9	86.3	95.7
10.5	28.9	36.1	44.5	52.7	60.7	70.1	79.6	88.4
11.0	26.8	33.4	41.1	48.8	56.1	64.9	73.6	81.7
11.5	24.9	31.0	38.0	45.3	51.9	60.1	68.0	75.6
12.0	23.1	28.7	35.3	42.0	48.0	55.6	62.8	70.0
12.5	21.4	26.7	32.7	39.0	44.4	51.4	57.9	64.8

MOLAR CONDUCTIVITY OF AQUEOUS HF, HCl, HBr, AND HI (continued)

c/mol L^{-1}	–20°C	–10°C	0°C	10°C	20°C	30°C	40°C	50°C
				HBr				
0.5			240.9	295.9	347.0	398.9	453.6	496.8
1.0			229.6	276.0	329.0	380.4	418.6	465.2
1.5			209.5	254.9	298.9	340.6	381.8	421.4
2.0		150.8	188.6	231.3	271.8	314.1	350.5	387.4
2.5		136.8	171.7	208.3	244.8	281.7	316.0	349.1
3.0		125.7	157.2	189.5	222.2	255.0	287.8	318.6
3.5		116.1	144.1	174.6	203.2	234.4	263.7	291.9
4.0	84.0	107.5	132.3	160.2	186.8	214.2	239.7	266.9
4.5	78.0	99.0	123.0	146.4	171.2	195.1	218.8	242.6
5.0	72.3	91.4	112.6	134.0	155.7	178.2	199.6	221.3
5.5	67.0	84.2	103.1	122.7	142.1	162.8	181.4	201.8
6.0	61.8	77.2	94.3	112.0	129.6	148.0	165.4	183.4
6.5	56.8	70.7	86.0	102.0	118.0	134.1	150.5	166.3
7.0	51.9	64.6	78.4	92.6	107.1	121.4	136.3	150.8

STANDARD KCl SOLUTIONS FOR CALIBRATING CONDUCTIVITY CELLS

This table presents recommended electrolytic conductivity (κ) values for aqueous potassium chloride solutions with molalities of 0.01 mol/kg, 0.1 mol/kg and 1.0 mol/kg at temperatures from 0˚C to 50˚C. The values, which are based on measurements at the National Institute of Standards and Technology, provide primary standards for the calibration of conductivity cells. The measurements at 0.01 and 0.1 molal are described in Reference 1, while those at 1.0 molal are in Reference 2. Temperatures are given on the ITS-90 scale. The uncertainty in the conductivity is about 0.03% for the 0.01 molal values and about 0.04% for the 0.1 and 1.0 molal values. The conductivity of water saturated with atmospheric CO_2 is given in the last column. These values were subtracted from the original measurements to give the values in the second, third, and fourth columns. All κ values are given in units of 10^{-4} S/m (numerically equal to μS/cm).

The assistance of Kenneth W. Pratt is appreciated.

REFERENCES

1. Wu, Y.C., Koch, W.F., and Pratt, K.W., *J. Res. Natl. Inst. Stand. Technol*. 96, 191, 1991.
2. Wu, Y.C., Koch, W.F., Feng, D., Holland, L.A., Juhasz, E., Arvay, E., and Tomek, A., *J. Res. Natl. Inst. Stand. Technol.* 99, 241, 1994.

	10^4 κ/S m^{-1}			
***t*/˚C**	**0.01 m KCl**	**0.1 m KCl**	**1.0 m KCl**	**H_2O (CO_2 sat.)**
0	772.92	7 116.85	63 488	0.58
5	890.96	8 183.70	72 030	0.68
10	1 013.95	9 291.72	80 844	0.79
15	1 141.45	10 437.1	89 900	0.89
18	1 219.93	11 140.6	—-	0.95
20	1 273.03	11 615.9	99 170	0.99
25	1 408.23	12 824.6	108 620	1.10
30	1 546.63	14 059.2	118 240	1.20
35	1 687.79	15 316.0	127 970	1.30
40	1 831.27	16 591.0	137 810	1.40
45	1 976.62	17 880.6	147 720	1.51
50	2 123.43	19 180.9	157 670	1.61

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EQUIVALENT CONDUCTIVITY OF ELECTROLYTES IN AQUEOUS SOLUTION

Petr Vanýsek

This table gives the equivalent (molar) conductivity Λ at 25°C for some common electrolytes in aqueous solution at concentrations up to 0.1 mol/L. The units of Λ are 10^{-4} m^2 S mol^{-1}.

For very dilute solutions, the equivalent conductivity for any electrolyte of concentration *c* can be approximately calculated using the Debye-Hückel-Onsager equation, which can be written for a symmetrical (equal charge on cation and anion) electrolyte as

$$\Lambda = \Lambda° - (A + B\Lambda°)c^{1/2}$$

For a solution at 25°C and both cation and anion with charge *1*, the constants are $A = 60.20$ and $B = 0.229$. Λ° can be found from the next table, "Ionic Conductivity and Diffusion at Infinite Dilution". The equation is reliable for $c < 0.001$ mol/L; with higher concentration the error increases.

Compound	Infinite dilution Λ°	Concentration (mol/L) 0.0005 Λ	0.001	0.005	0.01	0.02	0.05	0.1
$AgNO_3$	133.29	131.29	130.45	127.14	124.70	121.35	115.18	109.09
$1/2BaCl_2$	139.91	135.89	134.27	127.96	123.88	119.03	111.42	105.14
$1/2CaCl_2$	135.77	131.86	130.30	124.19	120.30	115.59	108.42	102.41
$1/2Ca(OH)_2$	258	—	—	233	226	214	—	—
$1/2CuSO_4$	133.6	121.6	115.20	94.02	83.08	72.16	59.02	50.55
HCl	425.95	422.53	421.15	415.59	411.80	407.04	398.89	391.13
KBr	151.9	149.8	148.9	146.02	143.36	140.41	135.61	131.32
KCl	149.79	147.74	146.88	143.48	141.20	138.27	133.30	128.90
$KClO_4$	139.97	138.69	137.80	134.09	131.39	127.86	121.56	115.14
$1/3K_3Fe(CN)_6$	174.5	166.4	163.1	150.7	—	—	—	—
$1/4K_4Fe(CN)_6$	184	—	167.16	146.02	134.76	122.76	107.65	97.82
$KHCO_3$	117.94	116.04	115.28	112.18	110.03	107.17	—	—
KI	150.31	148.2	143.32	144.30	142.11	139.38	134.90	131.05
KIO_4	127.86	125.74	124.88	121.18	118.45	114.08	106.67	98.2
KNO_3	144.89	142.70	141.77	138.41	132.75	132.34	126.25	120.34
$KMnO_4$	134.8	132.7	131.9	—	126.5	—	—	113
KOH	271.5	—	234	230	228	—	219	213
$KReO_4$	128.20	126.03	125.12	121.31	118.49	114.49	106.40	97.40
$1/3LaCl_3$	145.9	139.6	137.0	127.5	121.8	115.3	106.2	99.1
LiCl	114.97	113.09	112.34	109.35	107.27	104.60	100.06	95.81
$LiClO_4$	105.93	104.13	103.39	100.52	98.56	96.13	92.15	88.52
$1/2MgCl_2$	129.34	125.55	124.15	118.25	114.49	109.99	103.03	97.05
NH_4Cl	149.6	147.5	146.7	134.4	141.21	138.25	133.22	128.69
NaCl	126.39	124.44	123.68	120.59	118.45	115.70	111.01	106.69
$NaClO_4$	117.42	115.58	114.82	111.70	109.54	106.91	102.35	98.38
NaI	126.88	125.30	124.19	121.19	119.18	116.64	112.73	108.73
$NaOOCCH_3$	91.0	89.2	88.5	85.68	83.72	81.20	76.88	72.76
NaOH	247.7	245.5	244.6	240.7	237.9	—	—	—
Na picrate	80.45	78.7	78.6	75.7	73.7	—	66.3	61.8
$1/2Na_2SO_4$	129.8	125.68	124.09	117.09	112.38	106.73	97.70	89.94
$1/2SrCl_2$	135.73	131.84	130.27	124.18	120.23	115.48	108.20	102.14
$1/2ZnSO_4$	132.7	121.3	114.47	95.44	84.87	74.20	61.17	52.61

IONIC CONDUCTIVITY AND DIFFUSION AT INFINITE DILUTION

Petr Vanýsek

This table gives the molar (equivalent) conductivity λ for common ions at infinite dilution. All values refer to aqueous solutions at 25°C. It also lists the diffusion coefficient D of the ion in dilute aqueous solution, which is related to λ through the equation

$$D = \left(RT / F^2\right)\left(\lambda / |z|\right)$$

where R is the molar gas constant, T the temperature, F the Faraday constant, and z the charge on the ion. The variation with temperature is fairly sharp; for typical ions, λ and D increase by 2 to 3% per degree as the temperature increases from 25°C.

The diffusion coefficient for a salt, $D_{salt,}$ may be calculated from the D_+ and D_- values of the constituent ions by the relation

$$D_{\mathrm{salt}} = \frac{\left(z_+ + |z_-|\right) D_+ D_-}{z_+ D_+ + |z_-| D_-}$$

For solutions of simple, pure electrolytes (one positive and one negative ionic species), such as NaCl, equivalent ionic conductivity $\Lambda°$, which is the conductivity per unit concentration of charge, is defined as

$$\Lambda° = \lambda_+ + \lambda_-$$

where λ_+ and λ_- are equivalent ionic conductivities of the cation and anion. The more general formula is

$$\Lambda° = \nu_+\lambda_+ + \nu_-\lambda_-$$

where ν_+ and ν_- refer to the number of moles of cations and anions to which one mole of the electrolyte gives a rise in the solution.

REFERENCES

1. Gray, D. E., Ed., *American Institute of Physics Handbook,* McGraw-Hill, New York, 1972, 2—226.
2. Robinson, R. A., and Stokes, R. H., *Electrolyte Solutions*, Butterworths, London, 1959.
3. Lobo, V. M. M., and Quaresma, J. L., *Handbook of Electrolyte Solutions,* Physical Science Data Series 41, Elsevier, Amsterdam, 1989.
4. Conway, B. E., *Electrochemical Data,* Elsevier, Amsterdam, 1952.
5. Milazzo, G., *Electrochemistry: Theoretical Principles and Practical Applications,* Elsevier, Amsterdam, 1963.

Ion	λ 10^{-4} m^2 S mol^{-1}	D 10^{-5} cm^2 s^{-1}
Inorganic Cations		
Ag^+	61.9	1.648
1/3Al^{3+}	61	0.541
1/2Ba^{2+}	63.6	0.847
1/2Be^{2+}	45	0.599
1/2Ca^{2+}	59.47	0.792
1/2Cd^{2+}	54	0.719
1/3Ce^{3+}	69.8	0.620
1/2Co^{2+}	55	0.732
1/3$[Co(NH_3)_6]^{3+}$	101.9	0.904
1/3$[Co(en)_3]^{3+}$	74.7	0.663
1/6$[Co_2(trien)_3]^{6+}$	69	0.306
1/3Cr^{3+}	67	0.595
Cs^+	77.2	2.056
1/2Cu^{2+}	53.6	0.714
D^+	249.9	6.655
1/3Dy^{3+}	65.6	0.582
1/3Er^{3+}	65.9	0.585
1/3Eu^{3+}	67.8	0.602
1/2Fe^{2+}	54	0.719
1/3Fe^{3+}	68	0.604
1/3Gd^{3+}	67.3	0.597
H^+	349.65	9.311
1/2Hg^{2+}	68.6	0.913
1/2Hg^{2+}	63.6	0.847
1/3Ho^{3+}	66.3	0.589
K^+	73.48	1.957
1/3La^{3+}	69.7	0.619
Li^+	38.66	1.029
1/2Mg^{2+}	53.0	0.706
1/2Mn^{2+}	53.5	0.712
NH_4^+	73.5	1.957
$N_2H_5^+$	59	1.571
Na^+	50.08	1.334
1/3Nd^{3+}	69.4	0.616
1/2Ni^{2+}	49.6	0.661
1/4$[Ni_2(trien)_3]^{4+}$	52	0.346
1/2Pb^{2+}	71	0.945
1/3Pr^{3+}	69.5	0.617
1/2Ra^{2+}	66.8	0.889
Rb^+	77.8	2.072
1/3Sc^{3+}	64.7	0.574
1/3Sm^{3+}	68.5	0.608
1/2Sr^{2+}	59.4	0.791
Tl^+	74.7	1.989
1/3Tm^{3+}	65.4	0.581
1/2UO_2^{2+}	32	0.426
1/3Y^{3+}	62	0.550
1/3Yb^{3+}	65.6	0.582
1/2Zn^{2+}	52.8	0.703

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IONIC CONDUCTIVITY AND DIFFUSION AT INFINITE DILUTION (continued)

Ion	λ 10^{-4} m^2 S mol^{-1}	D 10^{-5} cm^2 s^{-1}
Inorganic Anions		
$Au(CN)_2^-$	50	1.331
$Au(CN)_4^-$	36	0.959
$B(C_6H_5)_4^-$	21	0.559
Br^-	78.1	2.080
Br_3^-	43	1.145
BrO_3^-	55.7	1.483
CN^-	78	2.077
CNO^-	64.6	1.720
$1/2CO_3^{2-}$	69.3	0.923
Cl^-	76.31	2.032
ClO_2^-	52	1.385
ClO_3^-	64.6	1.720
ClO_4^-	67.3	1.792
$1/3[Co(CN)_6]^{3-}$	98.9	0.878
$1/2CrO_4^{2-}$	85	1.132
F^-	55.4	1.475
$1/4[Fe(CN)_6]^{4-}$	110.4	0.735
$1/3[Fe(CN)_6]^{3-}$	100.9	0.896
$H_2AsO_4^-$	34	0.905
HCO_3^-	44.5	1.185
HF_2^-	75	1.997
$1/2HPO_4^{2-}$	57	0.759
$H_2PO_4^-$	36	0.959
$H_2PO_2^-$	46	1.225
HS^-	65	1.731
HSO_3^-	58	1.545
HSO_4^-	52	1.385
$H_2SbO_4^-$	31	0.825
I^-	76.8	2.045
IO_3^-	40.5	1.078
IO_4^-	54.5	1.451
MnO_4^-	61.3	1.632
$1/2MoO_4^{2-}$	74.5	1.984
$N(CN)_2^-$	54.5	1.451
NO_2^-	71.8	1.912
NO_3^-	71.42	1.902
$NH_2SO_3^-$	48.3	1.286
N_3^-	69	1.837
OCN^-	64.6	1.720
OD^-	119	3.169
OH^-	198	5.273
PF_6^-	56.9	1.515
$1/2PO_3F^{2-}$	63.3	0.843
$1/3PO_4^{3-}$	92.8	0.824
$1/4P_2O_7^{4-}$	96	0.639
$1/3P_3O_9^{3-}$	83.6	0.742
$1/5P_3O_{10}^{5-}$	109	0.581
ReO_4^-	54.9	1.462
SCN^-	66	1.758
$1/2SO_3^{2-}$	72	0.959
$1/2SO_4^{2-}$	80.0	1.065
$1/2S_2O_3^{2-}$	85.0	1.132
$1/2S_2O_4^{2-}$	66.5	0.885
$1/2S_2O_6^{2-}$	93	1.238
$1/2S_2O_8^{2-}$	86	1.145
$Sb(OH)_6^-$	31.9	0.849
$SeCN^-$	64.7	1.723
$1/2SeO_4^{2-}$	75.7	1.008
$1/2WO_4^{2-}$	69	0.919
Organic Cations		
Benzyltrimethylammonium$^+$	34.6	0.921
Isobutylammonium$^+$	38	1.012
Butyltrimethylammonium$^+$	33.6	0.895
Decylpyridinium$^+$	29.5	0.786
Decyltrimethylammonium$^+$	24.4	0.650
Diethylammonium$^+$	42.0	1.118
Dimethylammonium$^+$	51.8	1.379
Dipropylammonium$^+$	30.1	0.802
Dodecylammonium$^+$	23.8	0.634
Dodecyltrimethylammonium$^+$	22.6	0.602
Ethanolammonium$^+$	42.2	1.124
Ethylammonium$^+$	47.2	1.257
Ethyltrimethylammonium$^+$	40.5	1.078
Hexadecyltrimethylammonium$^+$	20.9	0.557
Hexyltrimethylammonium$^+$	29.6	0.788
Histidyl$^+$	23.0	0.612
Hydroxyethyltrimethylarsonium$^+$	39.4	1.049
Methylammonium$^+$	58.7	1.563
Octadecylpyridinium$^+$	20	0.533
Octadecyltributylammonium$^+$	16.6	0.442
Octadecyltriethylammonium$^+$	17.9	0.477
Octadecyltrimethylammonium$^+$	19.9	0.530
Octadecyltripropylammonium$^+$	17.2	0.458
Octyltrimethylammonium$^+$	26.5	0.706
Pentylammonium$^+$	37	0.985
Piperidinium$^+$	37.2	0.991
Propylammonium$^+$	40.8	1.086
Pyrilammonium$^+$	24.3	0.647
Tetrabutylammonium$^+$	19.5	0.519
Tetradecyltrimethylammonium$^+$	21.5	0.573
Tetraethylammonium$^+$	32.6	0.868
Tetramethylammonium$^+$	44.9	1.196
Tetraisopentylammonium$^+$	17.9	0.477
Tetrapentylammmonium$^+$	17.5	0.466
Tetrapropylammonium$^+$	23.4	0.623
Triethylammonium$^+$	34.3	0.913
Triethylsulfonium$^+$	36.1	0.961
Trimethylammonium$^+$	47.23	1.258
Trimethylhexylammonium$^+$	34.6	0.921
Trimethylsulfonium$^+$	51.4	1.369
Tripropylammonium$^+$	26.1	0.695
Organic Anions		
Acetate$^-$	40.9	1.089
p-Anisate$^-$	29.0	0.772
1/2Azelate^{2-}	40.6	0.541
Benzoate$^-$	32.4	0.863
Bromoacetate$^-$	39.2	1.044
Bromobenzoate$^-$	30	0.799
Butyrate$^-$	32.6	0.868
Chloroacetate$^-$	39.8	1.060
m-Chlorobenzoate$^-$	31	0.825
o-Chlorobenzoate$^-$	30.2	0.804

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Ion	λ 10^{-4} m^2 S mol^{-1}	*D* 10^{-5} cm^2 s^{-1}
1/3Citrate^{3-}	70.2	0.623
Crotonate^{-}	33.2	0.884
Cyanoacetate^{-}	43.4	1.156
Cyclohexane carboxylate^{-}	28.7	0.764
1/2 1,1-Cyclopropanedicarboxylate^{2-}	53.4	0.711
Decylsulfate^{-}	26	0.692
Dichloroacetate^{-}	38.3	1.020
1/2Diethylbarbiturate^{2-}	26.3	0.350
Dihydrogencitrate^{-}	30	0.799
1/2Dimethylmalonate^{2-}	49.4	0.658
3,5-Dinitrobenzoate^{-}	28.3	0.754
Dodecylsulfate^{-}	24	0.639
Ethylmalonate^{-}	49.3	1.313
Ethylsulfate^{-}	39.6	1.055
Fluoroacetate^{-}	44.4	1.182
Fluorobenzoate^{-}	33	0.879
Formate^{-}	54.6	1.454
1/2Fumarate^{2-}	61.8	0.823
1/2Glutarate^{2-}	52.6	0.700
Hydrogenoxalate^{-}	40.2	1.070
Isovalerate^{-}	32.7	0.871
Iodoacetate^{-}	40.6	1.081
Lactate^{-}	38.8	1.033
1/2Malate^{2-}	58.8	0.783
1/2Maleate^{2-}	61.9	0.824
1/2Malonate^{2-}	63.5	0.845
Methylsulfate^{-}	48.8	1.299
Naphthylacetate^{-}	28.4	0.756
1/2Oxalate^{2-}	74.11	0.987
Octylsulfate^{-}	29	0.772
Phenylacetate^{-}	30.6	0.815
1/2*o*-Phthalate^{2-}	52.3	0.696
1/2*m*-Phthalate^{2-}	54.7	0.728
Picrate^{-}	30.37	0.809
Pivalate^{-}	31.9	0.849
Propionate^{-}	35.8	0.953
Propylsulfate^{-}	37.1	0.988
Salicylate^{-}	36	0.959
1/2Suberate^{2-}	36	0.479
1/2Succinate^{2-}	58.8	0.783
p-Sulfonate	29.3	0.780
1/2Tartarate^{2-}	59.6	0.794
Trichloroacetate^{-}	35	0.932

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ACTIVITY COEFFICIENTS OF ACIDS, BASES, AND SALTS

Petr Vanýsek

This table gives mean activity coefficients at 25°C for molalities in the range 0.1 to 1.0. See the following table for definitions, references, and data over a wider concentration range.

	0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**
$AgNO_3$	0.734	0.657	0.606	0.567	0.536	0.509	0.485	0.464	0.446	0.429
$AlCl_3$	0.337	0.305	0.302	0.313	0.331	0.356	0.388	0.429	0.479	0.539
$Al_2(SO_4)_3$	0.035	0.0225	0.0176	0.0153	0.0143	0.014	0.0142	0.0149	0.0159	0.0175
$BaCl_2$	0.500	0.444	0.419	0.405	0.397	0.391	0.391	0.391	0.392	0.395
$BeSO_4$	0.150	0.109	0.0885	0.0769	0.0692	0.0639	0.0600	0.0570	0.0546	0.0530
$CaCl_2$	0.518	0.472	0.455	0.448	0.448	0.453	0.460	0.470	0.484	0.500
$CdCl_2$	0.2280	0.1638	0.1329	0.1139	0.1006	0.0905	0.0827	0.0765	0.0713	0.0669
$Cd(NO_3)_2$	0.513	0.464	0.442	0.430	0.425	0.423	0.423	0.425	0.428	0.433
$CdSO_4$	0.150	0.103	0.0822	0.0699	0.0615	0.0553	0.0505	0.0468	0.0438	0.0415
$CoCl_2$	0.522	0.479	0.463	0.459	0.462	0.470	0.479	0.492	0.511	0.531
$CrCl_3$	0.331	0.298	0.294	0.300	0.314	0.335	0.362	0.397	0.436	0.481
$Cr(NO_3)_3$	0.319	0.285	0.279	0.281	0.291	0.304	0.322	0.344	0.371	0.401
$Cr_2(SO_4)_3$	0.0458	0.0300	0.0238	0.0207	0.0190	0.0182	0.0181	0.0185	0.0194	0.0208
CsBr	0.754	0.694	0.654	0.626	0.603	0.586	0.571	0.558	0.547	0.538
CsCl	0.756	0.694	0.656	0.628	0.606	0.589	0.575	0.563	0.553	0.544
CsI	0.754	0.692	0.651	0.621	0.599	0.581	0.567	0.554	0.543	0.533
$CsNO_3$	0.733	0.655	0.602	0.561	0.528	0.501	0.478	0.458	0.439	0.422
CsOH	0.795	0.761	0.744	0.739	0.739	0.742	0.748	0.754	0.762	0.771
CsOAc	0.799	0.771	0.761	0.759	0.762	0.768	0.776	0.783	0.792	0.802
Cs_2SO_4	0.456	0.382	0.338	0.311	0.291	0.274	0.262	0.251	0.242	0.235
$CuCl_2$	0.508	0.455	0.429	0.417	0.411	0.409	0.409	0.410	0.413	0.417
$Cu(NO_3)_2$	0.511	0.460	0.439	0.429	0.426	0.427	0.431	0.437	0.445	0.455
$CuSO_4$	0.150	0.104	0.0829	0.0704	0.0620	0.0559	0.0512	0.0475	0.0446	0.0423
$FeCl_2$	0.5185	0.473	0.454	0.448	0.450	0.454	0.463	0.473	0.488	0.506
HBr	0.805	0.782	0.777	0.781	0.789	0.801	0.815	0.832	0.850	0.871
HCl	0.796	0.767	0.756	0.755	0.757	0.763	0.772	0.783	0.795	0.809
$HClO_4$	0.803	0.778	0.768	0.766	0.769	0.776	0.785	0.795	0.808	0.823
HI	0.818	0.807	0.811	0.823	0.839	0.860	0.883	0.908	0.935	0.963
HNO_3	0.791	0.754	0.735	0.725	0.720	0.717	0.717	0.718	0.721	0.724
H_2SO_4	0.2655	0.2090	0.1826	—	0.1557	—	0.1417	—	—	0.1316
KBr	0.772	0.722	0.693	0.673	0.657	0.646	0.636	0.629	0.622	0.617
KCl	0.770	0.718	0.688	0.666	0.649	0.637	0.626	0.618	0.610	0.604
$KClO_3$	0.749	0.681	0.635	0.599	0.568	0.541	0.518	—	—	—
K_2CrO_4	0.456	0.382	0.340	0.313	0.292	0.276	0.263	0.253	0.243	0.235
KF	0.775	0.727	0.700	0.682	0.670	0.661	0.654	0.650	0.646	0.645
$K_3Fe(CN)_6$	0.268	0.212	0.184	0.167	0.155	0.146	0.140	0.135	0.131	0.128
$K_4Fe(CN)_6$	0.139	0.0993	0.0808	0.0693	0.0614	0.0556	0.0512	0.0479	0.0454	—
KH_2PO_4	0.731	0.653	0.602	0.561	0.529	0.501	0.477	0.456	0.438	0.421
KI	0.778	0.733	0.707	0.689	0.676	0.667	0.660	0.654	0.649	0.645
KNO_3	0.739	0.663	0.614	0.576	0.545	0.519	0.496	0.476	0.459	0.443
KOAc	0.796	0.766	0.754	0.750	0.751	0.754	0.759	0.766	0.774	0.783
KOH	0.798	0.760	0.742	0.734	0.732	0.733	0.736	0.742	0.749	0.756
KSCN	0.769	0.716	0.685	0.663	0.646	0.633	0.623	0.614	0.606	0.599
K_2SO_4	0.441	0.360	0.316	0.286	0.264	0.246	0.232	—	—	—
LiBr	0.796	0.766	0.756	0.752	0.753	0.758	0.767	0.777	0.789	0.803
LiCl	0.790	0.757	0.744	0.740	0.739	0.743	0.748	0.755	0.764	0.774
$LiClO_4$	0.812	0.794	0.792	0.798	0.808	0.820	0.834	0.852	0.869	0.887
LiI	0.815	0.802	0.804	0.813	0.824	0.838	0.852	0.870	0.888	0.910
$LiNO_3$	0.788	0.752	0.736	0.728	0.726	0.727	0.729	0.733	0.737	0.743
LiOH	0.760	0.702	0.665	0.638	0.617	0.599	0.585	0.573	0.563	0.554
LiOAc	0.784	0.742	0.721	0.709	0.700	0.691	0.689	0.688	0.688	0.689
Li_2SO_4	0.468	0.398	0.361	0.337	0.319	0.307	0.297	0.289	0.282	0.277
$MgCl_2$	0.529	0.489	0.477	0.475	0.481	0.491	0.506	0.522	0.544	0.570
$MgSO_4$	0.150	0.107	0.0874	0.0756	0.0675	0.0616	0.0571	0.0536	0.0508	0.0485
$MnCl_2$	0.516	0.469	0.450	0.442	0.440	0.443	0.448	0.455	0.466	0.479
$MnSO_4$	0.150	0.105	0.0848	0.0725	0.0640	0.0578	0.0530	0.0493	0.0463	0.0439

ACTIVITY COEFFICIENTS OF ACIDS, BASES, AND SALTS (continued)

	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
NH_4Cl	0.770	0.718	0.687	0.665	0.649	0.636	0.625	0.617	0.609	0.603
NH_4NO_3	0.740	0.677	0.636	0.606	0.582	0.562	0.545	0.530	0.516	0.504
$(NH_4)_2SO_4$	0.439	0.356	0.311	0.280	0.257	0.240	0.226	0.214	0.205	0.196
NaBr	0.782	0.741	0.719	0.704	0.697	0.692	0.689	0.687	0.687	0.687
NaCl	0.778	0.735	0.710	0.693	0.681	0.673	0.667	0.662	0.659	0.657
$NaClO_3$	0.772	0.720	0.688	0.664	0.645	0.630	0.617	0.606	0.597	0.589
$NaClO_4$	0.775	0.729	0.701	0.683	0.668	0.656	0.648	0.641	0.635	0.629
Na_2CrO_4	0.464	0.394	0.353	0.327	0.307	0.292	0.280	0.269	0.261	0.253
NaF	0.765	0.710	0.676	0.651	0.632	0.616	0.603	0.592	0.582	0.573
NaH_2PO_4	0.744	0.675	0.629	0.593	0.563	0.539	0.517	0.499	0.483	0.468
NaI	0.787	0.751	0.735	0.727	0.723	0.723	0.724	0.727	0.731	0.736
$NaNO_3$	0.762	0.703	0.666	0.638	0.617	0.599	0.583	0.570	0.558	0.548
NaOAc	0.791	0.757	0.744	0.737	0.735	0.736	0.740	0.745	0.752	0.757
NaOH	0.766	0.727	0.708	0.697	0.690	0.685	0.681	0.679	0.678	0.678
NaSCN	0.787	0.750	—	0.720	0.715	0.712	0.710	0.710	0.711	0.712
Na_2SO_4	0.445	0.365	0.320	0.289	0.266	0.248	0.233	0.221	0.210	0.201
$NiCl_2$	0.522	0.479	0.463	0.460	0.464	0.471	0.482	0.496	0.515	0.563
$NiSO_4$	0.150	0.105	0.0841	0.0713	0.0627	0.0562	0.0515	0.0478	0.0448	0.0425
$Pb(NO_3)_2$	0.395	0.308	0.260	0.228	0.205	0.187	0.172	0.160	0.150	0.141
RbBr	0.763	0.706	0.673	0.650	0.632	0.617	0.605	0.595	0.586	0.578
RbCl	0.764	0.709	0.675	0.652	0.634	0.620	0.608	0.599	0.590	0.583
RbI	0.762	0.705	0.671	0.647	0.629	0.614	0.602	0.591	0.583	0.575
$RbNO_3$	0.734	0.658	0.606	0.565	0.534	0.508	0.485	0.465	0.446	0.430
RbOAc	0.796	0.767	0.756	0.753	0.755	0.759	0.766	0.773	0.782	0.792
Rb_2SO_4	0.451	0.374	0.331	0.301	0.279	0.263	0.249	0.238	0.228	0.219
$SrCl_2$	0.511	0.462	0.442	0.433	0.430	0.431	0.434	0.441	0.449	0.461
$TlClO_4$	0.730	0.652	0.599	0.559	0.527	—	—	—	—	—
$TlNO_3$	0.702	0.606	0.545	0.500	—	—	—	—	—	—
UO_2Cl_2	0.544	0.510	0.520	0.505	0.517	0.532	0.549	0.571	0.595	0.620
UO_2SO_4	0.150	0.102	0.0807	0.0689	0.0611	0.0566	0.0515	0.0483	0.0458	0.0439
$ZnCl_2$	0.515	0.462	0.432	0.411	0.394	0.380	0.369	0.357	0.348	0.339
$Zn(NO_3)_2$	0.531	0.489	0.474	0.469	0.473	0.480	0.489	0.501	0.518	0.535
$ZnSO_4$	0.150	0.140	0.0835	0.0714	0.0630	0.0569	0.0523	0.0487	0.0458	0.0435

MEAN ACTIVITY COEFFICIENTS OF ELECTROLYTES AS A FUNCTION OF CONCENTRATION

The mean activity coefficient γ of an electrolyte X_aY_b is defined as

$$\gamma = \left(\gamma_+^a \gamma_-^b\right)^{1/(a+b)}$$

where γ_+ and γ_- are activity coefficients of the individual ions (which cannot be directly measured). This table gives the mean activity coefficients of about 100 electrolytes in aqueous solution as a function of concentration, expressed in molality terms. All values refer to a temperature of 25°C. Substances are arranged in alphabetical order by formula.

REFERENCES

1. Hamer,W. J., and Wu, Y. C., *J. Phys. Chem. Ref. Data*, 1, 1047, 1972.
2. Staples, B. R., *J. Phys. Chem. Ref. Data*, 6, 385, 1977; 10, 767, 1981; 10, 779, 1981.
3. Goldberg, R. N. et al., *J. Phys. Chem. Ref. Data*, 7, 263, 1978; 8, 923, 1979; 8, 1005, 1979; 10, 1, 1981; 10, 671, 1981.

Mean Activity Coefficient at 25°C

m/mol kg^{-1}	$AgNO_3$	$BaBr_2$	$BaCl_2$	BaI_2	$CaBr_2$	$CaCl_2$	CaI_2
0.001	0.964	0.881	0.887	0.890	0.890	0.888	0.890
0.002	0.950	0.850	0.849	0.853	0.853	0.851	0.853
0.005	0.924	0.785	0.782	0.792	0.791	0.787	0.791
0.010	0.896	0.727	0.721	0.737	0.735	0.727	0.736
0.020	0.859	0.661	0.653	0.678	0.674	0.664	0.677
0.050	0.794	0.573	0.559	0.600	0.594	0.577	0.600
0.100	0.732	0.517	0.492	0.551	0.540	0.517	0.552
0.200	0.656	0.463	0.436	0.520	0.502	0.469	0.524
0.500	0.536	0.435	0.391	0.536	0.500	0.444	0.554
1.000	0.430	0.470	0.393	0.664	0.604	0.495	0.729
2.000	0.316	0.654		1.242	1.125	0.784	
5.000	0.181				18.7	5.907	
10.000	0.108					43.1	
15.000	0.085						

m/mol kg^{-1}	$Cd(NO_2)_2$	$Cd(NO_3)_2$	$CoBr_2$	$CoCl_2$	CoI_2	$Co(NO_3)_2$	CsBr
0.001	0.881	0.888	0.890	0.889	0.887	0.888	0.965
0.002	0.837	0.851	0.854	0.852	0.849	0.850	0.951
0.005	0.759	0.787	0.794	0.789	0.783	0.786	0.925
0.010	0.681	0.728	0.740	0.732	0.724	0.728	0.898
0.020	0.589	0.664	0.681	0.670	0.661	0.663	0.864
0.050	0.451	0.576	0.605	0.586	0.582	0.576	0.806
0.100	0.344	0.515	0.556	0.528	0.540	0.516	0.752
0.200	0.247	0.465	0.523	0.483	0.527	0.469	0.691
0.500	0.148	0.428	0.538	0.465	0.596	0.446	0.605
1.000	0.098	0.437	0.685	0.532	0.845	0.492	0.540
2.000	0.069	0.517	1.421	0.864	2.287	0.722	0.485
5.000	0.054		13.9		55.3	3.338	0.454
10.000					196		

m/mol kg^{-1}	CsCl	CsF	CsI	$CsNO_3$	CsOH	Cs_2SO_4	$CuBr_2$
0.001	0.965	0.965	0.965	0.964	0.966	0.885	0.889
0.002	0.951	0.952	0.951	0.951	0.953	0.845	0.853
0.005	0.925	0.929	0.925	0.924	0.930	0.775	0.791
0.010	0.898	0.905	0.898	0.897	0.906	0.709	0.735
0.020	0.864	0.876	0.863	0.860	0.878	0.634	0.674
0.050	0.805	0.830	0.804	0.796	0.836	0.526	0.594
0.100	0.751	0.792	0.749	0.733	0.802	0.444	0.541

MEAN ACTIVITY COEFFICIENTS OF ELECTROLYTES AS A FUNCTION OF CONCENTRATION (continued)

m/mol kg^{-1}	CsCl	CsF	CsI	$CsNO_3$	CsOH	Cs_2SO_4	$CuBr_2$
0.200	0.691	0.755	0.688	0.655	0.772	0.369	0.504
0.500	0.607	0.721	0.601	0.529	0.755	0.285	0.503
1.000	0.546	0.726	0.534	0.421	0.782	0.233	0.591
2.000	0.496	0.803	0.470				0.859
5.000	0.474						
10.000	0.508						

m/mol kg^{-1}	$CuCl_2$	$Cu(ClO_4)_2$	$Cu(NO_3)_2$	$FeCl_2$	HBr	HCl	$HClO_4$
0.001	0.887	0.890	0.888	0.888	0.966	0.965	0.966
0.002	0.849	0.854	0.851	0.850	0.953	0.952	0.953
0.005	0.783	0.795	0.787	0.785	0.930	0.929	0.929
0.010	0.722	0.741	0.729	0.725	0.907	0.905	0.906
0.020	0.654	0.685	0.664	0.659	0.879	0.876	0.878
0.050	0.561	0.613	0.577	0.570	0.837	0.832	0.836
0.100	0.495	0.572	0.516	0.509	0.806	0.797	0.803
0.200	0.441	0.553	0.466	0.462	0.783	0.768	0.776
0.500	0.401	0.617	0.431	0.443	0.790	0.759	0.769
1.000	0.405	0.892	0.456	0.500	0.872	0.811	0.826
2.000	0.453	2.445	0.615	0.782	1.167	1.009	1.055
5.000	0.601		2.083		3.800	2.380	3.100
10.000					33.4	10.4	30.8
15.000							323

m/mol kg^{-1}	HF	HI	HNO_3	H_2SO_4	KBr	KCNS	KCl
0.001	0.551	0.966	0.965	0.804	0.965	0.965	0.965
0.002	0.429	0.953	0.952	0.740	0.952	0.951	0.951
0.005	0.302	0.931	0.929	0.634	0.927	0.927	0.927
0.010	0.225	0.909	0.905	0.542	0.902	0.901	0.901
0.020	0.163	0.884	0.875	0.445	0.870	0.869	0.869
0.050	0.106	0.847	0.829	0.325	0.817	0.815	0.816
0.100	0.0766	0.823	0.792	0.251	0.771	0.768	0.768
0.200	0.0550	0.811	0.756	0.195	0.772	0.716	0.717
0.500	0.0352	0.845	0.725	0.146	0.658	0.647	0.649
1.000	0.0249	0.969	0.730	0.125	0.617	0.598	0.604
2.000	0.0175	1.363	0.788	0.119	0.593	0.556	0.573
5.000	0.0110	4.760	1.063	0.197	0.626	0.525	0.593
10.000	0.0085	49.100	1.644	0.527			
15.000	0.0077		2.212	1.077			
20.000	0.0075		2.607	1.701			

m/mol kg^{-1}	$KClO_3$	K_2CrO_4	KF	KH_2PO_4*	K_2HPO_4**	KI	KNO_3
0.001	0.965	0.886	0.965	0.964	0.886	0.965	0.964
0.002	0.951	0.847	0.952	0.950	0.847	0.952	0.950
0.005	0.926	0.779	0.927	0.924	0.779	0.927	0.924
0.010	0.899	0.715	0.902	0.896	0.715	0.902	0.896
0.020	0.865	0.643	0.870	0.859	0.643	0.871	0.860
0.050	0.805	0.539	0.818	0.793	0.538	0.820	0.797
0.100	0.749	0.460	0.773	0.730	0.457	0.776	0.735
0.200	0.681	0.385	0.726	0.652	0.379	0.731	0.662
0.500	0.569	0.296	0.670	0.529	0.283	0.676	0.546
1.000		0.239	0.645	0.422		0.646	0.444

MEAN ACTIVITY COEFFICIENTS OF ELECTROLYTES AS A FUNCTION OF CONCENTRATION (continued)

m/mol kg^{-1}	$KClO_3$	K_2CrO_4	KF	KH_2PO_4*	K_2HPO_4**	KI	KNO_3
2.000		0.199	0.658			0.638	0.332
5.000			0.871				
10.000			1.715				
15.000			3.120				

m/mol kg^{-1}	KOH	K_2SO_4	LiBr	LiCl	$LiClO_4$	LiI	$LiNO_3$
0.001	0.965	0.885	0.965	0.965	0.966	0.966	0.965
0.002	0.952	0.844	0.952	0.952	0.953	0.953	0.952
0.005	0.927	0.772	0.929	0.928	0.931	0.930	0.928
0.010	0.902	0.704	0.905	0.904	0.908	0.908	0.904
0.020	0.871	0.625	0.877	0.874	0.882	0.882	0.874
0.050	0.821	0.511	0.832	0.827	0.843	0.843	0.827
0.100	0.779	0.424	0.797	0.789	0.815	0.817	0.788
0.200	0.740	0.343	0.767	0.756	0.795	0.802	0.753
0.500	0.710	0.251	0.754	0.739	0.806	0.824	0.726
1.000	0.733		0.803	0.775	0.887	0.912	0.743
2.000	0.860		1.012	0.924	1.161	1.197	0.837
5.000	1.697		2.696	2.000			1.298
10.000	6.110		20.0	9.600			2.500
15.000	19.9		147	30.9			3.960
20.000	46.4		486				4.970

m/mol kg^{-1}	LiOH	Li_2SO_4	$MgBr_2$	$MgCl_2$	MgI_2	$MnBr_2$	$MnCl_2$
0.001	0.964	0.887	0.889	0.889	0.889	0.889	0.888
0.002	0.950	0.847	0.852	0.852	0.853	0.853	0.850
0.005	0.923	0.780	0.790	0.790	0.791	0.791	0.786
0.010	0.895	0.716	0.733	0.734	0.736	0.735	0.727
0.020	0.858	0.645	0.672	0.672	0.677	0.674	0.662
0.050	0.794	0.544	0.593	0.590	0.602	0.595	0.574
0.100	0.735	0.469	0.543	0.535	0.556	0.543	0.513
0.200	0.668	0.400	0.512	0.493	0.535	0.508	0.464
0.500	0.579	0.325	0.540	0.485	0.594	0.519	0.437
1.000	0.522	0.284	0.715	0.577	0.858	0.650	0.477
2.000	0.484	0.270	1.590	1.065	2.326	1.224	0.661
5.000	0.493		36.1	14.40	109.8	6.697	1.539

m/mol kg^{-1}	$Mn(ClO_4)_2$	NH_4Cl	NH_4ClO_4	$(NH_4)_2HPO_4$**	NH_4NO_3	NaBr	$NaBrO_3$
0.001	0.892	0.965	0.964	0.882	0.964	0.965	0.965
0.002	0.858	0.952	0.950	0.839	0.951	0.952	0.951
0.005	0.801	0.927	0.924	0.763	0.925	0.928	0.926
0.010	0.752	0.901	0.895	0.688	0.897	0.903	0.900
0.020	0.700	0.869	0.859	0.600	0.862	0.873	0.867
0.050	0.637	0.816	0.794	0.469	0.801	0.824	0.811
0.100	0.604	0.769	0.734	0.367	0.744	0.783	0.759
0.200	0.596	0.718	0.663	0.273	0.678	0.742	0.698
0.500	0.686	0.649	0.560	0.171	0.582	0.697	0.605
1.000	1.030	0.603	0.479	0.114	0.502	0.687	0.528
2.000	3.072	0.569	0.399	0.074	0.419	0.730	0.449
5.000		0.563			0.303	1.083	
10.000					0.220		
15.000					0.179		
20.000					0.154		

MEAN ACTIVITY COEFFICIENTS OF ELECTROLYTES AS A FUNCTION OF CONCENTRATION (continued)

m/mol kg^{-1}	Na_2CO_3	NaCl	$NaClO_3$	$NaClO_4$	Na_2CrO_4	NaF	Na_2HPO_4*
0.001	0.887	0.965	0.965	0.965	0.887	0.965	0.887
0.002	0.847	0.952	0.952	0.952	0.849	0.951	0.848
0.005	0.780	0.928	0.927	0.928	0.783	0.926	0.780
0.010	0.716	0.903	0.902	0.903	0.722	0.901	0.717
0.020	0.644	0.872	0.870	0.872	0.653	0.868	0.644
0.050	0.541	0.822	0.818	0.821	0.554	0.813	0.539
0.100	0.462	0.779	0.771	0.777	0.479	0.764	0.456
0.200	0.385	0.734	0.719	0.729	0.406	0.710	0.373
0.500	0.292	0.681	0.646	0.668	0.318	0.633	0.266
1.000	0.229	0.657	0.590	0.630	0.261	0.573	0.191
2.000	0.182	0.668	0.537	0.608	0.231		0.133
5.000		0.874		0.648			

m/mol kg^{-1}	NaI	$NaNO_3$	NaOH	Na_2SO_3	Na_2SO_4	Na_2WO_4	$NiBr_2$
0.001	0.965	0.965	0.965	0.887	0.886	0.886	0.889
0.002	0.952	0.951	0.952	0.847	0.846	0.846	0.853
0.005	0.928	0.926	0.927	0.779	0.777	0.777	0.791
0.010	0.904	0.900	0.902	0.716	0.712	0.712	0.735
0.020	0.874	0.866	0.870	0.644	0.637	0.638	0.675
0.050	0.827	0.810	0.819	0.540	0.529	0.534	0.596
0.100	0.789	0.759	0.775	0.462	0.446	0.457	0.546
0.200	0.753	0.701	0.731	0.386	0.366	0.388	0.514
0.500	0.722	0.617	0.685	0.296	0.268	0.320	0.535
1.000	0.734	0.550	0.674	0.237	0.204	0.291	0.692
2.000	0.823	0.480	0.714	0.196	0.155	0.291	1.476
5.000	1.402	0.388	1.076				
10.000	4.011	0.329	3.258				
15.000			9.796				
20.000			19.410				

m/mol kg^{-1}	$NiCl_2$	$Ni(ClO_4)_2$	$Ni(NO_3)_2$	$Pb(ClO_4)_2$	$Pb(NO_3)_2$	RbBr	RbCl
0.001	0.889	0.891	0.889	0.889	0.882	0.965	0.965
0.002	0.852	0.855	0.851	0.851	0.840	0.951	0.951
0.005	0.789	0.797	0.787	0.787	0.764	0.926	0.926
0.010	0.732	0.745	0.730	0.729	0.690	0.900	0.900
0.020	0.669	0.690	0.666	0.666	0.604	0.866	0.867
0.050	0.584	0.621	0.581	0.580	0.476	0.811	0.811
0.100	0.527	0.582	0.524	0.522	0.379	0.760	0.761
0.200	0.482	0.567	0.481	0.476	0.291	0.705	0.707
0.500	0.465	0.639	0.467	0.458	0.195	0.630	0.633
1.000	0.538	0.946	0.528	0.516	0.136	0.578	0.583
2.000	0.915	2.812	0.797	0.799		0.535	0.546
5.000	4.785			4.043		0.514	0.544
10.000				33.8			

m/mol kg^{-1}	RbF	RbI	$RbNO_3$	Rb_2SO_4	$SrBr_2$	$SrCl_2$	SrI_2
0.001	0.965	0.965	0.964	0.886	0.889	0.888	0.890
0.002	0.952	0.951	0.950	0.845	0.852	0.850	0.854
0.005	0.927	0.926	0.924	0.776	0.790	0.785	0.793
0.010	0.902	0.900	0.896	0.710	0.734	0.725	0.740
0.020	0.871	0.866	0.859	0.635	0.673	0.659	0.681

MEAN ACTIVITY COEFFICIENTS OF ELECTROLYTES AS A FUNCTION OF CONCENTRATION (continued)

m/mol kg^{-1}	RbF	RbI	$RbNO_3$	Rb_2SO_4	$SrBr_2$	$SrCl_2$	SrI_2
0.050	0.821	0.810	0.795	0.526	0.591	0.569	0.606
0.100	0.780	0.759	0.733	0.443	0.535	0.506	0.557
0.200	0.739	0.703	0.657	0.365	0.492	0.455	0.526
0.500	0.701	0.627	0.536	0.274	0.476	0.421	0.542
1.000	0.697	0.574	0.430	0.217	0.545	0.451	0.686
2.000	0.724	0.532	0.320		0.921	0.650	
5.000		0.517					

m/mol kg^{-1}	UO_2Cl_2	$UO_2(NO_3)_2$	$ZnBr_2$	$ZnCl_2$	ZnI_2
0.001	0.888	0.888	0.890	0.887	0.893
0.002	0.851	0.849	0.854	0.847	0.859
0.005	0.787	0.784	0.794	0.781	0.804
0.010	0.729	0.726	0.741	0.719	0.757
0.020	0.666	0.663	0.683	0.652	0.708
0.050	0.583	0.583	0.606	0.561	0.644
0.100	0.529	0.535	0.553	0.499	0.601
0.200	0.493	0.509	0.515	0.447	0.574
0.500	0.501	0.532	0.516	0.384	0.635
1.000	0.601	0.673	0.558	0.330	0.836
2.000	0.948	1.223	0.578	0.283	1.062
5.000		3.020	0.788	0.342	1.546
10.000			2.317	0.876	4.698
15.000			5.381	1.914	
20.000			7.965	2.968	

* The anion is $H_2PO_4^-$.
** The anion is HPO_4^{-2}.

ENTHALPY OF DILUTION OF ACIDS

The quantity given in this table is $-\Delta_{dil}H$, the negative of the enthalpy (heat) of dilution to infinite dilution for aqueous solutions of several common acids; i.e., the negative of the enthalphy change when a solution of molality *m* at a temperature of 25°C is diluted with an infinite amount of water. The tabulated numbers thus represent the heat produced (or, if the value is negative, the heat absorbed) when the acid is diluted. The initial molality *m* is given in the first column. The second column gives the dilution ratio, which is the number of moles of water that must be added to one mole of the acid to produce a solution of the molality in the first column.

REFERENCE

Parker, V. B., *Thermal Properties of Aqueous Uni-Univalent Electrolytes*, Natl. Stand. Ref. Data Ser. - Natl. Bur. Stand. (U.S.) 2, U.S. Government Printing Office, 1965.

$-\Delta_{dil}H$ in kJ/mol at 25°C

m	Dil. ratio	HF	HCl	$HClO_4$	HBr	HI	HNO_3	CH_2O_2	$C_2H_4O_2$
55.506	1.0		45.61		48.83		19.73	0.046	2.167
20	2.775	14.88	19.87	13.81	19.92	21.71	9.498	0.038	2.075
15	3.700	14.34	15.40	7.920	14.29	14.02	6.883	0.109	1.962
10	5.551	13.87	10.24	2.013	8.694	7.615	3.933	0.205	1.824
9	6.167	13.81	9.213	1.280	7.719	6.569	3.368	0.230	1.782
8	6.938	13.77	8.201	0.611	6.786	5.607	2.791	0.255	1.724
7	7.929	13.73	7.217	0.046	5.925	4.728	2.251	0.272	1.648
6	9.251	13.69	6.268	-0.351	5.004	3.975	1.749	0.280	1.540
5.5506	10	13.66	5.841	-0.490	4.590	3.577	1.540	0.285	1.477
5	11.10	13.62	5.318	-0.628	4.113	3.197	1.310	0.289	1.393
4.5	12.33	13.58	4.899	-0.732	3.711	2.828	1.109	0.289	1.310
4	13.88	13.53	4.402	-0.787	3.330	2.460	0.958	0.289	1.218
3.5	15.86	13.47	3.958	-0.820	2.966	2.105	0.791	0.289	1.121
3	18.50	13.45	3.506	-0.782	2.611	1.787	0.665	0.289	1.025
2.5	22.20	13.43	3.063	-0.724	2.301	1.527	0.582	0.285	0.912
2	27.75	13.40	2.623	-0.623	1.996	1.318	0.527	0.276	0.803
1.5	37.00	13.36	2.167	-0.431	1.665	1.125	0.506	0.259	0.678
1	55.51	13.30	1.695	-0.201	1.314	0.933	0.506	0.226	0.544
0.5551	100	13.22	1.234	0.050	0.983	0.736	0.502	0.184	0.423
0.5	111.0	13.20	1.172	0.075	0.941	0.711	0.498	0.176	0.406
0.2	277.5	13.09	0.761	0.247	0.649	0.536	0.439	0.146	0.331
0.1	555.1	12.80	0.556	0.272	0.498	0.439	0.372	0.134	0.289
0.0925	600	12.79	0.540	0.272	0.481	0.427	0.368	0.134	0.285
0.0793	700	12.70	0.502	0.272	0.452	0.402	0.351	0.134	0.285
0.0694	800	12.61	0.473	0.268	0.427	0.385	0.339	0.130	0.280
0.0617	900	12.50	0.448	0.264	0.406	0.368	0.326	0.126	0.276
0.05551	1000	12.42	0.427	0.259	0.385	0.351	0.318	0.121	0.272
0.05	1110	12.24	0.406	0.259	0.372	0.339	0.305	0.121	0.272
0.02775	2000	11.29	0.310	0.226	0.285	0.264	0.247	0.117	0.264
0.01850	3000	10.66	0.251	0.197	0.234	0.218	0.213	0.117	0.259
0.01388	4000	10.25	0.226	0.180	0.205	0.192	0.192	0.113	0.259
0.01110	5000	9.874	0.197	0.167	0.184	0.172	0.176	0.109	0.255
0.00555	10000	8.912	0.142	0.126	0.130	0.121	0.130	0.105	0.243
0.00278	20000	7.531	0.105	0.092	0.092	0.084	0.096	0.096	0.230
0.00111	50000	5.439	0.067	0.059	0.054	0.050	0.063	0.084	0.222
0.000555	100000	3.766	0.042	0.042	0.038	0.038	0.046	0.054	0.209
0.000111	500000	1.255	0.021	0.021	0.021	0.021	0.021	0.038	0.167
0	∞	0	0	0	0	0	0	0	0

ENTHALPY OF SOLUTION OF ELECTROLYTES

This table gives the molar enthalpy (heat) of solution at infinite dilution for some common uni-univalent electrolytes. This is the enthalpy change when 1 mol of solute in its standard state is dissolved in an infinite amount of water. Values are given in kilojoules per mole at 25°C.

REFERENCE

Parker, V. B., *Thermal Properties of Uni-Univalent Electrolytes*, Natl. Stand. Ref. Data Series — Natl. Bur. Stand.(U.S.), No.2, 1965.

Solute	State	$\Delta_{sol}H^\circ$ kJ/mol
HF	g	–61.50
HCl	g	–74.84
$HClO_4$	l	–88.76
$HClO_4 \cdot H_2O$	c	–32.95
HBr	g	–85.14
HI	g	–81.67
HIO_3	c	8.79
HNO_3	l	–33.28
HCOOH	l	–0.86
CH_3COOH	l	–1.51
NH_3	g	–30.50
NH_4Cl	c	14.78
NH_4ClO_4	c	33.47
NH_4Br	c	16.78
NH_4I	c	13.72
NH_4IO_3	c	31.80
NH_4NO_2	c	19.25
NH_4NO_3	c	25.69
$NH_4C_2H_3O_2$	c	–2.38
NH_4CN	c	17.57
NH_4CNS	c	22.59
CH_3NH_3Cl	c	5.77
$(CH_3)_3NHCl$	c	1.46
$N(CH_3)_4Cl$	c	4.08
$N(CH_3)_4Br$	c	24.27
$N(CH_3)_4I$	c	42.07
$AgClO_4$	c	7.36
$AgNO_2$	c	36.94
$AgNO_3$	c	22.59
LiOH	c	–23.56
$LiOH \cdot H_2O$	c	–6.69
LiF	c	4.73
LiCl	c	–37.03
$LiCl \cdot H_2O$	c	–19.08
$LiClO_4$	c	–26.55
$LiClO_4 \cdot 3H_2O$	c	32.61
LiBr	c	–48.83
$LiBr \cdot H_2O$	c	–23.26
$LiBr \cdot 2H_2O$	c	–9.41
$LiBrO_3$	c	1.42
LiI	c	–63.30
$LiI \cdot H_2O$	c	–29.66
$LiI \cdot 2H_2O$	c	–14.77
$LiI \cdot 3H_2O$	c	0.59
$LiNO_2$	c	–11.00
$LiNO_2 \cdot H_2O$	c	7.03
$LiNO_3$	c	–2.51
NaOH	c	–44.51
$NaOH \cdot H_2O$	c	–21.41
NaF	c	0.91
NaCl	c	3.88
$NaClO_2$	c	0.33
$NaClO_2 \cdot 3H_2O$	c	28.58
$NaClO_3$	c	21.72
$NaClO_4$	c	13.88
$NaClO_4 \cdot H_2O$	c	22.51
NaBr	c	–0.60
$NaBr \cdot 2H_2O$	c	18.64
$NaBrO_3$	c	26.90
NaI	c	–7.53
$NaI \cdot 2H_2O$	c	16.13
$NaIO_3$	c	20.29
$NaNO_2$	c	13.89
$NaNO_3$	c	20.50
$NaC_2H_3O_2$	c	–17.32
$NaC_2H_3O_2 \cdot 3H_2O$	c	19.66
NaCN	c	1.21
$NaCN \cdot 0.5H_2O$	c	3.31
$NaCN \cdot 2H_2O$	c	18.58
NaCNO	c	19.20
NaCNS	c	6.83
KOH	c	–57.61
$KOH \cdot H_2O$	c	–14.64
$KOH \cdot 1.5H_2O$	c	–10.46
KF	c	–17.73
$KF \cdot 2H_2O$	c	6.97
KCl	c	17.22
$KClO_3$	c	41.38
$KClO_4$	c	51.04
KBr	c	19.87
$KBrO_3$	c	41.13
KI	c	20.33
KIO_3	c	27.74
KNO_2	c	13.35
KNO_3	c	34.89
$KC_2H_3O_2$	c	–15.33
KCN	c	11.72
KCNO	c	20.25
KCNS	c	24.23
$KMnO_4$	c	43.56
RbOH	c	–62.34
$RbOH \cdot H_2O$	c	–17.99
$RbOH \cdot 2H_2O$	c	0.88
RbF	c	–26.11
$RbF \cdot H_2O$	c	–0.42
$RbF \cdot 1.5H_2O$	c	1.34
RbCl	c	17.28
$RbClO_3$	c	47.74
$RbClO_4$	c	56.74
RbBr	c	21.88
$RbBrO_3$	c	48.95
RbI	c	25.10
$RbNO_3$	c	36.48
CsOH	c	–71.55
$CsOH \cdot H_2O$	c	–20.50
CsF	c	–36.86
$CsF \cdot H_2O$	c	–10.46
$CsF \cdot 1.5H_2O$	c	–5.44
CsCl	c	17.78
$CsClO_4$	c	55.44
CsBr	c	25.98
$CsBrO_3$	c	50.46
CsI	c	33.35
$CsNO_3$	c	40.00

CHEMICAL KINETIC DATA FOR STRATOSPHERIC MODELING

The present compilation of kinetic data represents the 12th evaluation prepared by the NASA Panel for Data Evaluation. The Panel was established in 1977 by the NASA Upper Atmosphere Research Program Office for the purpose of providing a critical tabulation of the latest kinetic and photochemical data for use by modelers in computer simulations of stratospheric chemistry. The recommended rate data and cross sections are based on laboratory measurements. The major use of theoretical extrapolation of data is in connection with three-body reactions, in which the required pressure or temperature dependence is sometimes unavailable from laboratory measurements, and can be estimated by use of appropriate theoretical treatment. In the case of important rate constants for which no experimental data are available, the panel may provide estimates of rate constant parameters based on analogy to similar reactions for which data are available.

Rate constants are expressed in the form $k(T) = A \exp(-E/RT)$, where A is the pre-exponential factor, E the activation energy, R the gas constant, and T the absolute temperature. Uncertainties are expressed by the factor f, e.g., a value of 4.2×10^{-10} with $f = 2$ indicates that the true value is believed to lie between 2.1×10^{-10} and 8.4×10^{-10}. The value of f at other temperatures may be calculated from $f(298)$, given in the last column, by:

$$f(T) = f(298) \exp[(\Delta E/R)(1/T - 1/298)] ,$$

where $\Delta E/R$ is the uncertainty in E/R.

Table 1 covers rate constant data on second order reactions, grouped by class, while Table 2 covers association reactions. Relevant equilibrium constant data are given in Table 3. All concentrations are measured in molecules cm^{-3}. Notes on each reaction, as well as related photochemical data, may be found in the reference.

The assistance of Robert Hampson is gratefully acknowledged.

REFERENCE

DeMore, W. B., Sander, S. P., Golden, D. M., Hampson, R. F., Kurylo, M. J., Howard, C. J., Ravishankara, A. R., Kolb, C. E., and Molina, M. J., *Chemical Kinetics and Photochemical Data for use in Atmospheric Modeling. Evaluation Number 12*, Jet Propulsion Laboratory Publication 97-4, Pasadena CA, 1997.

The report is also available at the World Wide Web site < http://remus.jpl.nasa.gov/pub/jpl97>.

Table 1. Rate Constants for Second Order Reactions

Reaction	*A* cm³ molecule⁻¹ s⁻¹	*E/R* K	*k* (298 K) cm³ molecule⁻¹ s⁻¹	*f*(298)
O_x Reactions				
$O + O_3 \rightarrow O_2 + O_2$	8.0×10^{-12}	2060±250	8.0×10^{-15}	1.15
$O(^1D)$ Reactions				
$O(^1D) + O_2 \rightarrow O + O_2$	3.2×10^{-11}	-(70±100)	4.0×10^{-11}	1.2
$O(^1D) + O_3 \rightarrow O_2 + O_2$	1.2×10^{-10}	0±100	1.2×10^{-10}	1.3
$\rightarrow O_2 + O + O$	1.2×10^{-10}	0±100	1.2×10^{-10}	1.3
$O(^1D) + H_2 \rightarrow OH + H$	1.1×10^{-10}	0±100	1.1×10^{-10}	1.1
$O(^1D) + H_2O \rightarrow OH + OH$	2.2×10^{-10}	0±100	2.2×10^{-10}	1.2
$O(^1D) + N_2 \rightarrow O + N_2$	1.8×10^{-11}	-(110±100)	2.6×10^{-11}	1.2
$O(^1D) + N_2O \rightarrow N_2 + O_2$	4.9×10^{-11}	0±100	4.9×10^{-11}	1.3
$\rightarrow NO + NO$	6.7×10^{-11}	0±100	6.7×10^{-11}	1.3
$O(^1D) + NH_3 \rightarrow OH + NH_2$	2.5×10^{-10}	0±100	2.5×10^{-10}	1.3
$O(^1D) + CO_2 \rightarrow O + CO_2$	7.4×10^{-11}	-(120±100)	1.1×10^{-10}	1.2
$O(^1D) + CH_4 \rightarrow$ products	1.5×10^{-10}	0±100	1.5×10^{-10}	1.2
$O(^1D) + HCl \rightarrow$ products	1.5×10^{-10}	0±100	1.5×10^{-10}	1.2
$O(^1D) + HF \rightarrow OH + F$	1.4×10^{-10}	0±100	1.4×10^{-10}	2.0
$O(^1D) + HBr \rightarrow$ products	1.5×10^{-10}	0±100	1.5×10^{-10}	2.0
$O(^1D) + Cl_2 \rightarrow$ products	2.8×10^{-10}	0±100	2.8×10^{-10}	2.0
$O(^1D) + CCl_2O \rightarrow$ products	3.6×10^{-10}	0±100	3.6×10^{-10}	2.0
$O(^1D) + CClFO \rightarrow$ products	1.9×10^{-10}	0±100	1.9×10^{-10}	2.0
$O(^1D) + CF_2O \rightarrow$ products	7.4×10^{-11}	0±100	7.4×10^{-11}	2.0
$O(^1D) + CCl_4 \rightarrow$ products (CFC-10)	3.3×10^{-10}	0±100	3.3×10^{-10}	1.2
$O(^1D) + CH_3Br \rightarrow$ products	1.8×10^{-10}	0±100	1.8×10^{-10}	1.3
$O(^1D) + CH_2Br_2 \rightarrow$ products	2.7×10^{-10}	0±100	2.7×10^{-10}	1.3
$O(^1D) + CHBr_3 \rightarrow$ products	6.6×10^{-10}	0±100	6.6×10^{-10}	1.5
$O(^1D) + CH_3F \rightarrow$ products (HFC-41)	1.5×10^{-10}	0±100	1.5×10^{-10}	1.2

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	*A* cm^3 molecule^{-1} s^{-1}	*E*/*R* K	*k* (298 K) cm^3 molecule^{-1} s^{-1}	*f*(298)
$O(^1D) + CH_2F_2 \rightarrow$ products (HFC-32)	5.1×10^{-11}	0±100	5.1×10^{-11}	1.3
$O(^1D) + CHF_3 \rightarrow$ products (HFC-23)	9.1×10^{-12}	0±100	9.1×10^{-12}	1.2
$O(^1D) + CHCl_2F \rightarrow$ products (HCFC-21)	1.9×10^{-10}	0±100	1.9×10^{-10}	1.3
$O(^1D) + CHClF_2 \rightarrow$ products (HCFC-22)	1.0×10^{-10}	0±100	1.0×10^{-10}	1.2
$O(^1D) + CCl_3F \rightarrow$ products (CFC-11)	2.3×10^{-10}	0±100	2.3×10^{-10}	1.2
$O(^1D) + CCl_2F_2 \rightarrow$ products (CFC-12)	1.4×10^{-10}	0±100	1.4×10^{-10}	1.3
$O(^1D) + CClF_3 \rightarrow$ products (CFC-13)	8.7×10^{-11}	0±100	8.7×10^{-11}	1.3
$O(^1D) + CClBrF_2 \rightarrow$ products (Halon-1211)	1.5×10^{-10}	0±100	1.5×10^{-10}	1.3
$O(^1D) + CBr_2F_2 \rightarrow$ products (Halon-1202)	2.2×10^{-10}	0±100	2.2×10^{-10}	1.3
$O(^1D) + CBrF_3 \rightarrow$ products (Halon-1301)	1.0×10^{-10}	0±100	1.0×10^{-10}	1.3
$O(^1D) + CF_4 \rightarrow CF_4 + O$ (CFC-14)	-	-	2.0×10^{-14}	1.5
$O(^1D) + CH_3CH_2F \rightarrow$ products (HFC-161)	2.6×10^{-10}	0±100	2.6×10^{-10}	1.3
$O(^1D) + CH_3CHF_2 \rightarrow$ products (HFC-152a)	2.0×10^{-10}	0±100	2.0×10^{-10}	1.3
$O(^1D) + CH_3CCl_2F \rightarrow$ products (HCFC-141b)	2.6×10^{-10}	0±100	2.6×10^{-10}	1.3
$O(^1D) + CH_3CClF_2 \rightarrow$ products (HCFC-142b)	2.2×10^{-10}	0±100	2.2×10^{-10}	1.3
$O(^1D) + CH_3CF_3 \rightarrow$ products (HFC-143a)	1.0×10^{-10}	0±100	1.0×10^{-10}	3.0
$O(^1D) + CH_2ClCClF_2 \rightarrow$ products (HCFC-132b)	1.6×10^{-10}	0±100	1.6×10^{-10}	2.0
$O(^1D) + CH_2ClCF_3 \rightarrow$ products (HCFC-133a)	1.2×10^{-10}	0±100	1.2×10^{-10}	1.3
$O(^1D) + CH_2FCF_3 \rightarrow$ products (HFC-134a)	4.9×10^{-11}	0±100	4.9×10^{-11}	1.3
$O(^1D) + CHCl_2CF_3 \rightarrow$ products (HCFC-123)	2.0×10^{-10}	0±100	2.0×10^{-10}	1.3
$O(^1D) + CHClFCF_3 \rightarrow$ products (HCFC-124)	8.6×10^{-11}	0±100	8.6×10^{-11}	1.3
$O(^1D) + CHF_2CF_3 \rightarrow$ products (HFC-125)	1.2×10^{-10}	0±100	1.2×10^{-10}	2.0
$O(^1D) + CCl_3CF_3 \rightarrow$ products (CFC-113a)	2×10^{-10}	0±100	2×10^{-10}	2.0
$O(^1D) + CCl_2FCClF_2 \rightarrow$ products (CFC-113)	2×10^{-10}	0±100	2×10^{-10}	2.0
$O(^1D) + CCl_2FCF_3 \rightarrow$ products (CFC-114a)	1×10^{-10}	0±100	1×10^{-10}	2.0
$O(^1D) + CClF_2CClF_2 \rightarrow$ products (CFC-114)	1.3×10^{-10}	0±100	1.3×10^{-10}	1.3
$O(^1D) + CClF_2CF_3 \rightarrow$ products (CFC-115)	5×10^{-11}	0±100	5×10^{-11}	1.3
$O(^1D) + CBrF_2CBrF_2 \rightarrow$ products (Halon-2402)	1.6×10^{-10}	0±100	1.6×10^{-10}	1.3

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	*A* cm^3 molecule^{-1} s^{-1}	*E/R* K	*k* (298 K) cm^3 molecule^{-1} s^{-1}	*f*(298)
$O(^1D) + CF_3CF_3 \rightarrow O + CF_3CF_3$ (CFC-116)	-	-	$1.5x10^{-13}$	1.5
$O(^1D) + CHF_2CF_2CF_2CHF_2 \rightarrow$ products (HFC-338pcc)	$1.8x10^{-11}$	0±100	$1.8x10^{-11}$	1.5
$O(^1D) + c\text{-}C_4F_8 \rightarrow$ products	-	-	$8x10^{-13}$	1.3
$O(^1D) + CF_3CHFCHFCF_2CF_3 \rightarrow$ products (HFC-43-10mee)	$2.1x10^{-10}$	0±100	$2.1x10^{-10}$	4
$O(^1D) + C_5F_{12} \rightarrow$ products (CFC-41-12)	-	-	$3.9x10^{-13}$	2
$O(^1D) + C_6F_{14} \rightarrow$ products (CFC-51-14)	-	-	$1x10^{-12}$	2
$O(^1D) + 1,2\text{-}(CF_3)_2c\text{-}C_4F_6 \rightarrow$ products	-	-	$2.8x10^{-13}$	2
$O(^1D) + SF_6 \rightarrow$ products	-	-	$1.8x10^{-14}$	1.5
Singlet O_2 Reactions				
$O_2(^1\Delta) + O \rightarrow$ products	-	-	$<2x10^{-16}$	-
$O_2(^1\Delta) + O_2 \rightarrow$ products	$3.6x10^{-18}$	220±100	$1.7x10^{-18}$	1.2
$O_2(^1\Delta) + O_3 \rightarrow O + 2O_2$	$5.2x10^{-11}$	2840±500	$3.8x10^{-15}$	1.2
$O_2(^1\Delta) + H_2O \rightarrow$ products	-	-	$4.8x10^{-18}$	1.5
$O_2(^1\Delta) + N \rightarrow NO + O$	-	-	$<9x10^{-17}$	-
$O_2(^1\Delta) + N_2 \rightarrow$ products	-	-	$<10^{-20}$	-
$O_2(^1\Delta) + CO_2 \rightarrow$ products	-	-	$<2x10^{-20}$	-
$O_2(^1\Sigma) + O \rightarrow$ products	-	-	$8x10^{-14}$	5.0
$O_2(^1\Sigma) + O_2 \rightarrow$ products	-	-	$3.9x10^{-17}$	1.5
$O_2(^1\Sigma) + O_3 \rightarrow$ products	$2.2x10^{-11}$	0±200	$2.2x10^{-11}$	1.2
$O_2(^1\Sigma) + H_2O \rightarrow$ products	-	-	$5.4x10^{-12}$	1.3
$O_2(^1\Sigma) + N \rightarrow$ products	-	-	$<10^{-13}$	-
$O_2(^1\Sigma) + N_2 \rightarrow$ products	$2.1x10^{-15}$	0±200	$2.1x10^{-15}$	1.2
$O_2(^1\Sigma) + CO_2 \rightarrow$ products	$4.2x10^{-13}$	0±200	$4.2x10^{-13}$	1.2
HO_x Reactions				
$O + OH \rightarrow O_2 + H$	$2.2x10^{-11}$	-(120±100)	$3.3x10^{-11}$	1.2
$O + HO_2 \rightarrow OH + O_2$	$3.0x10^{-11}$	-(200±100)	$5.9x10^{-11}$	1.2
$O + H_2O_2 \rightarrow OH + HO_2$	$1.4x10^{-12}$	2000±1000	$1.7x10^{-15}$	2.0
$H + O_3 \rightarrow OH + O_2$	$1.4x10^{-10}$	470±200	$2.9x10^{-11}$	1.25
$H + HO_2 \rightarrow$ products	$8.1x10^{-11}$	0±100	$8.1x10^{-11}$	1.3
$OH + O_3 \rightarrow HO_2 + O_2$	$1.6x10^{-12}$	940±300	$6.8x10^{-14}$	1.3
$OH + H_2 \rightarrow H_2O + H$	$5.5x10^{-12}$	2000±100	$6.7x10^{-15}$	1.1
$OH + HD \rightarrow$ products	$5.0x10^{-12}$	2130±200	$4.0x10^{-15}$	1.2
$OH + OH \rightarrow H_2O + O$	$4.2x10^{-12}$	240±240	$1.9x10^{-12}$	1.4
$OH + HO_2 \rightarrow H_2O + O_2$	$4.8x10^{-11}$	-(250±200)	$1.1x10^{-10}$	1.3
$OH + H_2O_2 \rightarrow H_2O + HO_2$	$2.9x10^{-12}$	160±100	$1.7x10^{-12}$	1.2
$HO_2 + O_3 \rightarrow OH + 2O_2$	$1.1x10^{-14}$	500±	$2.0x10^{-15}$	1.3
$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$	$2.3x10^{-13}$	-(600±200)	$1.7x10^{-12}$	1.3
$H_2O_2 + O_2$	$1.7x10^{-33}$[M]	-(1000±400)	$4.9x10^{-32}$[M]	1.3
NO_x Reactions				
$O + NO_2 \rightarrow NO + O_2$	$6.5x10^{-12}$	-(120±120)	$9.7x10^{-12}$	1.1
$O + NO_3 \rightarrow O_2 + NO_2$	$1.0x10^{-11}$	0±150	$1.0x10^{-11}$	1.5
$O + N_2O_5 \rightarrow$ products			$<3.0x10^{-16}$	
$O + HNO_3 \rightarrow OH + NO_3$			$<3.0x10^{-17}$	
$O + HO_2NO_2 \rightarrow$ products	$7.8x10^{-11}$	3400±750	$8.6x10^{-16}$	3.0

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	*A* cm^3 molecule^{-1} s^{-1}	*E*/*R* K	*k* (298 K) cm^3 molecule^{-1} s^{-1}	*f*(298)
$H + NO_2 \rightarrow OH + NO$	4.0x10^{-10}	340±300	1.3x10^{-10}	1.3
$OH + NO_3 \rightarrow$ products			2.2x10^{-11}	1.5
$OH + HONO \rightarrow H_2O + NO_2$	1.8x10^{-11}	390±	4.5x10^{-12}	1.5
$OH + HNO_3 \rightarrow H_2O + NO_3$	See reference	1.3		
$OH + HO_2NO_2 \rightarrow$ products	1.3x10^{-12}	-(380±)	4.6x10^{-12}	1.5
$OH + NH_3 \rightarrow H_2O + NH_2$	1.7x10^{-12}	710±200	1.6x10^{-13}	1.2
$HO_2 + NO \rightarrow NO_2 + OH$	3.5x10^{-12}	-(250±50)	8.1x10^{-12}	1.15
$HO_2 + NO_2 \rightarrow HONO + O_2$	See reference			
$HO_2 + NO_3 \rightarrow$ products			3.5x10^{-12}	1.5
$HO_2 + NH_2 \rightarrow$ products			3.4x10^{-11}	2.0
$N + O_2 \rightarrow NO + O$	1.5x10^{-11}	3600±400	8.5x10^{-17}	1.25
$N + O_3 \rightarrow NO + O_2$			<2.0x10^{-16}	
$N + NO \rightarrow N_2 + O$	2.1x10^{-11}	-(100±100)	3.0x10^{-11}	1.3
$N + NO_2 \rightarrow N_2O + O$	5.8x10^{-12}	-(220±100)	1.2x10^{-11}	1.5
$NO + O_3 \rightarrow NO_2 + O_2$	2.0x10^{-12}	1400±200	1.8x10^{-14}	1.1
$NO + NO_3 \rightarrow 2NO_2$	1.5x10^{-11}	-(170±100)	2.6x10^{-11}	1.3
$NO_2 + O_3 \rightarrow NO_3 + O_2$	1.2x10^{-13}	2450±150	3.2x10^{-17}	1.15
$NO_2 + NO_3 \rightarrow NO + NO_2 + O_2$	See reference			
$NO_3 + NO_3 \rightarrow 2NO_2 + O_2$	8.5x10^{-13}	2450±500	2.3x10^{-16}	1.5
$NH_2 + O_2 \rightarrow$ products			<6.0x10^{-21}	
$NH_2 + O_3 \rightarrow$ products	4.3x10^{-12}	930±500	1.9x10^{-13}	3.0
$NH_2 + NO \rightarrow$ products	4.0x10^{-12}	-(450±150)	1.8x10^{-11}	1.3
$NH_2 + NO_2 \rightarrow$ products	2.1x10^{-12}	-(650±250)	1.9x10^{-11}	3.0
$NH + NO \rightarrow$ products	4.9x10^{-11}	0±300	4.9x10^{-11}	1.5
$NH + NO_2 \rightarrow$ products	3.5x10^{-13}	-(1140±500)	1.6x10^{-11}	2.0
$O_3 + HNO_2 \rightarrow O_2 + HNO_3$			<5.0x10^{-19}	
$N_2O_5 + H_2O \rightarrow 2HNO_3$			<2.0x10^{-21}	
$N_2(A,v) + O_2 \rightarrow$ products			2.5x10^{-12}, v=0	1.5
$N_2(A,v) + O_3 \rightarrow$ products			4.1x10^{-11}, v=0	2.0
Reactions of Organic Compounds				
$O + CH_3 \rightarrow$ products	1.1x10^{-10}	0±250	1.1x10^{-10}	1.3
$O + HCN \rightarrow$ products	1.0x10^{-11}	4000±1000	1.5x10^{-17}	10
$O + C_2H_2 \rightarrow$ products	3.0x10^{-11}	1600±250	1.4x10^{-13}	1.3
$O + H_2CO \rightarrow$ products	3.4x10^{-11}	1600±250	1.6x10^{-13}	1.25
$O + CH_3CHO \rightarrow CH_3CO + OH$	1.8x10^{-11}	1100±200	4.5x10^{-13}	1.25
$O_3 + C_2H_2 \rightarrow$ products	1.0x10^{-14}	4100±500	1.0x10^{-20}	3
$O_3 + C_2H_4 \rightarrow$ products	1.2x10^{-14}	2630±100	1.7x10^{-18}	1.25
$O_3 + C_3H_6 \rightarrow$ products	6.5x10^{-15}	1900±200	1.1x10^{-17}	1.2
$OH + CO \rightarrow$ Products	1.5x10^{-13} x (1+0.6P_{atm})	0±300	1.5x10^{-13} x (1+0.6P_{atm})	1.3
$OH + CH_4 \rightarrow CH_3 + H_2O$	2.45x10^{-12}	1775±100	6.3x10^{-15}	1.1
$OH + {}^{13}CH_4 \rightarrow {}^{13}CH_3 + H_2O$	See reference			
$OH + CH_3D \rightarrow$ products	3.5x10^{-12}	1950 ± 200	5.0x10^{-15}	1.15
$OH + H_2CO \rightarrow H_2O + HCO$	1.0x10^{-11}	0±200	1.0x10^{-11}	1.25
$OH + CH_3OH \rightarrow$ products	6.7x10^{-12}	600±300	8.9x10^{-13}	1.2
$OH + CH_3OOH \rightarrow$ Products	3.8x10^{-12}	-(200±200)	7.4x10^{-12}	1.5
$OH + HC(O)OH \rightarrow$ products	4.0x10^{-13}	0±200	4.0x10^{-13}	1.3
$OH + HCN \rightarrow$ products	1.2x10^{-13}	400±150	3.1x10^{-14}	3
$OH + C_2H_6 \rightarrow H_2O + C_2H_5$	8.7 x 10^{-12}	1070±100	2.4x10^{-13}	1.1
$OH + C_3H_8 \rightarrow H_2O + C_3H_7$	1.0 x 10^{-11}	660±100	1.1x10^{-12}	1.2
$OH + CH_3CHO \rightarrow CH_3CO + H_2O$	5.6x10^{-12}	-(270±200)	1.4x10^{-11}	1.2
$OH + C_2H_5OH \rightarrow$ products	7.0x10^{-12}	235±100	3.2x10^{-12}	1.3
$OH + CH_3C(O)OH \rightarrow$ products	4.0x10^{-13}	-(200±400)	8.0x10^{-13}	1.3

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	*A* cm^3 molecule^{-1} s^{-1}	*E*/*R* K	*k* (298 K) cm^3 molecule^{-1} s^{-1}	*f*(298)
$OH + CH_3C(O)CH_3 \rightarrow CH_3C(O)CH_2 + H_2O$	2.2 x 10^{-12}	685±100	2.2x10^{-13}	1.15
$OH + CH_3CN \rightarrow$ products	7.8x10^{-13}	1050±200	2.3x10^{-14}	1.5
$OH + CH_3ONO_2 \rightarrow$ products	5.0x10^{-13}	890±500	2.4x10^{-14}	3
$OH + CH_3C(O)O_2NO_2$ (PAN) $\rightarrow$ products			<4 x 10^{-14}	
$OH + C_2H_5ONO_2 \rightarrow$ products	8.2x10^{-13}	450±300	1.8x10^{-13}	3
$HO_2 + CH_2O \rightarrow$ adduct	6.7x10^{-15}	-(600±600)	5.0x10^{-14}	5
$HO_2 + CH_3O_2 \rightarrow CH_3OOH + O_2$	3.8x10^{-13}	-(800±400)	5.6x10^{-12}	2
$HO_2 + C_2H_5O_2 \rightarrow C_2H_5OOH + O_2$	7.5x10^{-13}	-(700±250)	8.0x10^{-12}	1.5
$HO_2 + CH_3C(O)O_2 \rightarrow$ products	4.5x10^{-13}	-(1000±600)	1.3x10^{-11}	2
$NO_3 + CO \rightarrow$ products			<4.0x10^{-19}	
$NO_3 + CH_2O \rightarrow$ products			5.8x10^{-16}	1.3
$NO_3 + CH_3CHO \rightarrow$ products	1.4x10^{-12}	1900±300	2.4x10^{-15}	1.3
$CH_3 + O_2 \rightarrow$ products			<3.0x10^{-16}	
$CH_3 + O_3 \rightarrow$ products	5.4x10^{-12}	220±150	2.6x10^{-12}	2
$HCO + O_2 \rightarrow CO + HO_2$	3.5x10^{-12}	-(140±140)	5.5x10^{-12}	1.3
$CH_2OH + O_2 \rightarrow CH_2O + HO_2$	9.1x10^{-12}	0±200	9.1x10^{-12}	1.3
$CH_3O + O_2 \rightarrow CH_2O + HO_2$	3.9x10^{-14}	900±300	1.9x10^{-15}	1.5
$CH_3O + NO \rightarrow CH_2O + HNO$	See reference			
$CH_3O + NO_2 \rightarrow CH_2O + HONO$	1.1 x 10^{-11}	1200±600	2.0 x 10^{-13}	5
$CH_3O_2 + O_3 \rightarrow$ products			<3.0x10^{-17}	
$CH_3O_2 + CH_3O_2 \rightarrow$ products	2.5x10^{-13}	-(190±190)	4.7x10^{-13}	1.5
$CH_3O_2 + NO \rightarrow CH_3O + NO_2$	3.0x10^{-12}	-(280±60)	7.7x10^{-12}	1.15
$CH_3O_2 + CH_3C(O)O_2 \rightarrow$ products	1.3x10^{-12}	-(640±200)	1.1x10^{-11}	1.5
$C_2H_5 + O_2 \rightarrow C_2H_4 + HO_2$			<2.0x10^{-14}	
$C_2H_5O + O_2 \rightarrow CH_3CHO + HO_2$	6.3 x 10^{-14}	550±200	1.0x10^{-14}	1.5
$C_2H_5O_2 + C_2H_5O_2 \rightarrow$ products	6.8x10^{-14}	0±300	6.8x10^{-14}	2
$C_2H_5O_2 + NO \rightarrow$ products	2.6x10^{-12}	-(365±150)	8.7x10^{-12}	1.2
$CH_3C(O)O_2 + CH_3C(O)O_2 \rightarrow$ products	2.9x10^{-12}	-(500±150)	1.5x10^{-11}	1.5
$CH_3C(O)O_2 + NO \rightarrow$ products	5.3x10^{-12}	-(360±150)	1.8x10^{-11}	1.4
FO_x Reactions				
$O + FO \rightarrow F + O_2$	2.7x10^{-11}	0±250	2.7x10^{-11}	3.0
$O + FO_2 \rightarrow FO + O_2$	5.0x10^{-11}	0±250	5.0x10^{-11}	5.0
$OH + CH_3F \rightarrow CH_2F + H_2O$ (HFC-41)	3.0x10^{-12}	1500±300	2.0x10^{-14}	1.1
$OH + CH_2F_2 \rightarrow CHF_2 + H_2O$ (HFC-32)	1.9x10^{-12}	1550±200	1.0x10^{-14}	1.2
$OH + CHF_3 \rightarrow CF_3 + H_2O$ (HFC-23)	1.0x10^{-12}	2440±200	2.8x10^{-16}	1.3
$OH + CF_3OH \rightarrow CF_3O + H_2O$			<2x10^{-17}	
$OH + CH_3CH_2F \rightarrow$ products (HFC-161)	7.0x10^{-12}	1100±300	1.7x10^{-13}	1.4
$OH + CH_3CHF_2 \rightarrow$ products (HFC-152a)	2.4x10^{-12}	1260±200	3.5x10^{-14}	1.2
$OH + CH_2FCH_2F \rightarrow CHFCH_2F + H_2O$ (HFC-152)	1.7x10^{-11}	1500±500	1.1x10^{-13}	2.0
$OH + CH_3CF_3 \rightarrow CH_2CF_3 + H_2O$ (HFC-143a)	1.8x10^{-12}	2170±150	1.2x10^{-15}	1.1
$OH + CH_2FCHF_2 \rightarrow$ products (HFC-143)	4.0x10^{-12}	1650±300	1.6x10^{-14}	1.5
$OH + CH_2FCF_3 \rightarrow CHFCF_3 + H_2O$ (HFC-134a)	1.5x10^{-12}	1750±200	4.2x10^{-15}	1.1

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	*A* cm^3 molecule^{-1} s^{-1}	*E*/*R* K	*k* (298 K) cm^3 molecule^{-1} s^{-1}	*f*(298)
OH + CHF_2CHF_2 → CF_2CHF_2 + H_2O (HFC-134)	1.6x10^{-12}	1680±300	5.7x10^{-15}	2.0
OH + CHF_2CF_3 → CF_2CF_3 + H_2O (HFC-125)	5.6x10^{-13}	1700±300	1.9x10^{-15}	1.3
OH + CH_3OCHF_2 → products (HFOC-152a)	6.0x10^{-12}	1530±150	3.5x10^{-14}	1.2
OH + CF_3OCH_3 → CF_3OCH_2 + H_2O (HFOC-143a)	1.5x10^{-12}	1450±150	1.2x10^{-14}	1.1
OH + CF_2HOCF_2H → CF_2OCF_2H + H_2O (HFOC-134)	1.9x10^{-12}	2000±150	2.3x10^{-15}	1.2
OH + CF_3OCHF_2 → CF_3OCF_2 + H_2O (HFOC-125)	4.7x10^{-13}	2100±300	4.1x10^{-16}	1.2
OH + $CF_3CH_2CH_3$ → products (HFC-263fb)	-	-	4.2x10^{-14}	1.5
OH + $CH_2FCF_2CHF_2$ → products (HFC-245ca)	2.4x10^{-12}	1660±150	9.1x10^{-15}	1.3
OH + $CHF_2CHFCHF_2$ → products (HFC-245ea)	-	-	1.6x10^{-14}	2.0
OH + CF_3CHFCH_2F → products (HFC-245eb)	-	-	1.5x10^{-14}	2.0
OH + $CHF_2CH_2CF_3$ → products (HFC-245fa)	6.1x10^{-13}	1330±150	7.0x10^{-15}	1.2
OH + $CF_3CF_2CH_2F$ → CF_3CF_2CHF + H_2O (HFC-236cb)	1.5x10^{-12}	1750±500	4.2x10^{-15}	2.0
OH + $CF_3CHFCHF_2$ → products (HFC-236ea)	1.1x10^{-12}	1590±150	5.3x10^{-15}	1.1
OH + $CF_3CH_2CF_3$ → CF_3CHCF_3 + H_2O (HFC-236fa)	1.3x10^{-12}	2480±150	3.2x10^{-16}	1.1
OH + CF_3CHFCF_3 → CF_3CFCF_3+H_2O (HFC-227ea)	5.0x10^{-13}	1700±300	1.7x10^{-15}	1.1
OH + $CHF_2OCH_2CF_3$ → products (HFOC-245fa)	2.6x10^{-12}	1610±150	1.2x10^{-14}	2.0
OH + $CF_3CH_2CF_2CH_3$ → products (HFC-365mfc)	2.0x10^{-12}	1750±200	5.7x10^{-15}	1.3
OH + $CF_3CH_2CH_2CF_3$ → products (HFC-356mff)	3.0x10^{-12}	1800±300	7.1x10^{-15}	1.3
OH + $CF_3CF_2CH_2CH_2F$ → products (HFC-356mcf)	1.7x10^{-12}	1110±200	4.2x10^{-14}	2.0
OH + $CHF_2CF_2CF_2CF_2H$ → products (HFC-338pcc)	7.8x10^{-13}	1530±200	4.6x10^{-15}	1.5
OH + $CF_3CH_2CF_2CH_2CF_3$ → products (HFC-458mfcf)	1.2x10^{-12}	1830±200	2.6x10^{-15}	2.0
OH + $CF_3CHFCHFCF_2CF_3$ → products (HFC-43-10mee)	5.2x10^{-13}	1500±300	3.4x10^{-15}	1.3
OH + $CF_3CF_2CH_2CH_2CF_2CF_3$ → products (HFC-55-10-mcff)	-	-	8.3x10^{-15}	1.5
F + O_3 → FO + O_2	2.2x10^{-11}	230±200	1.0x10^{-11}	1.5
F + H_2 → HF + H	1.4x10^{-10}	500±200	2.6x10^{-11}	1.2
F + H_2O → HF + OH	1.4x10^{-11}	0±200	1.4x10^{-11}	1.3
F + HNO_3 → HF + NO_3	6.0x10^{-12}	-(400±200)	2.3x10^{-11}	1.3
F + CH_4 → HF + CH_3	1.6x10^{-10}	260±200	6.7x10^{-11}	1.4
FO + O_3 → products			<1 x 10^{-14}	
FO + NO → NO_2 + F	8.2x10^{-12}	-(300±200)	2.2x10^{-11}	1.5
FO + FO → 2 F + O_2	1.0x10^{-11}	0±250	1.0x10^{-11}	1.5
FO_2 + O_3 → products			<3.4x10^{-16}	
FO_2 + NO → FNO + O_2	7.5x10^{-12}	690±400	7.5x10^{-13}	2.0

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	*A* cm^3 molecule^{-1} s^{-1}	*E*/*R* K	*k* (298 K) cm^3 molecule^{-1} s^{-1}	*f*(298)
$FO_2 + NO_2 \rightarrow$ products	3.8x10^{-11}	2040±500	4.0x10^{-14}	2.0
$FO_2 + CO \rightarrow$ products			<5.1x10^{-16}	
$FO_2 + CH_4 \rightarrow$ products			<2x10^{-16}	
$CF_3O + O_2 \rightarrow FO_2 + CF_2O$	<3 x 10^{-11}	5000	<1.5 x 10^{-18}	
$CF_3O + O_3 \rightarrow CF_3O_2 + O_2$	2 x 10^{-12}	1400±600	1.8 x 10^{-14}	1.3
$CF_3O + H_2O \rightarrow OH + CF_3OH$	3 x 10^{-12}	>3600	<2 x 10^{-17}	
$CF_3O + NO \rightarrow CF_2O + FNO$	3.7 x 10^{-11}	-(110±70)	5.4 x 10^{-11}	1.2
$CF_3O + NO_2 \rightarrow$ products	See reference			
$CF_3O + CO \rightarrow$ products			<2 x 10^{-15}	
$CF_3O + CH_4 \rightarrow CH_3 + CF_3OH$	2.6 x 10^{-12}	1420±200	2.2 x 10^{-14}	1.1
$CF_3O + C_2H_6 \rightarrow C_2H_5 + CF_3OH$	4.9 x 10^{-12}	400±100	1.3 x 10^{-12}	1.2
$CF_3O_2 + O_3 \rightarrow CF_3O + 2O_2$			<3 x 10^{-15}	
$CF_3O_2 + CO \rightarrow CF_3O + CO_2$			<5 x 10^{-16}	
$CF_3O_2 + NO \rightarrow CF_3O + NO_2$	5.4 x 10^{-12}	-(320±150)	1.6 x 10^{-11}	1.1
ClO_x Reactions				
$O + ClO \rightarrow Cl + O_2$	3.0x10^{-11}	-(70±70)	3.8x10^{-11}	1.2
$O + OClO \rightarrow ClO + O_2$	2.4x10^{-12}	960±300	1.0x10^{-13}	2.0
$O + Cl_2O \rightarrow ClO + ClO$	2.7x10^{-11}	530±150	4.5x10^{-12}	1.3
$O + HCl \rightarrow OH + Cl$	1.0x10^{-11}	3300±350	1.5x10^{-16}	2.0
$O + HOCl \rightarrow OH + ClO$	1.7x10^{-13}	0±300	1.7x10^{-13}	3.0
$O + ClONO_2 \rightarrow$ products	2.9x10^{-12}	800±200	2.0x10^{-13}	1.5
$O_3 + OClO \rightarrow$ products	2.1x10^{-12}	4700±1000	3.0x10^{-19}	2.5
$O_3 + Cl_2O_2 \rightarrow$ products	-	-	<1.0x10^{-19}	-
$OH + Cl_2 \rightarrow HOCl + Cl$	1.4x10^{-12}	900±400	6.7x10^{-14}	1.2
$OH + ClO \rightarrow$ products	1.1x10^{-11}	-(120±150)	1.7x10^{-11}	1.5
$OH + OClO \rightarrow HOCl + O_2$	4.5x10^{-13}	-(800±200)	6.8x10^{-12}	2.0
$OH + HCl \rightarrow H_2O + Cl$	2.6x10^{-12}	350±100	8.0x10^{-13}	1.2
$OH + HOCl \rightarrow H_2O + ClO$	3.0x10^{-12}	500±500	5.0x10^{-13}	3.0
$OH + ClNO_2 \rightarrow HOCl + NO_2$	2.4x10^{-12}	1250±300	3.6x10^{-14}	2.0
$OH + ClONO_2 \rightarrow$ products	1.2x10^{-12}	330±200	3.9x10^{-13}	1.5
$OH + CH_3Cl \rightarrow CH_2Cl + H_2O$	4.0x10^{-12}	1400±250	3.6x10^{-14}	1.2
$OH + CH_2Cl_2 \rightarrow CHCl_2 + H_2O$	3.8x10^{-12}	1050±150	1.1x10^{-13}	1.4
$OH + CHCl_3 \rightarrow CCl_3 + H_2O$	2.0x10^{-12}	900±150	1.0x10^{-13}	1.2
$OH + CCl_4 \rightarrow$ products	~1.0x10^{-12}	>2300	<5.0x10^{-16}	-
$OH + CFCl_3 \rightarrow$ products (CFC-11)	~1.0x10^{-12}	>3700	<5.0x10^{-18}	-
$OH + CF_2Cl_2 \rightarrow$ products (CFC-12)	~1.0x10^{-12}	>3600	<6.0x10^{-18}	-
$OH + CH_2ClF \rightarrow CHClF + H_2O$ (HCFC-31)	2.8x10^{-12}	1270±200	3.9x10^{-14}	1.2
$OH + CHFCl_2 \rightarrow CFCl_2 + H_2O$ (HCFC-21)	1.7x10^{-12}	1250±150	2.6x10^{-14}	1.2
$OH + CHF_2Cl \rightarrow CF_2Cl + H_2O$ (HCFC-22)	1.0x10^{-12}	1600±150	4.7x10^{-15}	1.1
$OH + CH_3OCl \rightarrow$ products	2.4x10^{-12}	360±200	7.2x10^{-13}	3.0
$OH + CH_3CCl_3 \rightarrow CH_2CCl_3 + H_2O$ (HCC-140)	1.8x10^{-12}	1550±150	1.0x10^{-14}	1.1
$OH + C_2HCl_3 \rightarrow$ products	4.9x10^{-13}	-(450±200)	2.2x10^{-12}	1.25
$OH + C_2Cl_4 \rightarrow$ products	9.4x10^{-12}	1200±200	1.7x10^{-13}	1.25
$OH + CCl_3CHO \rightarrow H_2O + CCl_3CO$	8.2x10^{-12}	600±300	1.1x10^{-12}	1.5
$OH + CH_3CFCl_2 \rightarrow CH_2CFCl_2 + H_2O$ (HCFC-141b)	1.7x10^{-12}	1700±150	5.7x10^{-15}	1.2
$OH + CH_3CF_2Cl \rightarrow CH_2CF_2Cl + H_2O$ (HCFC-142b)	1.3x10^{-12}	1800±150	3.1x10^{-15}	1.2

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	*A* cm^3 molecule^{-1} s^{-1}	*E*/*R* K	*k* (298 K) cm^3 molecule^{-1} s^{-1}	*f*(298)
$OH + CH_2ClCF_2Cl \rightarrow CHClCF_2Cl + H_2O$ (HCFC-132b)	3.6x10^{-12}	1600±400	1.7x10^{-14}	2.0
$OH + CHCl_2CF_2Cl \rightarrow CCl_2CF_2Cl + H_2O$ (HCFC-122)	1.0x10^{-12}	900±150	4.9x10^{-14}	1.2
$OH + CHFClCFCl_2 \rightarrow CFClCFCl_2 + H_2O$ (HCFC-122a)	1.0x10^{-12}	1250±150	1.5x10^{-14}	1.1
$OH + CH_2ClCF_3 \rightarrow CHClCF_3 + H_2O$ (HCFC-133a)	5.2x10^{-13}	1100±300	1.3x10^{-14}	1.3
$OH + CHCl_2CF_3 \rightarrow CCl_2CF_3 + H_2O$ (HCFC-123)	7.0x10^{-13}	900±150	3.4x10^{-14}	1.2
$OH + CHFClCF_2Cl \rightarrow CFClCF_2Cl$ + H2O (HCFC-123a)	9.2x10^{-13}	1280±150	1.3x10^{-14}	1.2
$OH + CHFClCF_3 \rightarrow CFClCF_3 + H_2O$ (HCFC-124)	8.0x10^{-13}	1350±150	8.6x10^{-15}	1.2
$OH + CH_3CF_2CFCl_2 \rightarrow$ products (HCFC-243cc)	7.7x10^{-13}	1700±300	2.6x10^{-15}	2.0
$OH + CF_3CF_2CHCl_2 \rightarrow$ products (HCFC-225ca)	1.0x10^{-12}	1100±200	2.5x10^{-14}	1.3
$OH + CF_2ClCF_2CHFCl \rightarrow$ products (HCFC-225cb)	5.5x10^{-13}	1250±200	8.3x10^{-15}	1.3
$HO_2 + Cl \rightarrow HCl + O_2$	1.8x10^{-11}	-(170±200)	3.2x10^{-11}	1.5
$\rightarrow OH + ClO$	4.1x10^{-11}	450±200	9.1x10^{-12}	2.0
$HO_2 + ClO \rightarrow HOCl + O_2$	4.8x10^{-13}	-(700±)	5.0x10^{-12}	1.4
$H_2O + ClONO_2 \rightarrow$ products	-	-	<2.0x10^{-21}	-
$NO + OClO \rightarrow NO_2 + ClO$	2.5x10^{-12}	600±300	3.4x10^{-13}	2.0
$NO + Cl_2O_2 \rightarrow$ products	-	-	<2.0x10^{-14}	-
$NO_3 + HCl \rightarrow HNO_3 + Cl$	-	-	<5.0x10^{-17}	-
$HO_2NO_2 + HCl \rightarrow$ products	-	-	<1.0x10^{-21}	-
$Cl + O_3 \rightarrow ClO + O_2$	2.9x10^{-11}	260±100	1.2x10^{-11}	1.15
$Cl + H_2 \rightarrow HCl + H$	3.7x10^{-11}	2300±200	1.6x10^{-14}	1.25
$Cl + H_2O_2 \rightarrow HCl + HO_2$	1.1x10^{-11}	980±500	4.1x10^{-13}	1.5
$Cl + NO_3 \rightarrow ClO + NO_2$	2.4x10^{-11}	0±400	2.4x10^{-11}	1.5
$Cl + N_2O \rightarrow ClO + N_2$	See reference			
$Cl + HNO_3 \rightarrow$ products	-	-	<2.0x10^{-16}	-
$Cl + CH_4 \rightarrow HCl + CH_3$	1.1x10^{-11}	1400±150	1.0x10^{-13}	1.1
$Cl + CH_3D \rightarrow$ products	-	-	7.4x10^{-14}	2.0
$Cl + H_2CO \rightarrow HCl + HCO$	8.1x10^{-11}	30±100	7.3x10^{-11}	1.15
$Cl + CH_3O_2 \rightarrow$ products	-	-	1.6x10^{-10}	1.5
$Cl + CH_3OH \rightarrow CH_2OH + HCl$	5.4x10^{-11}	0±250	5.4x10^{-11}	1.5
$Cl + C_2H_6 \rightarrow HCl + C_2H_5$	7.7x10^{-11}	90±90	5.7x10^{-11}	1.1
$Cl + C_2H_5O_2 \rightarrow ClO + C_2H_5O$	-	-	7.4x10^{-11}	2.0
$\rightarrow HCl + C_2H_4O_2$	-	-	7.7x10^{-11}	2.0
$Cl + CH_3CN \rightarrow$ products	1.6x10^{-11}	2140±300	1.2x10^{-14}	2.0
$Cl + CH_3CO_3NO_2 \rightarrow$ products	-	-	<1x10^{-14}	
$Cl + C_3H_8 \rightarrow HCl + C_3H_7$	1.2x10^{-10}	-(40±250)	1.4x10^{-10}	1.3
$Cl + OClO \rightarrow ClO + ClO$	3.4x10^{-11}	-(160±200)	5.8x10^{-11}	1.25
$Cl + ClOO \rightarrow Cl_2 + O_2$	2.3x10^{-10}	0±250	2.3x10^{-10}	3.0
$\rightarrow ClO + ClO$	1.2x10^{-11}	0±250	1.2x10^{-11}	3.0
$Cl + Cl_2O \rightarrow Cl_2 + ClO$	6.2x10^{-11}	-(130±130)	9.6x10^{-11}	1.2
$Cl + Cl_2O_2 \rightarrow$ products	-	-	1.0x10^{-10}	2.0
$Cl + HOCl \rightarrow$ products	2.5x10^{-12}	130±250	1.6x10^{-12}	1.5
$Cl + ClNO \rightarrow NO + Cl_2$	5.8x10^{-11}	-(100±200)	8.1x10^{-11}	1.5
$Cl + ClONO_2 \rightarrow$ products	6.5x10^{-12}	-(135±50)	1.0x10^{-11}	1.2
$Cl + CH_3Cl \rightarrow CH_2Cl + HCl$	3.2x10^{-11}	1250±200	4.8x10^{-13}	1.2
$Cl + CH_2Cl_2 \rightarrow HCl + CHCl_2$	3.1x10^{-11}	1350±500	3.3x10^{-13}	1.5
$Cl + CHCl_3 \rightarrow HCl + CCl_3$	8.2x10^{-12}	1325±300	9.6x10^{-14}	1.3

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	*A* cm³ molecule⁻¹ s⁻¹	*E/R* K	*k* (298 K) cm³ molecule⁻¹ s⁻¹	*f*(298)
$Cl + CH_3F \rightarrow HCl + CH_2F$ (HFC-41)	$2.0x10^{-11}$	1200±500	$3.5x10^{-13}$	1.3
$Cl + CH_2F_2 \rightarrow HCl + CHF_2$ (HFC-32)	$1.2x10^{-11}$	1630±500	$5.0x10^{-14}$	1.5
$Cl + CF_3H \rightarrow HCl + CF_3$ (HFC-23)	-	-	$3.0x10^{-18}$	5.0
$Cl + CH_2FCl \rightarrow HCl + CHFCl$ (HCFC-31)	$1.2x10^{-11}$	1390±500	$1.1x10^{-13}$	2.0
$Cl + CHFCl_2 \rightarrow HCl + CFCl_2$ (HCFC-21)	$5.5x10^{-12}$	1675±200	$2.0x10^{-14}$	1.3
$Cl + CHF_2Cl \rightarrow HCl + CF_2Cl$ (HCFC-22)	$5.9x10^{-12}$	2430±200	$1.7x10^{-15}$	1.3
$Cl + CH_3CCl_3 \rightarrow CH_2CCl_3 + HCl$	$2.8x10^{-12}$	1790±400	$7.0x10^{-15}$	2.0
$Cl + CH_3CH_2F \rightarrow HCl + CH_3CHF$ (HFC-161)	$1.8x10^{-11}$	290±500	$6.8x10^{-12}$	3.0
$\rightarrow HCl + CH_2CH_2F$	$1.4x10^{-11}$	880±500	$7.3x10^{-13}$	3.0
$Cl + CH_3CHF_2 \rightarrow HCl + CH_3CF_2$ (HFC-152a)	$6.4x10^{-12}$	950±500	$2.6x10^{-13}$	1.3
$\rightarrow HCl + CH_2CHF_2$	$7.2x10^{-12}$	2390±500	$2.4x10^{-15}$	3.0
$Cl + CH_2FCH_2F \rightarrow HCl + CHFCH_2F$ (HFC-152)	$2.6x10^{-11}$	1060±500	$7.5x10^{-13}$	3.0
$Cl + CH_3CFCl_2 \rightarrow HCl + CH_2CFCl_2$ (HCFC-141b)	$1.8x10^{-12}$	2000±300	$2.2x10^{-15}$	1.2
$Cl + CH_3CF_2Cl \rightarrow HCl + CH_2CF_2Cl$ (HCFC-142b)	$1.4x10^{-12}$	2420±500	$4.2x10^{-16}$	1.2
$Cl + CH_3CF_3 \rightarrow HCl + CH_2CF_3$ (HFC-143a)	$1.2x10^{-11}$	3880±500	$2.6x10^{-17}$	5.0
$Cl + CH_2FCHF_2 \rightarrow HCl + CH_2FCF_2$ (HFC-143)	$5.5x10^{-12}$	1610±500	$2.5x10^{-14}$	3.0
$\rightarrow HCl + CHFCHF_2$	$7.7x10^{-12}$	1720±500	$2.4x10^{-14}$	3.0
$Cl + CH_2ClCF_3 \rightarrow HCl + CHClCF_3$ (HCFC-133a)	$1.8x10^{-12}$	1710±500	$5.9x10^{-15}$	3.0
$Cl + CH_2FCF_3 \rightarrow HCl + CHFCF_3$ (HFC-134a)	-	-	$1.5x10^{-15}$	1.2
$Cl + CHF_2CHF_2 \rightarrow HCl + CF_2CHF_2$ (HCF-134)	$7.5x10^{-12}$	2430±500	$2.2x10^{-15}$	1.5
$Cl + CHCl_2CF_3 \rightarrow HCl + CCl_2CF_3$ (HCFC-123)	$4.4x10^{-12}$	1750±500	$1.2x10^{-14}$	1.3
$Cl + CHFClCF_3 \rightarrow HCl + CFClCF_3$ (HCFC-124)	$1.1x10^{-12}$	1800±500	$2.7x10^{-15}$	1.3
$Cl + CHF_2CF_3 \rightarrow HCl + CF_2CF_3$ (HFC-125)	-	-	$2.4x10^{-16}$	1.3
$ClO + O_3 \rightarrow ClOO + O_2$	-	-	$<1.4x10^{-17}$	-
$\rightarrow OClO + O_2$	$1.0x10^{-12}$	>4000	$<1.0x10^{-18}$	-
$ClO + H_2 \rightarrow$ products	$\sim1.0x10^{-12}$	>4800	$<1.0x10^{-19}$	-
$ClO + NO \rightarrow NO_2 + Cl$	$6.4x10^{-12}$	-(290±100)	$1.7x10^{-11}$	1.15
$ClO + NO_3 \rightarrow ClOO + NO_2$	$4.7x10^{-13}$	0±400	$4.7x10^{-13}$	1.5
$ClO + N_2O \rightarrow$ products	$\sim1.0x10^{-12}$	>4300	$<6.0x10^{-19}$	-
$ClO + CO \rightarrow$ products	$\sim1.0x10^{-12}$	>3700	$<4.0x10^{-18}$	-
$ClO + CH_4 \rightarrow$ products	$\sim1.0x10^{-12}$	>3700	$<4.0x10^{-18}$	-
$ClO + H_2CO \rightarrow$ products	$\sim1.0x10^{-12}$	>2100	$<1.0x10^{-15}$	-
$ClO + CH_3O_2 \rightarrow$ products	$3.3x10^{-12}$	115±115	$2.2x10^{-12}$	1.5
$ClO + ClO \rightarrow Cl_2 + O_2$	$1.0x10^{-12}$	1590±300	$4.8x10^{-15}$	1.5
$\rightarrow ClOO + Cl$	$3.0x10^{-11}$	2450±500	$8.0x10^{-15}$	1.5
$\rightarrow OClO + Cl$	$3.5x10^{-13}$	1370±300	$3.5x10^{-15}$	1.5
$HCl + ClONO_2 \rightarrow$ products	-	-	$<1.0x10^{-20}$	-

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	*A* cm³ molecule⁻¹ s⁻¹	*E*/*R* K	*k* (298 K) cm³ molecule⁻¹ s⁻¹	*f*(298)
$CH_2ClO + O_2 \rightarrow CHClO + HO_2$	-	-	6×10^{-14}	5
$CH_2ClO_2 + HO_2 \rightarrow$				
$CH_2ClO_2H + O_2$	3.3×10^{-13}	-(820±200)	5.2×10^{-12}	1.5
$CH_2ClO_2 + NO \rightarrow CH_2ClO + NO_2$	7×10^{-12}	-(300±200)	1.9×10^{-11}	1.5
$CCl_3O_2 + NO \rightarrow CCl_2O + NO_2 + Cl$	7.3×10^{-12}	-(270±200)	1.8×10^{-11}	1.3
$CCl_2FO_2 + NO \rightarrow CClFO +$				
$NO_2 + Cl$	4.5×10^{-12}	-(350±200)	1.5×10^{-11}	1.3
$CClF_2O_2 + NO \rightarrow CF_2O +$				
$NO_2 + Cl$	3.8×10^{-12}	-(400±200)	1.5×10^{-11}	1.2
BrO_x Reactions				
$O + BrO \rightarrow Br + O_2$	1.9×10^{-11}	-(230±150)	4.1×10^{-11}	1.5
$O + HBr \rightarrow OH + Br$	5.8×10^{-12}	1500±200	3.8×10^{-14}	1.3
$O + HOBr \rightarrow OH + BrO$	1.2×10^{-10}	430±300	2.8×10^{-11}	3.0
$OH + Br_2 \rightarrow HOBr + Br$	4.2×10^{-11}	0±600	4.2×10^{-11}	1.3
$OH + BrO \rightarrow$ products	-	-	7.5×10^{-11}	3.0
$OH + HBr \rightarrow H_2O + Br$	1.1×10^{-11}	0±250	1.1×10^{-11}	1.2
$OH + CH_3Br \rightarrow CH_2Br + H_2O$	4.0×10^{-12}	1470±150	2.9×10^{-14}	1.1
$OH + CH_2Br_2 \rightarrow CHBr_2 + H_2O$	2.4×10^{-12}	900±300	1.2×10^{-13}	1.1
$OH + CHBr_3 \rightarrow CBr_3 + H_2O$	1.6×10^{-12}	710±200	1.5×10^{-13}	2.0
$OH + CHF_2Br \rightarrow CF_2Br + H_2O$	1.1×10^{-12}	1400±200	1.0×10^{-14}	1.1
$OH + CH_2ClBr \rightarrow CHClBr + H_2O$	2.3×10^{-12}	930±150	1.0×10^{-13}	1.2
$OH + CF_2ClBr \rightarrow$ products	-	-	$<1.5 \times 10^{-16}$	-
$OH + CF_2Br_2 \rightarrow$ products	-	-	$<5.0 \times 10^{-16}$	-
$OH + CF_3Br \rightarrow$ products	-	-	$<1.2 \times 10^{-16}$	-
$OH + CH_2BrCF_3 \rightarrow CHBrCF_3 + H_2O$	1.4×10^{-12}	1340±200	1.6×10^{-14}	1.3
$OH + CHFBrCF_3 \rightarrow CFBrCF_3$	7.2×10^{-13}	1110±150	1.8×10^{-14}	1.5
$OH + CHClBrCF_3 \rightarrow CClBrCF_3 + H_2O$	1.3×10^{-12}	995±150	4.5×10^{-14}	1.5
$OH + CF_2BrCHFCl \rightarrow CF_2BrCFCl + H_2O$	9.3×10^{-13}	1250±150	1.4×10^{-14}	1.5
$OH + CF_2BrCF_2Br \rightarrow$ products	-	-	$<1.5 \times 10^{-16}$	-
$HO_2 + Br \rightarrow HBr + O_2$	1.5×10^{-11}	600±600	2.0×10^{-12}	2.0
$HO_2 + BrO \rightarrow$ products	3.4×10^{-12}	-(540±200)	2.1×10^{-11}	1.5
$NO_3 + HBr \rightarrow HNO_3 + Br$	-	-	$<1.0 \times 10^{-16}$	-
$Cl + CH_2ClBr \rightarrow HCl + CHClBr$	4.3×10^{-11}	1370±500	4.3×10^{-13}	3.0
$Cl + CH_3Br \rightarrow HCl + CH_2Br$	1.5×10^{-11}	1060±100	4.3×10^{-13}	1.2
$Cl + CH_2Br_2 \rightarrow HCl + CHBr_2$	6.4×10^{-12}	810±100	4.2×10^{-13}	1.2
$Br + O_3 \rightarrow BrO + O_2$	1.7×10^{-11}	800±200	1.2×10^{-12}	1.2
$Br + H_2O_2 \rightarrow HBr + HO_2$	1.0×10^{-11}	>3000	$<5.0 \times 10^{-16}$	-
$Br + NO_3 \rightarrow BrO + NO_2$	-	-	1.6×10^{-11}	2.0
$Br + H_2CO \rightarrow HBr + HCO$	1.7×10^{-11}	800±200	1.1×10^{-12}	1.3
$Br + OClO \rightarrow BrO + ClO$	2.6×10^{-11}	1300±300	3.4×10^{-13}	2.0
$Br + Cl_2O \rightarrow BrCl + ClO$	2.1×10^{-11}	470±150	4.3×10^{-12}	1.3
$Br + Cl_2O_2 \rightarrow$ products	-	-	3.0×10^{-12}	2.0
$BrO + O_3 \rightarrow$ products	$\sim 1.0 \times 10^{-12}$	>3200	$<2.0 \times 10^{-17}$	-
$BrO + NO \rightarrow NO_2 + Br$	8.8×10^{-12}	-(260±130)	2.1×10^{-11}	1.15
$BrO + NO_3 \rightarrow$ products	-	-	1.0×10^{-12}	3.0
$BrO + ClO \rightarrow Br + OClO$	1.6×10^{-12}	-(430±200)	6.8×10^{-12}	1.25
$\rightarrow Br + ClOO$	2.9×10^{-12}	-(220±200)	6.1×10^{-12}	1.25
$\rightarrow BrCl + O_2$	5.8×10^{-13}	-(170±200)	1.0×10^{-12}	1.25
$BrO + BrO \rightarrow$ products	1.5×10^{-12}	-(230±150)	3.2×10^{-12}	1.15
$CH_2BrO_2 + NO \rightarrow CH_2O +$				
$NO_2 + Br$	4×10^{-12}	-(300±200)	1.1×10^{-11}	1.5

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	*A* cm^3 molecule^{-1} s^{-1}	*E*/*R* K	*k* (298 K) cm^3 molecule^{-1} s^{-1}	*f*(298)
IO_x Reactions				
$O + I_2 \rightarrow IO + I$	1.4x10^{-10}	0±250	1.4x10^{-10}	1.4
$O + IO \rightarrow O_2 + I$			1.2x10^{-10}	2.0
$OH + I_2 \rightarrow HOI + I$			1.8x10^{-10}	2.0
$OH + HI \rightarrow H_2O + I$			3.0x10^{-11}	2.0
$OH + CH_3I \rightarrow H_2O + CH_2I$	3.1x10^{-12}	1120±500	7.2x10^{-14}	3.0
$OH + CF_3I \rightarrow HOI + CF_3$			3.1x10^{-14}	5.0
$HO_2 + I \rightarrow HI + O_2$	1.5x10^{-11}	1090±500	3.8x10^{-13}	2.0
$HO_2 + IO \rightarrow HOI + O_2$			8.4x10^{-11}	1.5
$NO_3 + HI \rightarrow HNO_3 + I$	See reference			
$I + O_3 \rightarrow IO + O_2$	2.3x10^{-11}	870±200	1.2x10^{-12}	1.2
$I + BrO \rightarrow IO + Br$	-	-	1.2x10^{-11}	2.0
$IO + NO \rightarrow I + NO_2$	9.1x10^{-12}	-(240±150)	2.0x10^{-11}	1.2
$IO + ClO \rightarrow$ products	5.1x10^{-12}	-(280±200)	1.3x10^{-11}	2.0
$IO + BrO \rightarrow$ products	-	-	6.9x10^{-11}	1.5
$IO + IO \rightarrow$ products	1.5x10^{-11}	-(500±500)	8.0x10^{-11}	1.5
$INO + INO \rightarrow I_2 + 2NO$	8.4x10^{-11}	2620±600	1.3x10^{-14}	2.5
$INO_2 + INO_2 \rightarrow I_2 + 2NO_2$	2.9x10^{-11}	2600±1000	4.7x10^{-15}	3.0
SO_x Reactions				
$O + SH \rightarrow SO + H$	-	-	1.6x10^{-10}	5.0
$O + CS \rightarrow CO + S$	2.7x10^{-10}	760±250	2.1x10^{-11}	1.1
$O + H_2S \rightarrow OH + SH$	9.2x10^{-12}	1800±550	2.2x10^{-14}	1.7
$O + OCS \rightarrow CO + SO$	2.1x10^{-11}	2200±150	1.3x10^{-14}	1.2
$O + CS_2 \rightarrow CS + SO$	3.2x10^{-11}	650±150	3.6x10^{-12}	1.2
$O + CH_3SCH_3 \rightarrow CH_3SO + CH_3$	1.3x10^{-11}	-(410±100)	5.0x10^{-11}	1.1
$O + CH_3SSCH_3 \rightarrow CH_3SO + CH_3S$	5.5x10^{-11}	-(250±100)	1.3x10^{-10}	1.3
$O_3 + H_2S \rightarrow$ products	-	-	<2.0x10^{-20}	-
$O_3 + CH_3SCH_3 \rightarrow$ products	-	-	<1.0x10^{-18}	-
$O_3 + SO_2 \rightarrow SO_3 + O_2$	3.0x10^{-12}	>7000	<2.0x10^{-22}	-
$OH + H_2S \rightarrow SH + H_2O$	6.0x10^{-12}	75±75	4.7x10^{-12}	1.2
$OH + OCS \rightarrow$ products	1.1x10^{-13}	1200±500	1.9x10^{-15}	2.0
$OH + CS_2 \rightarrow$ products	See reference	-	-	-
$OH + CH_3SH \rightarrow CH_3S + H_2O$	9.9x10^{-12}	-(360±100)	3.3x10^{-11}	1.2
$OH + CH_3SCH_3 \rightarrow H_2O + CH_2SCH_3$	1.2x10^{-11}	260±100	5.0x10^{-12}	1.15
$OH + CH_3SSCH_3 \rightarrow$ products	6.0x10^{-11}	-(400±200)	2.3x10^{-10}	1.2
$OH + S \rightarrow H + SO$	-	-	6.6x10^{-11}	3.0
$OH + SO \rightarrow H + SO_2$	-	-	8.6x10^{-11}	2.0
$HO_2 + H_2S \rightarrow$ products	-	-	<3.0x10^{-15}	-
$HO_2 + CH_3SH \rightarrow$ products	-	-	<4.0x10^{-15}	-
$HO_2 + CH_3SCH_3 \rightarrow$ products	-	-	<5.0x10^{-15}	-
$HO_2 + SO_2 \rightarrow$ products	-	-	<1.0x10^{-18}	-
$NO_2 + SO_2 \rightarrow$ products	-	-	<2.0x10^{-26}	-
$NO_3 + H_2S \rightarrow$ products	-	-	<8.0x10^{-16}	-
$NO_3 + OCS \rightarrow$ products	-	-	<1.0x10^{-16}	-
$NO_3 + CS_2 \rightarrow$ products	-	-	<4.0x10^{-16}	-
$NO_3 + CH_3SH \rightarrow$ products	4.4x10^{-13}	-(210±210)	8.9x10^{-13}	1.25
$NO_3 + CH_3SCH_3 \rightarrow CH_3SCH_2 + HNO_3$	1.9x10^{-13}	-(500±200)	1.0x10^{-12}	1.2
$NO_3 + CH_3SSCH_3 \rightarrow$ products	1.3x10^{-12}	270±270	5.3x10^{-13}	1.4
$NO_3 + SO_2 \rightarrow$ products	-	-	<7.0x10^{-21}	-
$N_2O_5 + CH_3SCH_3 \rightarrow$ products	-	-	<1.0x10^{-17}	-
$CH_3O_2 + SO_2 \rightarrow$ products	-	-	<5.0x10^{-17}	-
$F + CH_3SCH_3 \rightarrow$ products	-	-	2.4.x10^{-10}	2.0

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	*A* cm^3 molecule^{-1} s^{-1}	*E*/*R* K	*k* (298 K) cm^3 molecule^{-1} s^{-1}	*f*(298)
$Cl + H_2S \rightarrow HCl + SH$	3.7×10^{-11}	-(210±100)	7.4×10^{-11}	1.25
$Cl + OCS \rightarrow$ products	-	-	$<1.0 \times 10^{-16}$	-
$Cl + CS_2 \rightarrow$ products	-	-	$<4.0 \times 10^{-15}$	-
$Cl + CH_3SH \rightarrow CH_3S + HCl$	1.2×10^{-10}	-(150±50)	2.0×10^{-10}	1.25
$Cl + CH_3SCH_3 \rightarrow$ products	See reference	-	-	-
$ClO + OCS \rightarrow$ products	-	-	$<2.0 \times 10^{-16}$	-
$ClO + CH_3SCH_3 \rightarrow$ products	-	-	9.5×10^{-15}	2.0
$ClO + SO \rightarrow Cl + SO_2$	2.8×10^{-11}	0±50	2.8×10^{-11}	1.3
$ClO + SO_2 \rightarrow Cl + SO_3$	-	-	$<4.0 \times 10^{-18}$	-
$Br + H_2S \rightarrow HBr + SH$	1.4×10^{-11}	2750±300	1.4×10^{-15}	2.0
$Br + CH_3SH \rightarrow CH_3S + HBr$	9.2×10^{-12}	390±100	2.5×10^{-12}	2.0
$Br + CH_3SCH_3 \rightarrow$ products	See reference			
$BrO + CH_3SCH_3 \rightarrow$ products	1.5×10^{-14}	-(850±200)	2.6×10^{-13}	1.3
$BrO + SO \rightarrow Br + SO_2$			5.7×10^{-11}	1.4
$IO + CH_3SH \rightarrow$ products			6.6×10^{-16}	2.0
$IO + CH_3SCH_3 \rightarrow$ products			1.2×10^{-14}	1.5
$S + O_2 \rightarrow SO + O$	2.3×10^{-12}	0±200	2.3×10^{-12}	1.2
$S + O_3 \rightarrow SO + O_2$			1.2×10^{-11}	2.0
$SO + O_2 \rightarrow SO_2 + O$	2.6×10^{-13}	2400±500	8.4×10^{-17}	2.0
$SO + O_3 \rightarrow SO_2 + O_2$	3.6×10^{-12}	1100±200	9.0×10^{-14}	1.2
$SO + NO_2 \rightarrow SO_2 + NO$	1.4×10^{-11}	0±50	1.4×10^{-11}	1.2
$SO + OClO \rightarrow SO_2 + ClO$			1.9×10^{-12}	3.0
$SO_3 + H_2O \rightarrow$ products	See reference		-	-
$SO_3 + NO_2 \rightarrow$ products			1.0×10^{-19}	10.0
$SH + O_2 \rightarrow OH + SO$			$<4.0 \times 10^{-19}$	-
$SH + O_3 \rightarrow HSO + O_2$	9.0×10^{-12}	280±200	3.5×10^{-12}	1.3
$SH + H_2O_2 \rightarrow$ products			$<5.0 \times 10^{-15}$	-
$SH + NO_2 \rightarrow HSO + NO$	2.9×10^{-11}	-(240±50)	6.5×10^{-11}	1.2
$SH + Cl_2 \rightarrow ClSH + Cl$	1.7×10^{-11}	690±200	1.7×10^{-12}	2.0
$SH + BrCl \rightarrow$ products	2.3×10^{-11}	-(350±200)	7.4×10^{-11}	2.0
$SH + Br_2 \rightarrow BrSH + Br$	6.0×10^{-11}	-(160±160)	1.0×10^{-10}	2.0
$SH + F_2 \rightarrow FSH + F$	4.3×10^{-11}	1390±200	4.0×10^{-13}	2.0
$HSO + O_2 \rightarrow$ products			$<2.0 \times 10^{-17}$	-
$HSO + O_3 \rightarrow$ products			1.0×10^{-13}	1.3
$HSO + NO \rightarrow$ products			$<1.0 \times 10^{-15}$	-
$HSO + NO_2 \rightarrow HSO_2 + NO$			9.6×10^{-12}	2.0
$HSO_2 + O_2 \rightarrow HO_2 + SO_2$			3.0×10^{-13}	3.0
$HOSO_2 + O_2 \rightarrow HO_2 + SO_3$	1.3×10^{-12}	330±200	4.4×10^{-13}	1.2
$CS + O_2 \rightarrow OCS + O$			2.9×10^{-19}	2.0
$CS + O_3 \rightarrow OCS + O_2$			3.0×10^{-16}	3.0
$CS + NO_2 \rightarrow OCS + NO$			7.6×10^{-17}	3.0
$CH_3S + O_2 \rightarrow$ products			$<3.0 \times 10^{-18}$	-
$CH_3S + O_3 \rightarrow$ products	2.0×10^{-12}	-(290±100)	5.3×10^{-12}	1.15
$CH_3S + NO \rightarrow$ products			$<1.0 \times 10^{-13}$	-
$CH_3S + NO_2 \rightarrow CH_3SO + NO$	2.1×10^{-11}	-(320±100)	6.1×10^{-11}	1.15
$CH_2SH + O_2 \rightarrow$ products			6.5×10^{-12}	2.0
$CH_2SH + O_3 \rightarrow$ products			3.5×10^{-11}	2.0
$CH_2SH + NO \rightarrow$ products			1.9×10^{-11}	2.0
$CH_2SH + NO_2 \rightarrow$ products			5.2×10^{-11}	2.0
$CH_3SO + O_3 \rightarrow$ products			6.0×10^{-13}	1.5
$CH_3SO + NO_2 \rightarrow CH_3SO_2 + NO$			1.2×10^{-11}	1.4
$CH_3SOO + O_3 \rightarrow$ products			$<8.0 \times 10^{-13}$	-
$CH_3SOO + NO \rightarrow$ products	1.1×10^{-11}	0±100	1.1×10^{-11}	2.0
$CH_3SO_2 + NO_2 \rightarrow$ products	2.2×10^{-11}	0±100	2.2×10^{-11}	2.0
$CH_3SCH_2 + NO_3 \rightarrow$ products			3.0×10^{-10}	2.0
$CH_3SCH_2O_2 + NO \rightarrow CH_3SCH_2O + NO_2$			1.9×10^{-11}	2.0

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Table 1. Rate Constants for Second Order Reactions (continued)

Reaction	A cm^3 molecule^{-1} s^{-1}	E/R K	k (298 K) cm^3 molecule^{-1} s^{-1}	$f(298)$
$CH_3SS + O_3 \rightarrow$ products			4.6×10^{-13}	2.0
$CH_3SS + NO_2 \rightarrow$ products			1.8×10^{-11}	2.0
$CH_3SSO + NO_2 \rightarrow$ products			4.5×10^{-12}	2.0
Metal Reactions				
$Na + O_3 \rightarrow NaO + O_2$	1.0×10^{-9}	95±50	7.3×10^{-10}	1.2
$\rightarrow NaO_2 + O$	-	-	$<4.0 \times 10^{-11}$	-
$Na + N_2O \rightarrow NaO + N_2$	2.8×10^{-10}	1600±400	1.3×10^{-12}	1.2
$Na + Cl_2 \rightarrow NaCl + Cl$	7.3×10^{-10}	0±200	7.3×10^{-10}	1.3
$NaO + O \rightarrow Na + O_2$	3.7×10^{-10}	0±400	3.7×10^{-10}	3.0
$NaO + O_3 \rightarrow NaO_2 + O_2$	1.1×10^{-9}	570±300	1.6×10^{-10}	1.5
$\rightarrow Na + 2O_2$	6.0×10^{-11}	0±800	6.0×10^{-11}	3.0
$NaO + H_2 \rightarrow NaOH + H$	2.6×10^{-11}	0±600	2.6×10^{-11}	2.0
$NaO + H_2O \rightarrow NaOH + OH$	2.2×10^{-10}	0±400	2.2×10^{-10}	2.0
$NaO + NO \rightarrow Na + NO_2$	1.5×10^{-10}	0±400	1.5×10^{-10}	4.0
$NaO + HCl \rightarrow$ products	2.8×10^{-10}	0±400	2.8×10^{-10}	3.0
$NaO_2 + O \rightarrow NaO + O_2$	2.2×10^{-11}	0±600	2.2×10^{-11}	5.0
$NaO_2 + NO \rightarrow NaO + NO_2$	-	-	$<10^{-14}$	-
$NaO_2 + HCl \rightarrow$ products	2.3×10^{-10}	0±400	2.3×10^{-10}	3.0
$NaOH + HCl \rightarrow NaCl + H_2O$	2.8×10^{-10}	0±400	2.8×10^{-10}	3.0

Table 2. Rate Constants for Association Reactions

The values quoted are suitable for air as the third body, M. The integer in parentheses is the power of ten.

	Low pressure limit $k_0(T) = k_0(300)\,(T/300)^{-n}$ cm^6 molecule^{-2} s^{-1}		**High pressure limit** $k_\infty(T) = k_\infty(300)\,(T/300)^{-m}$ cm^3 molecule^{-1} s^{-1}	
Reaction	$k_0(300)$	n	$k_\infty(300)$	m
O_x Reactions				
$O + O_2 \rightarrow O_3$	(6.0±0.5) (-34)	2.3±0.5	-	-
$O(^1D)$ Reactions				
$O(^1D) + N_2 \rightarrow N_2O$	(3.5±3.0) (-37)	0.6	-	-
HO_x Reactions				
$H + O_2 \rightarrow HO_2$	(5.7±0.5) (-32)	1.6±0.5	(7.5±4.0) (-11)	0±1.0
$OH + OH \rightarrow H_2O_2$	(6.2±1.2) (-31)	1.0	(2.6±1.0) (-11)	0±0.5
NO_x Reactions				
$O + NO \rightarrow NO_2$	(9.0±2.0) (-32)	1.5±0.3	(3.0±1.0) (-11)	0±1.0
$O + NO_2 \rightarrow NO_3$	(9.0±1.0) (-32)	2.0±1.0	(2.2±0.3) (-11)	0±1.0
$OH + NO \rightarrow HONO$	(7.0±1.0) (-31)	2.6±0.3	(3.6±1.0) (-11)	0.1±0.5
$OH + NO_2 \rightarrow HNO_3$	(2.5±0.1) (-30)	4.4±0.3	(1.6±0.2) (-11)	1.7±0.2
$HO_2 + NO_2 \rightarrow HO_2NO_2$	(1.8±0.3) (-31)	3.2±0.4	(4.7±1.0) (-12)	1.4±1.4
$NO_2 + NO_3 \rightarrow N_2O_5$	(2.2±0.5) (-30)	3.9±1.0	(1.5±0.8) (-12)	0.7±0.4
$NO_3 \rightarrow NO + O_2$	See reference			
Hydrocarbon Reactions				
$CH_3 + O_2 \rightarrow CH_3O_2$	(4.5±1.5) (-31)	3.0±1.0	(1.8±0.2) (-12)	1.7±1.7
$C_2H_5 + O_2 \rightarrow C_2H_5O_2$	(1.5±1.0) (-28)	3.0±1.0	(8.0±1.0) (-12)	0±1.0
$OH + C_2H_2 \rightarrow HOCHCH$	(5.5±2.0) (-30)	0.0±0.2	(8.3±1.0) (-13)	-2
$OH + C_2H_4 \rightarrow HOCH_2CH_2$	(1.0±0.6) (-28)	0.8±2.0	(8.8±0.9) (-12)	0

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Table 2. Rate Constants for Association Reactions (continued)

The values quoted are suitable for air as the third body, M. The integer in parentheses is the power of ten.

	Low pressure limit $k_0(T) = k_0(300)\,(T/300)^{-n}$ cm^6 molecule^{-2} s^{-1}		High pressure limit $k_\infty(T) = k_\infty(300)\,(T/300)^{-m}$ cm^3 molecule^{-1} s^{-1}	
Reaction	$k_0(300)$	n	$k_\infty(300)$	m
$CH_3O + NO \rightarrow CH_3ONO$	(1.4±0.5) (-29)	3.8±1.0	(3.6±1.6) (-11)	0.6±1.0
$CH_3O + NO_2 \rightarrow CH_3ONO_2$	(1.1±0.4) (-28)	4.0±2.0	(1.6±0.5) (-11)	1.0±1.0
$C_2H_5O + NO \rightarrow C_2H_5ONO$	(2.8±1.0) (-27)	4.0±2.0	(5.0±1.0) (-11)	1.0±1.0
$C_2H_5O + NO_2 \rightarrow C_2H_5ONO_2$	(2.0±1.0) (-27)	4.0±2.0	(2.8±0.4) (-11)	1.0±1.0
$CH_3O_2 + NO_2 \rightarrow CH_3O_2NO_2$	(1.5±0.8) (-30)	4.0±2.0	(6.5±3.2) (-12)	2.0±2.0
$CH_3C(O)O_2 + NO_2 \rightarrow$ $CH_3C(O)O_2NO_2$	(9.7±3.8) (-29)	5.6±2.8	(9.3±0.4)(-12)	1.5±0.3
FO_x Reactions				
$F + O_2 \rightarrow FO_2$	(4.4±0.4) (-33)	1.2±0.5	-	-
$F + NO \rightarrow FNO$	(1.8±0.3) (-31)	1.0±10	(2.8±1.4) (-10)	0.0±1.0
$F + NO_2 \rightarrow FNO_2$	(6.3±3.0) (-32)	2.0±2.0	(2.6±1.3) (-10)	0.0±1.0
$FO + NO_2 \rightarrow FONO_2$	(2.6±2.0) (-31)	1.3±1.3	(2.0±1.0) (-11)	1.5±1.5
$CF_3 + O_2 \rightarrow CF_3O_2$	(3.0±0.3) (-29)	4.0±2.0	(4.0±1.0) (-12)	1.0±1.0
$CF_3O + NO_2 \rightarrow CF_3ONO_2$	See reference			
$CF_3O_2 + NO_2CF_3O_2NO_2$	(2.2±0.5) (-29)	5.0±1.0	(6.0±1.0) (-12)	2.5±1.0
$CF_3O + CO \rightarrow CF_3OCO$	(2.5±0.2) (-31)	-	(6.8±0.4) (-14)	-1.2
$CF_3O \rightarrow CF_2O + F$	See reference			
ClO_x Reactions				
$Cl + O_2 \rightarrow ClOO$	(2.7±1.0) (-33)	1.5±0.5	-	-
$Cl + NO \rightarrow ClNO$	(9.0±2.0) (-32)	1.6±0.5	-	-
$Cl + NO_2$ $ClONO \rightarrow$	(1.3±0.2) (-30)	2.0±1.0	(1.0±0.5) (-10)	1.0±1.0
$ClNO_2$	(1.8±0.3) (-31)	2.0±1.0	(1.0±0.5) (-10)	1.0±1.0
$Cl + CO \rightarrow ClCO$	(1.3±0.5) (-33)	3.8±0.5	-	-
$Cl + C_2H_2 \rightarrow ClC_2H_2$	((5.9±1.0) (-30)	2.1±1.0	(2.1±0.4) (-10)	1.0±0.5
$Cl + C_2H_4 \rightarrow ClC_2H_4$	(1.6±1) (-29)	3.3±1.0	(3.1±2) (-10)	1.0±0.5
$Cl + C_2Cl_4 \rightarrow C_2Cl_5$	(1.4±0.6) (-28)	8.5±1.0	(4.0±1.0) (-11)	1.2±0.5
$ClO + NO_2 \rightarrow ClONO_2$	(1.8±0.3) (-31)	3.4±1.0	(1.5±0.7) (-11)	1.9±1.9
$OClO + NO_3 \rightarrow O_2ClONO_2$	See reference			
$ClO + ClO \rightarrow Cl_2O_2$	(2.2±0.4) (-32)	3.1±0.5	(3.5±2) (-12)	1.0±1.0
$ClO + OClO \rightarrow Cl_2O_3$	(6.2±1.0) (-32)	4.7±0.6	(2.4±1.2) (-11)	0±1.0
$OClO + O \rightarrow ClO_3$	(1.9±0.5) (-31)	1.1±1.0	(3.1±0.8) (-11)	0±1.0
$CH_2Cl + O_2 \rightarrow CH_2ClO_2$	(1.9±0.1) (-30)	3.2±0.2	(2.9±0.2) (-12)	1.2±0.6
$CHCl_2 + O_2 \rightarrow CHCl_2O_2$	(1.3±0.1) (-30)	4.0±0.2	(2.8±0.2) (-12)	1.4±0.6
$CCl_3 + O_2 \rightarrow CCl_3O_2$	(6.9±0.2) (-31)	6.4±0.3	(2.4±0.2) (-12)	2.1±0.6
$CFCl_2 + O_2 \rightarrow CFCl_2O_2$	(5.0±0.8) (-30)	4.0±2.0	(6.0±1.0) (-12)	1.0±1.0
$CF_2Cl + O_2 \rightarrow CF_2ClO_2$	(3.0±1.5) (-30)	4.0±2.0	(3±2) (-12)	1.0±1.0
$CCl_3O_2 + NO_2 \rightarrow CCl_3O_2NO_2$	(5.0±1.0) (-29)	5.0±1.0	(6.0±1.0) (-12)	2.5±1.0
$CFCl_2O_2 + NO_2 \rightarrow CFCl_2O_2NO_2$	(3.5±0.5) (-29)	5.0±1.0	(6.0±1.0) (-12)	2.5±1.0
$CF_2ClO_2 + NO_2 \rightarrow CF_2ClO_2NO_2$	(3.3±0.7) (-29)	6.7±1.3	(4.1±1.9) (-12)	2.8±0.7
BrO_x Reactions				
$Br + NO_2 \rightarrow BrNO_2$	(4.2±0.8) (-31)	2.4±0.5	(2.7±0.5) (-11)	0±1.0
$BrO + NO_2 \rightarrow BrONO_2$	(5.2±0.6) (-31)	3.2±0.8	(6.9±1.0) (-12)	2.9±1.0
IO_x Reactions				
$I + NO \rightarrow INO$	(1.8±0.5) (-32)	1.0±0.5	(1.7±1.0) (-11)	0±1.0
$I + NO_2 \rightarrow INO_2$	(3.0±1.5) (-31)	1.0±1.0	(6.6±5.0) (-11)	0±1.0
$IO + NO_2 \rightarrow IONO_2$	(5.9±2.0) (-31)	3.5±1.0	(9.0±1.0) (-12)	1.5±1.0

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Table 2. Rate Constants for Association Reactions (continued)

The values quoted are suitable for air as the third body, M. The integer in parentheses is the power of ten.

Reaction	Low pressure limit $k_0(T) = k_0(300)\,(T/300)^{-n}$ cm^6 molecule^{-2} s^{-1}		High pressure limit $k_\infty(T) = k_\infty(300)\,(T/300)^{-m}$ cm^3 molecule^{-1} s^{-1}	
	$k_0(300)$	n	$k_\infty(300)$	m
SO_x Reactions				
$HS + NO \rightarrow HSNO$	(2.4±0.4) (-31)	3.0±1.0	(2.7±0.5) (-11)	0
$CH_3S + NO \rightarrow CH_3SNO$	(3.2±0.4) (-29)	4.0±1.0	(3.9±0.6) (-11)	2.7±1.0
$O + SO_2 \rightarrow SO_3$	(1.3±)(-33)	-3.6±0.7		
$OH + SO_2 \rightarrow HOSO_2$	(3.0±1.0) (-31)	3.3±1.5	(1.5±0.5) (-12)	0
$CH_3SCH_2 + O_2 \rightarrow CH_3SCH_2O_2$	See reference			
$SO_3 + NH_3 \rightarrow H_3NSO_3$	(3.9±0.8) (-30)	3.0±3.0	(4.7±1.3) (-11)	0±1.0
Metal Reactions				
$Na + O_2 \rightarrow NaO_2$	(3.2±0.3) (-30)	1.4±0.3	(6.0±2.0) (-10)	0±1.0
$NaO + O_2 \rightarrow NaO_3$	(3.5±0.7) (-30)	2.0±2.0	(5.7±3.0) (-10)	0±1.0
$NaO + CO_2 \rightarrow NaCO_3$	(8.7±2.6) (-28)	2.0±2.0	(6.5±3.0) (-10)	0±1.0
$NaOH + CO_2 \rightarrow NaHCO_3$	(1.3±0.3) (-28)	2.0±2.0	(6.8±4.0) (-10)	0±1.0

Table 3. Equilibrium Constants

$K(T)$/cm^3 molecule^{-1} = $A \exp(B/T)$ [200 < T/K < 300]

Reaction	A/cm^3 molecule^{-1}	B/K	K (298 K)	f (298 K)
$HO_2 + NO_2 \rightarrow HO_2NO_2$	2.1×10^{-27}	10900±1000	1.6×10^{-11}	5
$NO + NO_2 \rightarrow N_2O_3$	3.3×10^{-27}	4667±100	2.1×10^{-20}	2
$NO_2 + NO_2 \rightarrow N_2O_4$	5.2×10^{-29}	6643±250	2.5×10^{-19}	2
$NO_2 + NO_3 \rightarrow N_2O_5$	2.7×10^{-27}	11000±500	2.9×10^{-11}	1.3
$CH_3O_2 + NO_2 \rightarrow CH_3O_2NO_2$	1.3×10^{-28}	11200±1000	2.7×10^{-12}	2
$CH_3C(O)O_2 + NO_2 \rightarrow CH_3C(O)O_2NO_2$	9.0×10^{-29}	14000±200	2.3×10^{-8}	2
$F + O_2 \rightarrow FOO$	3.2×10^{-25}	6100±1200	2.5×10^{-16}	1.0
$Cl + O_2 \rightarrow ClOO$	5.7×10^{-25}	2500±750	2.5×10^{-21}	2
$Cl + CO \rightarrow ClCO$	1.6×10^{-25}	4000±500	1.1×10^{-19}	5
$ClO + O_2 \rightarrow ClO{\cdot}O_2$	2.9×10^{-26}	<3700	$<7.2\times10^{-21}$	-
$ClO + ClO \rightarrow Cl_2O_2$	1.3×10^{-27}	8744±850	7.2×10^{-15}	1.5
$ClO + OClO \rightarrow Cl_2O_3$	1.1×10^{-24}	5455±300	9.8×10^{-17}	3
$OClO + NO_3 \rightarrow O_2ClONO_2$	1×10^{-28}	9300±1000	3.6×10^{-15}	5
$OH + CS_2 \rightarrow CS_2OH$	4.5×10^{-25}	5140±500	1.4×10^{-17}	1.4
$CH_3S + O_2 \rightarrow CH_3SO_2$	1.8×10^{-27}	5545±300	2.2×10^{-19}	1.4

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KINETIC DATA FOR COMBUSTION MODELLING

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The following tables present evaluated rate constants and other chemical kinetic data required for modelling the combustion of hydrocarbons. The compilation was prepared as part of the project "Kinetics and Mechanisms of Chemical Processes in Combustion", which is one of the projects in the third European Community Energy Research and Development Program. The tables are reprinted from the *Journal of Physical and Chemical Reference Data* by permission of the authors and the American Institute of Physics.

Table 1 lists all the reactions studied and gives the recommended rate constant *k* for every bimolecular reaction, as well as the applicable temperature range and the associated error limits. Where more than one set of products is possible, rate constants or branching ratios are given for all channels considered feasible. The data for decomposition reactions and combination reactions are given in Tables 2 and 3, respectively. The reference includes a detailed data sheet for each reaction listed here, covering the thermodynamic data, kinetic measurements, and reliability assessments.

REFERENCE

Baulch, D. L., et al., *J. Phys. Chem. Ref. Data*, 21, 411-734, 1992.

Table 1
BIMOLECULAR REACTIONS

Reaction	k/cm^3 molecule^{-1}s^{-1}	Temp/K	Error limits ($\Delta \log k$)
O Atom Reactions			
$O + H_2 \rightarrow OH + H$	$8.5 \times 10^{-20} T^{2.67} \exp(-3160/T)$	300–2500	± 0.5 at 300 K falling to ± 0.2 for T > 500 K
$O + OH \rightarrow O_2 + H$	$2.0 \times 10^{-11} \exp(112/T)$	220–500	± 0.2
	$2.4 \times 10^{-11} \exp(-353/T)$	1000–2000	± 0.1
$O + HO_2 \rightarrow OH + O_2$	5.3×10^{-11}	300–1000	± 0.3 at 300 K rising to ± 0.5 at 1000 K
$O + H_2O_2 \rightarrow OH + HO_2$	$1.1 \times 10^{-12} \exp(-2000/T)$	300–500	± 0.3
$O + NH_3 \rightarrow OH + NH_2$	$1.6 \times 10^{-11} \exp(-3670/T)$	500–2500	± 0.5
$O + CH \rightarrow CO + H$	6.6×10^{-11}	300–2000	± 0.5
$\rightarrow CHO^+ + e$	$4.2 \times 10^{-13} \exp(-850/T)$	300–2500	± 0.5
$O + {}^3CH_2 \rightarrow CO + 2H$	2×10^{-10}	300–2500	± 0.2 at 300 K rising to
$\rightarrow CO + H_2$	k_1/k = 0.6 ± 0.3 over whole range		± 0.7 at 2500 K
$O + CH_3 \rightarrow HCHO + H$	1.4×10^{-10}	300–2500	± 0.2
$O + CH_4 \rightarrow OH + CH_3$	$1.5 \times 10^{-15} T^{1.56} \exp(-4270/T)$	300–2500	± 0.3 at 300 K falling to ± 0.15 at 2500 K
$O + CHO \rightarrow OH + CO$	5.0×10^{-11}	300–2500	± 0.3
$\rightarrow CO_2 + H$	5.0×10^{-11}	300–2500	± 0.3
$O + HCHO \rightarrow OH + CHO$	$6.9 \times 10^{-13} T^{0.57} \exp(-1390/T)$	250–2200	± 0.1 at 250 K rising to ± 0.3 at 2200 K
$O + CH_3O \rightarrow O_2 + CH_3$	2.5×10^{-11}	300–1000	± 0.3 at 300 K rising to
$\rightarrow OH + HCHO$	k_2/k = (0.12 ± 0.1) at 300 K		± 0.7 at 1000 K
$O + CN \rightarrow CO + N(^4S)$	1.7×10^{-11}	300–5000	± 0.2 at 300 K rising to
$\rightarrow CO + N(^2D)$			± 0.6 × 5000 K
$O + NCO \rightarrow NO + CO$	7.0×10^{-11}	1450–2600	± 0.8
$\rightarrow O_2 + CN$			

Table 1
BIMOLECULAR REACTIONS (continued)

Reaction	k/cm^3 molecule^{-1}s^{-1}	Temp/K	Error limits ($\Delta \log k$)
$O + HCN \rightarrow NCO + H$ $\rightarrow CO + NH$ $\rightarrow OH + CN$	$2.3 \times 10^{-18}\ T^{2.1} \exp(-3075/T)$	450–2500	± 0.2 at 450 K rising to ±0.3 at 2500 K.
$O + CH_3OOH \rightarrow OH + CH_2COOH$ $\rightarrow OH + CH_3O_2$	$6.9 \times 10^{-13}\ T^{0.57} \exp(-1390/T)$ [estimate]	250–2200	± 0.1 at 250 K rising to ± 0.3 at 2200 K.
$O + C_2H \rightarrow CO + CH$	1.7×10^{-11}	300–2500	± 1.0
$O + C_2H_2 \rightarrow CO + {}^3CH_2$ $\rightarrow CHCO + H$	$3.6 \times 10^{-20}\ T^{2.8} \exp(-250/T)$ $k_1/k = 0.5 \pm 0.3$ over whole range.	300–2500	± 0.2
$O + C_2H_3 \rightarrow OH + C_2H_2$ $\rightarrow CO + CH_3$ $\rightarrow HCO + CH_2$	5×10^{-11}	300–2000	± 0.5
$O + C_2H_4 \rightarrow CH_2CHO + H$ $\rightarrow HCO + CH_3$ $\rightarrow HCHO + CH_2$ $\rightarrow CH_2CO + H_2$	$5.75 \times 10^{-18}\ T^{2.08}$ $k_1/k = 0.35 \pm 0.05$ at p> 3 Torr $k_2/k = 0.6 \pm 0.10$	300–2000 over whole temperature range	± 0.1 for $T < 1000$ K rising to ± 0.3 at 2000 K.
$O + C_2H_5 \rightarrow CH_3CHO + H$ $\rightarrow HCHO + CH_3$	1.1×10^{-10} $k_2/k = 0.17 \pm 0.2$ at 300 K	300–2500	± 0.3 from 300 to 1000 K ± 0.5 from 1000 to 2500 K
$O + C_2H_6 \rightarrow OH + C_2H_5$	$1.66 \times 10^{-15}\ T^{1.5} \exp(-2920/T)$	300–1200	± 0.3 at 300 K falling to ± 0.15 at 1200 K.
$O + CHCO \rightarrow 2CO + H$	1.6×10^{-10}	300–2500	± 0.3
$O + CH_2CO \rightarrow CH_2O + CO$ $\rightarrow HCO + H + CO$ $\rightarrow HCO + HCO$	$3.8 \times 10^{-12} \exp(-680/T)$	230–500	± 0.3
$O + CH_3CHO \rightarrow OH + CH_3CO$ $\rightarrow OH + CH_2CHO$	$9.7 \times 10^{-12} \exp(-910/T)$	300–1500	± 0.05 at 300 K rising to ± 0.5 at 1500 K.
$O + C_2H_5OOH \rightarrow OH + C_2H_4OOH$ $\rightarrow OH + C_2H_5OO$	$6.9 \times 10^{-13}\ T^{0.57} \exp(-1390/T)$ [estimate]	250–2200	± 0.1 at 150 K rising to ± 0.3 at 2200 K.
$O + C_6H_6 \rightarrow OH + C_6H_5$ $\rightarrow C_6H_5OH$	$1.2 \times 10^{-22}\ T^{3.7} \exp(-570/T)$	300–1000	± 0.5
$O + C_6H_5CH_2 \rightarrow HCO + C_6H_6$ $\rightarrow C_6H_5CH + H$	5.5×10^{-10}	300	±0.3
$\rightarrow CH_2O + C_6H_5$	No recommendation		
$O + C_6H_5CH_3 \rightarrow$ products	$5.3 \times 10^{-15}\ T^{1.21} \exp(-1260/T)$	300–2800	± 0.1 at 300 K rising to ± 0.4 at 2800 K
$O + p\text{-}C_6H_4(CH_3)_2 \rightarrow$ products	$2.6 \times 10^{-11} \exp(-1409/T)$	300–600	± 0.3
$O + C_6H_5C_2H_5 \rightarrow$ products	1.0×10^{-13}	298	± 0.3
O_2 Reactions			
$O_2 + CH_4 \rightarrow HO_2 + CH_3$	$6.6 \times 10^{-11} \exp(-28630/T)$	500–2000	± 0.5 at 500 K rising to ± 1.0 at 2000 K.

Table 1
BIMOLECULAR REACTIONS (continued)

Reaction	k/cm^3 molecule^{-1}s^{-1}	Temp/K	Error limits ($\Delta \log k$)
$O_2 + C_2H_6 \rightarrow HO_2 + C_2H_5$	$1.0 \times 10^{-10} \exp(-26100/T)$	500–2000	± 0.5 at 500 K rising to ± 1.0 at 2000 K
$O_2 + HCHO \rightarrow HO_2 + HCO$	$1.0 \times 10^{-10} \exp(-20460/T)$	700–1000	± 0.5
$O_2 + CH_3CHO \rightarrow HO_2 + CH_3CO$	$5.0 \times 10^{-11} \exp(-19700/T)$	600–1100	± 0.5 at 600 K rising to ± 1.0 at 1100 K.
H Atom Reactions			
$H + O_2 \rightarrow OH + O$	$3.3 \times 10^{-10} \exp(-8460/T)$	300–2500	± 0.1 at 300 K rising to ± 0.2 at 2500 K.
$H + O_2 + Ar \rightarrow HO_2 + Ar$	See Table 3		
$H + O_2 + H_2 \rightarrow HO_2 + H_2$	See Table 3		
$H + O_2 + N_2 \rightarrow HO_2 + N_2$	See Table 3		
$H + O_2 + H_2O \rightarrow HO_2 + H_2O$	See Table 3		
$H + H + Ar \rightarrow H_2 + Ar$	See Table 3		
$H + H + H_2 \rightarrow H_2 + H_2$	See Table 3		
$H + OH + H_2O \rightarrow H_2O + H_2O$	See Table 3		
$H + OH + Ar \rightarrow H_2O + Ar$	See Table 3		
$H + HO + N_2 \rightarrow H_2O + N_2$	See Table 3		
$H + HO_2 \rightarrow H_2 + O_2$	$7.1 \times 10^{-11} \exp(-710/T)$	300–1000	± 0.3
$\rightarrow 2\,OH$	$2.8 \times 10^{-10} \exp(-440/T)$	300–1000	± 0.3
$\rightarrow H_2O + O$	$5.0 \times 10^{-11} \exp(-866/T)$	300–1000	± 0.3
$H + H_2O \rightarrow OH + H_2$	$7.5 \times 10^{-16}\, T^{1.6} \exp(-9270/T)$	300–2500	±0.2
$H + H_2O_2 \rightarrow H_2 + HO_2$	$2.8 \times 10^{-12} \exp(-1890/T)$	300–1000	± 0.3
$\rightarrow OH + H_2O$	$1.7 \times 10^{-11} \exp(-1800/T)$	300–1000	± 0.3
$H + NH \rightarrow H_2 + N$	1.7×10^{-11}	1500–2500	± 1.0
$H + NH_2 \rightarrow H_2 + NH$	1.0×10^{-11}	2000–3000	± 1.0
$H + {}^3CH_2 \rightarrow H_2 + CH$	$1.0 \times 10^{-11} \exp(900/T)$	300–3000	± 0.7
$H + CH_3 \rightarrow H_2 + {}^1CH_2$	$1.0 \times 10^{-10} \exp(-7600/T)$	300–2500	± 1.0
$\rightarrow CH_4$	See Table 3		
$H + CH_4 \rightarrow H_2 + CH_3$	$2.2 \times 10^{-20}\, T^{3.0} \exp(-4045/T)$	300–2500	± 0.2
$H + CHO \rightarrow H_2 + CO$	1.5×10^{-10}	300–2500	± 0.3
$H + HCHO \rightarrow H_2 + HCO$	$3.8 \times 10^{-14}\, T^{1.05} \exp(-1650/T)$	300–2200	± 0.1 at 300 K rising to ± 0.5 at 2200 K
$H + CH_3O \rightarrow H_2 + HCHO$	3.0×10^{-11}	300–1000	± 0.5
$H + HNCO \rightarrow NH_2 + CO$	No recommendation		
$\rightarrow H_2 + NCO$	$3.4 \times 10^{-10}\, T^{-0.27} \exp(-10190/T)$	500–1000	± 1.0
$H + NCO \rightarrow NH + CO$] $\rightarrow HCN + O$]	8.7×10^{-11}	1400–1500	± 0.5

Table 1
BIMOLECULAR REACTIONS (continued)

Reaction	k/cm^3 molecule^{-1}s^{-1}	Temp/K	Error limits (Δ log k)
$H + C_2H_2 \rightarrow H_2 + C_2H$	1.0×10^{-10} exp($-14000/T$)	1000–3000	± 1.0
$\rightarrow C_2H_3$	See Table 3		
$H + C_2H_3 \rightarrow H_2 + C_2H_2$	2.0×10^{-11}	300–2500	± 0.5
$\rightarrow C_2H_4$	See Table 3		
$H + C_2H_4 \rightarrow C_2H_3 + H_2$	9.0×10^{-10} exp($-7500/T$)	700–2000	± 0.5
$\rightarrow C_2H_5$	See Table 3		
$H + C_2H_5 \rightarrow 2CH_3$	6.0×10^{-11}	300–2000	± 0.3
$\rightarrow C_2H_6$	See Table 3		
$H + C_2H_6 \rightarrow H_2 + C_2H_5$	$2.4 \times 10^{-15}\ T^{1.5}$ exp($-3730/T$)	300–2000	± 0.15 at 300 K rising to ± 0.3 at 2000 K
$H + CHCO \rightarrow CH_2 + CO$ / $\rightarrow H_2 + C_2O$ / $\rightarrow HCCOH$ (combined)	2.5×10^{-10}	300–2500	± 0.4
$H + CH_2CO \rightarrow CH_3 + CO$	3.0×10^{-11} exp($-1700/T$)	200–2000	± 0.5 at 200 K rising to ± 1.0 at 2000 K.
$\rightarrow CH_2CHO$	k_2/k very small		
$H + CH_3CHO \rightarrow H_2 + CH_3CO$ / $\rightarrow H_2 + CH_2CHO$ (combined)	$6.8 \times 10^{-15}\ T^{1.16}$ exp($-1210/T$)	300–2000	± 0.1 at 300 rising to ± 0.4 at 2000 K.
$H + C_6H_5 + M \rightarrow C_6H_6 + M$	See Table 3		
$H + C_6H_6 \rightarrow H_2 + C_6H_5$	No recommendation		
$\rightarrow C_6H_7$	See Table 3		
$H + C_6H_5O + M \rightarrow C_6H_5OH + M$	See Table 3		
$H + C_6H_5OH \rightarrow C_6H_5O + H_2$	1.9×10^{-10} exp($-6240/T$)	1000–1150	± 0.3
$\rightarrow C_6H_6 + OH$	3.7×10^{-11} exp($-3990/T$)	1000–1150	± 0.3
$H + C_6H_5CH_2 + M \rightarrow C_6H_5CH_3 + M$	See Table 3		
$H + C_6H_5CH_3 \rightarrow H_2 + C_6H_5CH_2$	$6.6 \times 10^{-22}\ T^{3.44}$ exp($-1570/T$)	600–2800	± 0.3 at 600 K rising to ± 0.5 at 2800 K.
$\rightarrow H_2 + C_6H_4CH_3$	No recommendation		
$\rightarrow C_6H_6 + CH_3$	No recommendation		
$\rightarrow C_6H_6CH_3$	See Table 3		
$H + p\text{-}C_6H_4(CH_3)_2 \rightarrow$ products	5.8×10^{-13}	298	± 0.1
$H + C_6H_5C_2H_5 \rightarrow H_2 + C_6H_5C_2H_4$	2.4×10^{-12}	773	± 0.1
$\rightarrow C_6H_6C_2H_5$	See Table 3		
H_2 Reactions			
$H_2 + Ar \rightarrow 2H + Ar$	See Table 2		
$H_2 + H_2 \rightarrow 2H + H_2$	See Table 2		
OH Radical Reactions			
$OH + H_2 \rightarrow H_2O + H$	$1.7 \times 10^{-16}\ T^{1.6}$ exp($-1660/T$)	300–2500	± 0.1 at 300 K rising to ± 0.3 at 2500 K
$OH + OH \rightarrow H_2O + O$	$2.5 \times 10^{-15}\ T^{1.14}$ exp($-50/T$)	250–2500	± 0.2
$OH + OH + M \rightarrow H_2O_2 + M$	See Table 3		

Table 1
BIMOLECULAR REACTIONS (continued)

Reaction	k/cm^3 molecule^{-1}s^{-1}	Temp/K	Error limits (Δ log k)
$OH + HO_2 \rightarrow H_2O + O_2$	4.8×10^{-11} exp(250/T)	300–2000	± 0.2 at 300 K rising to ± 0.5 at 2000 K.
$OH + H_2O_2 \rightarrow H_2O + HO_2$	1.3×10^{-11} exp(−670/T)	300–1000	± 0.2
$OH + NH \rightarrow NO + H_2$] $\rightarrow H_2O + N$]	8.0×10^{-11}	300–1000	± 0.5
$OH + NH_2 \rightarrow O + NH_3$	$3.3 \times 10^{-14}\ T^{0.405}$ exp(−250/T)	500–2500	± 0.5
$\rightarrow H_2O + NH$	No recommendation		
$OH + CO \rightarrow H + CO_2$	$1.05 \times 10^{-17}\ T^{1.5}$ exp(250/T)	300–2000	± 0.2 at 300 K rising to ± 0.5 at 2000 K.
$OH + CH_3 \rightarrow H + CH_2OH$] $\rightarrow H + CH_3O$] $\rightarrow H_2O + {}^1CH_2$]	6.0×10^{-11}	300–2000	± 0.7
$\rightarrow CH_3OH$	See Table 3		
$OH + CH_4 \rightarrow H_2O + CH_3$	$2.6 \times 10^{-17}\ T^{1.83}$ exp(−1400/T)	250–2500	± 0.07 at 250 K rising to ± 0.15 at 1200 K.
$OH + CHO \rightarrow H_2O + CO$	1.7×10^{-10}	300–2500	± 0.3
$OH + HCHO \rightarrow H_2O + CHO$	$5.7 \times 10^{-15}\ T^{1.18}$ exp(225/T)	300–3000	± 0.1 at 300 K rising to ± 0.7 at 3000 K.
$OH + CN \rightarrow O + HCN$] $\rightarrow NCO + H$]	1.0×10^{-10}	1500–3000	± 0.5
$OH + HCN \rightarrow H_2O + CN$	1.5×10^{-11} exp(−5400/T)	1500–2500	± 0.5
$\rightarrow HOCN + H$] $\rightarrow HNCO + H$]	No recommendation		
$OH + CH_3OOH \rightarrow H_2O + CH_3OO$	1.2×10^{-12} exp(130/T)	300–1000	± 0.2 at 300 K rising to ± 0.4 at 1000 K
$\rightarrow H_2O + CH_2OOH$	1.8×10^{-12} exp(220/T)	300–1000	± 0.1 at 300 K rising to ±0.3 at 1000 K.
$OH + C_2H_2 \rightarrow H_2O + C_2H$] $\rightarrow H + CH_2CO$]	1.0×10^{-10} exp(−6500/T)	1000–2000	± 1.0
$\rightarrow C_2H_2OH$	See Table 3		
$OH + C_2H_4 \rightarrow H_2O + C_2H_3$	3.4×10^{-11} exp(−2990/T)	650–1500	± 0.5
$OH + C_2H_6 \rightarrow H_2O + C_2H_5$	$1.2 \times 10^{-17}\ T^{2.0}$ exp(−435/T)	250–2000	± 0.07 at 250 K rising to ± 0.15 at 2000 K.
$OH + CH_2CO \rightarrow CH_2OH + CO$] $\rightarrow H_2CO + HCO$]	1.7×10^{-11}	300–2000	± 1.0
$OH + CH_3CHO \rightarrow H_2O + CH_3CO$] $\rightarrow H_2O + CH_2CHO$]	$3.9 \times 10^{-14}\ T^{0.73}$ exp(560/T)	250–1200	± 0.1 at 250 K rising to ± 0.3 at 1200 K.
$OH + C_2H_5OOH \rightarrow H_2O + C_2H_5OO$] $\rightarrow H_2O + C_2H_4OOH$]	3.0×10^{-12} exp(190/T) [estimate]	250–1000	± 0.3 at 250 K rising to ± 0.7 at 1000 K

Table 1
BIMOLECULAR REACTIONS (continued)

Reaction	k/cm^3 molecule^{-1}s^{-1}	Temp/K	Error limits ($\Delta \log k$)
$OH + C_6H_6 \rightarrow H_2O + C_6H_5$	$2.7 \times 10^{-16} T^{1.42} \exp(-730/T)$	400–1500	± 0.3
$\rightarrow H + C_6H_5OH$	$2.2 \times 10^{-11} \exp(-5330/T)$	1000–1150	± 0.3
$\rightarrow C_6H_6OH$	See Table 3		
$OH + C_6H_5OH \rightarrow C_6H_5(OH)_2$	See Table 3		
$\rightarrow H_2O + C_6H_5O$] $\rightarrow H_2O + C_6H_4OH$]	1.0×10^{-11}	1000–1150	± 0.5
$OH + C_6H_5CH_3 \rightarrow H_2O + C_6H_5CH_2$	$8.6 \cdot 10^{-15} T \exp(-1440/T)$	400–1200	± 0.5 at 400 K reducing to ±0.3 at 1200 K.
	See Table 3		
$OH + p\text{-}C_6H_4(CH_3)_2 \rightarrow C_6H_4CH_2CH_3 + H_2O$	$6.4 \times 10^{-11} \exp(-1440/T)$	500–960	±0.1
$\rightarrow p\text{-}C_6H_4(CH_3)_2OH$	See Table 3		
$OH + C_6H_5C_2H_5 \rightarrow HOC_6H_5C_2H_5$	See Table 3		
$\rightarrow H_2O + C_6H_5C_2H_4$] $\rightarrow H_2O + C_6H_4C_2H_5$]	8.7×10^{-12}	773	± 0.1
H_2O Reactions			
$H_2O + M \rightarrow H + OH + M$	See Table 2		
HO_2 Radical Reactions			
$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$	$3.1 \times 10^{-12} \exp(-775/T)$	550–1250	± 0.15 at 550 K rising to ± 0.3 at 1250 K.
$HO_2 + NH_2 \rightarrow NH_3 + O_2$] $\rightarrow HNO + H_2O$]	2.6×10^{-11}	300–400	± 0.4
$HO_2 + CH_3 \rightarrow OH + CH_3O$	3×10^{-11}	300–2500	± 0.7
$\rightarrow O_2 + CH_4$	No recommendation		
$HO_2 + CH_4 \rightarrow H_2O_2 + CH_3$	$1.5 \times 10^{-11} \exp(-12400/T)$	600–1000	± 0.2 at 600 K rising to ± 0.3 at 1000 K.
$HO_2 + HCHO \rightarrow H_2O_2 + CHO$	$5.0 \times 10^{-12} \exp(-6580/T)$	600–1000	± 0.5
$HO_2 + C_2H_4 \rightarrow OH + C_2H_4O$	$3.7 \times 10^{-12} \exp(-8650/T)$	600–900	± 0.15 at 600 K rising to ± 0.25 at 900 K.
$HO_2 + C_2H_6 \rightarrow H_2O_2 + C_2H_5$	$2.2 \times 10^{-11} \exp(-10300/T)$	500–1000	± 0.2 at 500 K rising to ± 0.3 at 1000 K.
$HO_2 + CH_3CHO \rightarrow H_2O_2 + CH_3CO$	$5.0 \times 10^{-12} \exp(-6000/T)$	900–1200	± 0.7
H_2O_2 Reactions			
$H_2O_2 + M \rightarrow 2OH + M$	See Table 2		
N Atom Reactions			
$N + CN \rightarrow N_2 + C$	3×10^{-10}	300–2500	± 1.0
$N + NCO \rightarrow NO + CN$	No recommendation		
$\rightarrow N_2 + CO$	3.3×10^{-11}	1700	± 0.5

Table 1
BIMOLECULAR REACTIONS (continued)

Reaction	k/cm³ molecule⁻¹s⁻¹	Temp/K	Error limits (Δ log k)
NH Radical Reactions			
$NH + O_2 \rightarrow NO + OH$ $\rightarrow NO_2 + H$ $\rightarrow HNO + O$	$1.26 \times 10^{-13} \exp(-770/T)$	270–550	± 0.2 at 270 K rising to ± 0.5 at 550 K.
$NH + NO \rightarrow N_2O + H$ $\rightarrow HN_2 + O$ $\rightarrow N_2 + OH$	5.0×10^{-11}	270–380	± 0.2
NH_2 Radical Reactions			
$NH_2 + O_2 \rightarrow$ products	$<3 \times 10^{-18}$	298	
$NH_2 + NO \rightarrow N_2 + H_2O$ $\rightarrow N_2 + H + OH$ $\rightarrow N_2H + OH$ $\rightarrow N_2O + H_2$	$1.8 \times 10^{-12} \exp(650/T)$ $(k_2 + k_3)/k \approx 0.12$ at 298 K.	220–2000	± 0.5
$^1C_2$ and $^3C_2$ Radical Reactions	See data sheets.		
CH Radical Reactions			
$CH + O_2 \rightarrow CHO + O$ $\rightarrow CO + OH$	5.5×10^{-11}	300–2000	± 0.3 at 300 K rising to ± 0.5 at 2000 K.
$CH + H_2 \rightarrow CH_2 + H$ $\rightarrow CH_3$	$2.4 \times 10^{-10} \exp(-1760/T)$	300–1000	± 0.3
$CH + H_2O \rightarrow$ products	$9.5 \times 10^{-12} \exp(380/T)$	300–1000	± 1.0
$CH + CO \rightarrow$ products	$4.6 \times 10^{-13} \exp(860/T)$	300–1000	± 1.0
$CH + CO_2 \rightarrow$ products	$5.7 \times 10^{-12} \exp(-345/T)$	300–1000	± 1.0
$CH + CH_4 \rightarrow$ products	$5.0 \times 10^{-11} \exp(200/T)$	200–700	± 1.0
$CH + C_2H_2 \rightarrow$ products	$3.5 \times 10^{-10} \exp(61/T)$	200–700	± 1.0
$CH + C_2H_4 \rightarrow$ products	$2.2 \times 10^{-10} \exp(173/T)$	200–700	± 1.0
$CH + C_2H_6 \rightarrow$ products	$1.8 \times 10^{-10} \exp(132/T)$	200–700	± 1.0
$CH + C_3H_8 \rightarrow$ products	$1.9 \times 10^{-10} \exp(240/T)$	300–700	± 1.0
$CH + n\text{-}C_4H_{10} \rightarrow$ products	$4.4 \times 10^{-10} \exp(28/T)$	250–700	± 1.0
$CH + i\text{-}C_4H_{10} \rightarrow$ products	$2.0 \times 10^{-10} \exp(240/T)$	300–700	± 1.0
$CH + \text{neo-}C_5H_{12} \rightarrow$ products	$1.6 \times 10^{-10} \exp(340/T)$	300–700	± 1.0
$CH + CH_3C_2H \rightarrow$ products	No recommendation		
$CH + CH_2O \rightarrow$ products	$1.6 \times 10^{-10} \exp(260/T)$	300–700	± 1.0

Table 1
BIMOLECULAR REACTIONS (continued)

Reaction	k/cm³ molecule⁻¹s⁻¹	Temp/K	Error limits (Δ log k)
$^3CH_2$ Radical Reactions			
$^3CH_2 + O_2 \rightarrow CO + H + OH$ $\rightarrow CO_2 + H + H$ $\rightarrow CO + H_2O$ $\rightarrow CO_2 + H_2$ $\rightarrow HCHO + O$	$4.1 \times 10^{-11} \exp(-750/T)$	300–1000	± 0.3 at 300 K rising to ± 0.5 at 1000 K.
$^3CH_2 + {}^3CH_2 \rightarrow C_2H_2 + H_2$ $\rightarrow C_2H_2 + 2H$	$2.0 \times 10^{-10} \exp(-400/T)$ $k_2/k = 0.9 \pm 0.1$ over range 300–3000 K.	300–3000	± 0.5
$^3CH_2 + CH_3 \rightarrow C_2H_4 + H$	7.0×10^{-11}	300–3000	± 0.3 at 300 K rising to ± 0.5 at 3000 K.
$^3CH_2 + C_2H_2 \rightarrow C_3H_4$	See Table 3		
$^3CH_2 + C_2H_4 \rightarrow C_3H_6$ $\rightarrow c\text{-}C_3H_6$ $\rightarrow CH_2CHCH_2 + H$	See Table 3		
$^1CH_2$ Radical Reactions			
$^1CH_2 + Ar \rightarrow {}^3CH_2 + Ar$	6.0×10^{-12}	300–2000	± 0.3
$^1CH_2 + N_2 \rightarrow {}^3CH_2 + N_2$	1.0×10^{-11}	300–2000	± 0.3
$^1CH_2 + CH_4 \rightarrow {}^3CH_2 + CH_4$	1.2×10^{-11}	300–2000	± 0.4
$^1CH_2 + C_2H_2 \rightarrow {}^3CH_2 + C_2H_2$	8.0×10^{-11}	300–2000	± 0.4
$^1CH_2 + C_2H_4 \rightarrow {}^3CH_2 + C_2H_4$	2.3×10^{-11}	300–2000	± 0.4
$^1CH_2 + C_2H_6 \rightarrow {}^3CH_2 + C_2H_6$	3.6×10^{-11}	300–2000	± 0.4
$^1CH_2 + O_2 \rightarrow CO + H + OH$ $\rightarrow CO_2 + H_2$ $\rightarrow CO + H_2O$ $\rightarrow {}^3CH_2 + O_2$	5.2×10^{-11}	300–1000	± 0.3 at 300 K rising to ± 0.5 at 1000 K
$^1CH_2 + H_2 \rightarrow CH_3 + H$	1.2×10^{-10}	300–1000	± 0.1 at 300 K rising to ± 0.3 at 1000 K
$^1CH_2 + C_2H_2 \rightarrow CH_2CCH_2$ $\rightarrow CH_3CCH$ $\rightarrow CH_2CCH + H$	See Table 3		
$\rightarrow {}^3CH_2 + C_2H_2$	See earlier entry		
$^1CH_2 + C_2H_4 \rightarrow C_3H_6$ $\rightarrow {}^3CH_2 + C_2H_4$	See Table 3 See earlier entry		
CH_3 Radical Reactions			
$CH_3 + M \rightarrow CH_2 + H + M$	See Table 2		
$CH_3 + O_2 \rightarrow CH_3O + O$	$2.2 \times 10^{-10} \exp(-15800/T)$	300–2500	± 0.5
$\rightarrow HCHO + OH$	$5.5 \times 10^{-13} \exp(-4500/T)$	1000–2500	± 0.5
$\rightarrow CH_3O_2$	See Table 3		

Table 1
BIMOLECULAR REACTIONS (continued)

Reaction	k/cm^3 molecule^{-1}s^{-1}	Temp/K	Error limits (Δ log k)
$CH_3 + H_2 \rightarrow CH_4 + H$	$1.14 \times 10^{-20}\ T^{2.74} \exp(-4740/T)$	300–2500	± 0.15 in the range 300–700 K. ± 0.3 in the range 700–2500 K.
$CH_3 + CH_3 \rightarrow C_2H_5 + H$	$5 \times 10^{-11} \exp(-6800/T)$	1300–2500	± 0.6
$\rightarrow C_2H_4 + H_2$	No recommendation (see data sheets)		
$\rightarrow C_2H_6$	See Table 3		
$CH_3 + HCHO \rightarrow CH_4 + HCO$	$6.8 \times 10^{-12} \exp(-4450/T)$	300–1000	± 0.3
$CH_3 + C_2H_2 + M \rightarrow C_3H_5 + M$	See Table 3		
$\rightarrow CH_4 + C_2H$	No recommendation		
$CH_3 + C_2H_4 \rightarrow CH_4 + C_2H_3$	$6.9 \times 10^{-12} \exp(-5600/T)$	400–3000	± 0.5
$\rightarrow n\text{-}C_3H_7$	See Table 3		
$CH_3 + C_2H_5 \rightarrow CH_4 + C_2H_4$	1.9×10^{-12}	300–800	± 0.4
$\rightarrow C_3H_8$	See Table 3		
$CH_3 + C_2H_6 \rightarrow CH_4 + C_2H_5$	$2.5 \times 10^{-31}\ T^{6.0} \exp(-3043/T)$	300–1500	± 0.1 at 300 K rising to ± 0.2 at 1500 K.
$CH_3 + CH_3CHO \rightarrow CH_4 + CH_3CO$	$3.3 \times 10^{-30}\ T^{5.64} \exp(-1240/T)$	300–1250	± 0.3
$\rightarrow CH_4 + CH_2CHO$	No recommendation (see data sheets)		
CH_4 Reactions			
$CH_4 + M \rightarrow CH_3 + H + M$	See Table 2		
CHO Radical Reactions			
$CHO + O_2 \rightarrow CO + HO_2$ / $\rightarrow OH + CO_2$ / $\rightarrow HCO_3$	5.0×10^{-12}	300–2500	± 0.3
$CHO + CHO \rightarrow HCHO + CO$	5.0×10^{-11}	300	± 0.3
HCHO Reactions			
$HCHO + M \rightarrow H + CHO + M$ / $\rightarrow H_2 + CO + M$	See Table 2		
CH_2OH Reactions			
$CH_2OH + O_2 \rightarrow CH_2O + HO_2$	$2.6 \times 10^{-9}\ T^{-1.0} + 1.2 \times 10^{-10} \exp(-1800/T)$	300–1200	± 0.1 at 300 K rising to ± 0.3 at 1200 K.
CH_3O Radical Reactions			
$CH_3O + M \rightarrow HCHO + H + M$	See Table 2		
$CH_3O + O_2 \rightarrow HCHO + HO_2$	$6.7 \times 10^{-14} \exp(-1070/T)$	300–1000	± 0.2 at 500 K rising to ± 0.3 at 300 K and 1000 K.

Table 1

BIMOLECULAR REACTIONS (continued)

Reaction	k/cm^3 molecule^{-1}s^{-1}	Temp/K	Error limits (Δ log k)
CH_3OOH Reactions			
$CH_3OOH + M \rightarrow CH_3O + OH + M$	See Table 2		
CN Radical Reactions			
$CN + O_2 \rightarrow NCO + O$	$1.1 \times 10^{-11} \exp(205/T)$	300–2500	± 0.25 at 300 K rising to ± 0.5 at 2500 K.
$CN + H_2O \rightarrow HCN + OH$ $\rightarrow HOCN + H$	$1.3 \times 10^{-11} \exp(-3750/T)$	500–3000	± 0.3 at 500 K rising to ± 0.5 at 3000 K.
$CN + CH_4 \rightarrow HCN + CH_3$	$1.5 \times 10^{-11} \exp(-940/T)$	260–400	± 0.3
NCO Radical Reactions			
$NCO + M \rightarrow N + CO + M$	See Table 2		
$NCO + NO \rightarrow N_2O + CO$ $\rightarrow N_2 + CO_2$ $\rightarrow N_2 + CO + O$	$1.7 \times 10^{-11} \exp(200/T)$	300–600	± 0.5
C_2H Radical Reactions			
$C_2H + O_2 \rightarrow CO_2 + CH$ $\rightarrow 2CO + H$ $\rightarrow C_2HO + O$ $\rightarrow CO + HCO$	3.0×10^{-11}	300	± 0.5
$C_2H + H_2 \rightarrow C_2H_2 + H$	$2.5 \times 10^{-11} \exp(-1560/T)$	300–2500	± 0.3 at 300 K rising to ± 0.7 at 2500 K
$C_2H + C_2H_2 \rightarrow C_4H_2 + H$	5.0×10^{-11}	300–2700	± 0.3
$C_2H + CH_4 \rightarrow$ products	2.0×10^{-12}	298	± 1
$C_2H + C_2H_6 \rightarrow$ products	No recommendation		
C_2H_3 Radical Reactions			
$C_2H_3 + M \rightarrow C_2H_2 + H + M$	See Table 2		
$C_2H_3 + O_2 \rightarrow HCHO + CHO$	9.0×10^{-12}	300–2000	± 0.3 at 300 K rising to ± 0.5 at 2000 K
C_2H_5 Radical Reactions			
$C_2H_5 + O_2 \rightarrow C_2H_4 + HO_2$	$1.7 \times 10^{-14} \exp(1100/T)$	600–1200	± 0.3
$C_2H_5 + C_2H_5 \rightarrow C_2H_6 + C_2H_4$ $\rightarrow n\text{-}C_4H_{10}$	2.4×10^{-12} See Table 3	300–1200	± 0.4
C_2H_6 Reactions			
$C_2H_6 + M \rightarrow CH_3 + CH_3 + M$	See Table 2		

Table 1
BIMOLECULAR REACTIONS (continued)

Reaction	k/cm^3 molecule^{-1}s^{-1}	Temp/K	Error limits (Δ log k)
CHCO Reactions			
$CHCO + O_2 \rightarrow CO_2 + HCO$ $\rightarrow 2CO + OH$ $\rightarrow C_2O + HO_2$ $\rightarrow CHO_2CO$	$2.7 \times 10^{-12} \exp(430/T)$ M = He, 2 Torr	300–550	± 0.7
CH_2CHO Radical Reactions			
$CH_2CHO + O_2 \rightarrow HO_2 + CH_2CHO$ $\rightarrow HCHO + CO + OH$ $\rightarrow O_2CH_2CHO$	$k_\infty = 2.6 \times 10^{-13}$ $k_2 = 3.0 \times 10^{-14}$	250–1000 300	± 0.2 ± 0.3
CH_3CO Radical Reactions			
$CH_3CO + O_2 + M \rightarrow CH_3CO_3 + M$	See Table 3		
CH_3CHO Reactions			
$CH_3CHO + M \rightarrow CH_3 + HCO + M$	See Table 2		
C_2H_5O Reactions			
$C_2H_5O + M \rightarrow HCHO + CH_3 + M$ $\rightarrow CH_3CHO + H + M$	See Table 2		
$C_2H_5O + O_2 \rightarrow CH_3CHO + HO_2$	$1.0 \times 10^{-13} \exp(-830/T)$	300–1000	± 0.3 at 300 K rising to ± 0.5 at 1000 K
C_2H_5OOH Reactions			
$C_2H_5OOH + M \rightarrow C_2H_5O + OH + M$	See Table 2		
C_6H_5 Radical Reactions			
$C_6H_5 + M \rightarrow C_2H_2 + C_4H_3 + M$ $\rightarrow C_2H_3 + C_4H_2 + M$ $\rightarrow$ linear-$C_6H_5 + M$	See Table 2		
C_6H_6 Reactions			
$C_6H_6 + M \rightarrow C_6H_5 + H + M$ $\rightarrow C_4H_4 + C_2H_2 + M$	See Table 2		
C_6H_5O Radical Reactions			
$C_6H_5O + M \rightarrow C_5H_5 + CO + M$	See Table 2		
$C_6H_5CH_2$ Radical Reactions			
$C_6H_5CH_2 + M \rightarrow C_3H_3 + 2C_2H_2 + M$ $\rightarrow C_4H_4 + C_3H_3 + M$ $\rightarrow C_5H_5 + C_2H_2 + M$ $\rightarrow C_7H_7(BCH) + M$	See Table 2		

Table 1
BIMOLECULAR REACTIONS (continued)

Reaction	k/cm^3 molecule^{-1}s^{-1}	Temp/K	Error limits ($\Delta \log k$)
$C_6H_5CH_3$ Reactions			
$C_6H_5CH_3 + M \rightarrow C_6H_5CH_2 + H + M$ $\rightarrow C_6H_5 + CH_3 + M$	See Table 2		
p-$C_6H_4(CH_3)_2$ Reactions			
p-$C_6H_4(CH_3)_2 + M \rightarrow C_6H_4CH_2CH_3 + H + M$	See Table 2		
$C_6H_5C_2H_5$ Reactions			
$C_6H_5C_2H_5 + M \rightarrow C_6H_5CH_2 + CH + M$ $\rightarrow C_6H_6 + C_2H_4 + M$ $\rightarrow C_6H_5CHCH_2 + H_2 + M$ $\rightarrow C_6H_5 + C_2H_5 + M$ $\rightarrow C_6H_5CHCH_3 + H + M$	See Table 2		

Table 2
DECOMPOSITION REACTIONS

Reaction	k_∞/s^{-1} k_0/cm^3 molecule^{-1} s^{-1} F_c $k/\text{s}^{-1} = \dfrac{k_0 k_\infty [M]}{k_0[M] + k_\infty} F$	Temp/K	Error limits ($\Delta \log k$)
$H_2 + Ar \rightarrow 2H + Ar$	$k_0 = 3.7 \times 10^{-10} \exp(-48350/T)$	2500–8000	± 0.3
$H_2 + H_2 \rightarrow 2H + H_2$	$k_0 = 1.5 \times 10^{-9} \exp(-48350/T)$	2500–8000	± 0.5
$H_2O + N_2 \rightarrow H + OH + N_2$	$k_0 = 5.8 \times 10^{-9} \exp(-52920/T)$	2000–6000	± 0.5
$H_2O_2 + M \rightarrow 2\,OH + M$	$k_0(Ar) = 3 \times 10^{-8} \exp(-21600/T)$ $k_0(N_2) = 2 \times 10^{-7} \exp(-22900/T)$ $k_\infty = 3 \times 10^{14} \exp(-24400/T)$ $F_c(Ar) = 0.5$	1000–1500 700–1500 1000–1500 700–1500	± 0.2 ± 0.2 ± 0.5 ΔF_c = ± 0.1
$CH_3 + M \rightarrow CH_2 + H + M$	$k_0 = 1.7 \times 10^{-8} \exp(-45600/T)$	1500–3000	± 0.5
$CH_4 + M \rightarrow CH_3 + H + M$	$k_0(Ar) = 1.2 \times 10^{-6} \exp(-47000/T)$ $k_0(CH_4) = 1.4 \times 10^{-5} \exp(-48100/T)$ $k_\infty = 2.4 \times 10^{16} \exp(-52800/T)$ $F_c\,(Ar) = \exp(-0.45 - T/3231)$ $F_c\,(CH_4) = \exp(-0.37 - T/2210)$	1000–3000 1000–2000 1000–3000 1000–3000 1000–2000	± 0.3 ± 0.3 ± 0.5 ΔF_c = ± 0.1 ΔF_c = ± 0.1
$HCHO + M \rightarrow H + CHO + M$ $\rightarrow H_2 + CO + M$	$k_0(1) = 2.1 \times 10^{-8} \exp(-39200/T)$ $k_1/k_2 = 0.5$ at 2200 K	1500–2500	± 0.3
$CH_3O + M \rightarrow HCHO + H + M$	$k_0 = 3.16 \times 10^2\, T^{-2.7} \exp(-15400/T)$ [estimate]	300–1000	± 1.0
$CH_3OOH + M \rightarrow CH_3O + OH + M$	$k_\infty = 4 \times 10^{15} \exp(-21600/T)$	400–1000	± 0.5 at 600 K rising to ± 1.0 at 400 and 1000 K
$NCO + Ar \rightarrow N + CO + Ar$	$k_0 = 1.7 \times 10^{-9} \exp(-23500/T)$	1450–2600	± 0.4

Table 2
DECOMPOSITION REACTIONS (continued)

Reaction	k_∞/s^{-1} k_0/cm^3 molecule^{-1} s^{-1} F_c $k/s^{-1} = \frac{k_0 k_\infty [M]}{k_0[M] + k_\infty} F$	Temp/K	Error limits ($\Delta \log k$)
$C_2H_3 + M \rightarrow C_2H_2 + H + M$	$k_0 = 6.9 \times 10^{17} T^{-7.5} \exp(-22900/T)$	500–2500	± 0.5
	$k_\infty = 2 \times 10^{14} \exp(-20000/T)$	500–2500	± 0.5
	$F_c = 0.35$	500–2500	ΔF_c = ± 0.1
$C_2H_6 + M \rightarrow 2CH_3 + M$	$k_0(Ar) = 1.1 \times 10^{25} T^{-8.24} \exp(-47090/T)$	300–2000	± 0.5
	$k_0(C_2H_6) = 4.5 \times 10^{-2} \exp(-41930/T)$	800–1000	± 0.5
	$k_\infty = 1.8 \times 10^{21} T^{-1.24} \exp(-45700/T)$	300–2000	± 0.3
	$F_c(Ar) = 0.38 \exp(-T/73) + 0.62 \exp(-T/1180)$	300–2000	ΔF_c = ± 0.1
	$F_c(C_2H_6) = 0.54 \exp(-T/1250)$	800–1000	ΔF_c = ± 0.1
$CH_3CHO + M \rightarrow CH_3 + CHO + M$	$k(1\ atm.) = 7 \times 10^{15} \exp(-41100/T)$ (pressure dependent region)	750–1200	± 0.4
$C_2H_5O + M \rightarrow HCHO + CH_3 + M$	$k_\infty = 8 \times 10^{13} \exp(-10830/T)$ [estimate]	300–600	± 1.0
$C_2H_5OOH + M \rightarrow C_2H_5O + OH + M$	$k_\infty\ 4 \times 10^{15} \exp(-21600/T)$	400–1000	± 1.0
$C_6H_5 + M \rightarrow C_2H_2 + C_4H_3 + M$ $\rightarrow C_2H_3 + C_4H_2 + M$	No recommendation		
$\rightarrow$ linear-CH_5 + M	$4.0 \times 10^{13} \exp(-36700/T)$	1450–1900	± 0.4
$C_6H_6 + M \rightarrow C_6H_5 + H + M$ $\rightarrow C_4H_4 + H_2 + M$	$9.0 \times 10^{15} \exp(-54060/T)$	1200–2500	± 0.4 at 1200 K reducing to ± 0.3 at 2500 K
$C_6H_5O + M \rightarrow C_5H_5 + CO + M$	$2.5 \times 10^{11} \exp(-22100/T)$	1000–1580	± 0.2
$C_6H_5CH_2 + M \rightarrow C_3H_3 + 2C_2H_2 + M$ $\rightarrow C_4H_4 + C_3H_3 + M$ $\rightarrow C_5H_5 + C_2H_2 + M$ $\rightarrow C_7H_7$ (BCH) + M	$5.1 \times 10^{13} \exp(-36370/T)$	1350–1900	± 0.3 at 1350 K rising to ± 0.5 1900 K
$C_6H_5CH_3 + M \rightarrow C_6H_5CH_2 + H + M$	$3.1 \times 10^{15} \exp(-44890/T)$	920–2200	± 0.3 at 900 K rising to ± 0.5 at 2200 K
$\rightarrow C_6H_5 + CH_3 + M$	No recommendation		
p-$C_6H_4(CH_3)_2 + M \rightarrow p$-$C_6H_4CH_2CH_3 + H + M$	$4.0 \times 10^{15} \exp(-42600/T)$	1400–1800	± 0.5
$C_6H_5C_2H_5 + M \rightarrow C_6H_5CH_2 + CH + M$	$6.1 \times 10^{15} \exp(-37800/T)$	770–1800	± 0.1 at 770 K rising to ± 0.4 at
$\rightarrow C_6H_6 + C_2H_4 + M$ $\rightarrow C_6H_5CHCH_2 + H_2 + M$ $\rightarrow C_6H_5 + C_2H_5 + M$ $\rightarrow C_6H_5CHCH_3 + H + M$	No recommendations		

Table 3
COMBINATION REACTIONS

Reaction	k_∞/cm^3 molecule^{-1}s^{-1} k_0/cm^6 molecule^{-2} s^{-1} F_c k/cm^3 molecule^{-1}s^{-1} $= \frac{k_0 k_\infty [M]}{k_0[M] + k_\infty} F$	Temp/K	Error limits ($\Delta \log k$)
$H + O_2 + Ar \rightarrow HO_2 + Ar$	$k_0 = 1.7 \times 10^{-30} T^{-0.8}$	300–2000	± 0.5

Table 3
COMBINATION REACTIONS (continued)

Reaction	k_∞/cm^3 molecule^{-1}s^{-1} k_0/cm^6 molecule^{-2} s^{-1} F_c k/cm^3 molecule^{-1}s^{-1} = $\frac{k_0 k_\infty [M]}{k_0[M] + k_\infty} F$	Temp/K	Error limits ($\Delta \log k$)
$H + O_2 + H_2 \rightarrow HO_2 + H_2$	$k_0 = 5.8 \times 10^{-30} T^{-0.8}$	300–2000	± 0.5
$H + O_2 + N_2 \rightarrow HO_2 + N_2$	$k_0 = 3.9 \times 10^{-30} T^{-0.8}$	300–2000	± 0.5
$H + O_2 + H_2O \rightarrow HO_2 + H_2O$	$k_0 = 4.3 \times 10^{-30} T^{-0.8}$	300–2000	± 0.5
$H + H + Ar \rightarrow H_2 + Ar$	$k_0 = 1.8 \times 10^{-30} T^{-1.0}$	300–2500	± 0.5
$H + H + H_2 \rightarrow H_2 + H_2$	$k_0 = 2.7 \times 10^{-31} T^{-0.6}$	100–5000	± 0.5
$H + OH + H_2O \rightarrow H_2O + H_2O$	$k_0 = 3.9 \times 10^{-25} T^{-2.0}$	300–3000	± 0.3
$H + OH + Ar \rightarrow H_2O + Ar$	$k_0 = 2.3 \times 10^{-26} T^{-2.0}$	300–3000	± 0.3
$H + OH + N_2 \rightarrow H_2O + N_2$	$k_0 = 6.1 \times 10^{-26} T^{-2.0}$	300–3000	± 0.3
$H + CH_3 + M \rightarrow CH_4 + M$	$k_0(He) = 6.2 \times 10^{-29} (T/3000)^{-1.8}$ $k_0(Ar) = 6 \times 10^{-29} (T/300)^{-1.8}$ $k_0(C_2H_6) = 3 \times 10^{-28} (T/300)^{-1.8}$ $k_\infty = 3.5 \times 10^{-10}$ $F_c(He,Ar) = \exp(-0.45 - T/3231)$ $F_c(C_2H_6) = \exp(-0.34 - T/3053)$	300–1000 300–1000 300–1000 300–1000 300–1000 300–1000	± 0.3 ± 0.5 ± 0.5 ± 0.3 ΔF_c = ± 0.1 ΔF_c = ± 0.1
$H + C_2H_2 + He \rightarrow C_2H_3 + He$	$k_\infty = 1.4 \times 10^{-11} \exp(-1300/T)$ $k_0 = 3.3 \times 10^{-30} \exp(-740/T)$ $F_c = 0.44$	200–400 200–400 200–400	± 0.3 ± 0.5 ΔF_c = ± 0.1
$H + C_2H_3 + M \rightarrow C_2H_4 + M$	No recommendation		
$H + C_2H_4 + M \rightarrow C_2H_5 + M$	No recommendation		
$H + C_2H_5 + M \rightarrow C_2H_6 + M$	No recommendation		
$H + C_6H_5 + M \rightarrow C_6H_6 + M$	$k_\infty = 1.3 \times 10^{-10}$	1400–1700	± 0.5
$H + C_6H_6 + M \rightarrow C_6H_7 + M$	$k_\infty = 6.7 \times 10^{-11} \exp(-2170/T)$	300–1000	± 0.2
$H + C_6H_5O + M \rightarrow C_6H_5OH + M$	$k_\infty = 4.2 \times 10^{-10}$	1000	± 0.3
$H + C_6H_5CH_2 + M \rightarrow C_6H_5CH_3 + M$	$k_\infty = 5.5 \times 10^{-10}$	300–2000	± 0.2 at 300 K rising to ± 0.7 at 2000 K.
$H + C_6H_5CH_3 + M \rightarrow C_6H_6CH_3 + M$	$k_\infty = 1.2 \times 10^{-13}$	298	± 0.2
$H + C_6H_5C_2H_5 + M \rightarrow C_6H_6C_2H_5 + M$	$k_\infty = 3.3 \times 10^{-13}$	298	± 0.1
$OH + OH + M \rightarrow H_2O_2 + M$	$k_0(N_2) = 8 \times 10^{-31} (T/300)^{-0.76}$ $k_0(H_2O) = 4 \times 10^{-30}$ $k_\infty = 1.5 \times 10^{-11} (T/300)^{-0.37}$ $F_c(N_2) = 0.5$	250–1400 300–400 200–1500 200–1500	± 0.4 ± 0.5 ΔF_c = ± 0.2
$OH + CH_3 + M \rightarrow CH_3OH + M$	No data available for this channel (See Table 1)		

Table 3
COMBINATION REACTIONS (continued)

Reaction	k_∞/cm^3 molecule^{-1}s^{-1} k_0/cm^6 molecule^{-2} s^{-1} F_c k/cm^3 molecule^{-1}s^{-1} = $\frac{k_0 k_\infty [M]}{k_0[M] + k_\infty} F$	Temp/K	Error limits ($\Delta \log k$)
$OH + C_2H_2 + M \rightarrow C_2H_2OH + M$	See data sheet		
$OH + C_6H_6 + M \rightarrow C_6H_6OH + M$	$k_\infty = 3.8 \times 10^{-12} \exp(-340/T)$	240–340	± 0.2
$OH + C_6H_5OH + M \rightarrow C_6H_5(OH)_2 + M$	$k_\infty = 2.8 \times 10^{-11}$	298	± 0.1
$OH + C_6H_5CH_3 + M \rightarrow HOC_6H_5CH_3 + M$	$k_\infty = 3.8 \times 10^{-12} \exp(180/T)$	200–300	± 0.4
$OH + C_6H_4(CH_3)_2 + M \rightarrow C_6H_4(CH_3)_2OH + M$	$k_\infty = 1.4 \times 10^{-11}$	300–320	± 0.1
$OH + C_6H_5C_2H_5 + M \rightarrow HOC_6H_5C_2H_5 + M$	7.5×10^{-12} at $p \leq 1$ atm.	298	± 0.1
$^3CH_2 + C_2H_2 + M \rightarrow C_3H_4 + M$	$2.0 \times 10^{-11} \exp(-3330/T)$ at $p = \leq 10$ Torr.	300–1000	± 0.3
$^3CH_2 + C_2H_4 + M \rightarrow C_3H_6 + M$ $\rightarrow c\text{-}C_3H_6 + M$ $\rightarrow C_3H_5 + H + M$	$5.3 \times 10^{-12} \exp(-2660/T)$	300–1000	± 0.2 at 300 K rising to ± 0.3 at 1000 K
$^1CH_2 + C_2H_2 + M \rightarrow CH_2CCH_2 + M$ $\rightarrow CH_3CCH + M$ $\rightarrow CH_2CCH + H + M$	3.7×10^{-10} independent of p	300–1000	± 0.3 at 300 K rising to ± 0.7 at 1000 K.
$^1CH_2 + C_2H_4 + M \rightarrow C_3H_6$	1.1×10^{-10} independent of p	300–1000	± 0.2 at 300 K rising to ± 0.5 at 1000 K.
$CH_3 + O_2 + M \rightarrow CH_3O_2 + M$	$k_0(Ar) = 1.5 \times 10^{-22} T^{-3.3}$ $k_0(N_2) = 1.6 \times 10^{-22} T^{-3.3}$ $k_\infty = 1.3 \times 10^{-15} T^{-1.2}$ $F_c = 0.466 - 1.30 \times 10^{-4} T$	300–800 300–800 300–800 300–800	± 0.3 ± 0.3 ± 0.3
$CH_3 + CH_3 + Ar \rightarrow C_2H_6 + Ar$	$k_\infty = 6 \times 10^{-11}$	300–2000	± 0.05 at 300 K rising to ± 0.3 at 2000 K
	$k_0 = 3.5 \times 10^{-7} T^{-7.0} \exp(-1390/T)$	300–2000	± 0.3
	$F_c = 0.38 \exp(-T/73)$ $+ 0.62 \exp(-T/1180)$	300–2000	$\Delta F_c = \pm 0.1$
$CH_3 + C_2H_2 + M \rightarrow C_3H_5 + M$	$k_\infty = 1 \times 10^{-12} \exp(-3900/T)$	300–600	± 0.5
$CH_3 + C_2H_4 + M \rightarrow n\text{-}C_3H_7 + M$	$3.5 \times 10^{-13} \exp(-3700/T)$	300–600	± 0.3
$CH_3 + C_2H_5 + M \rightarrow C_3H_8 + M$	$k_\infty = 4.7 \times 10^{-11}$	300–800	± 0.3
$C_2H_5 + C_2H_5 + M \rightarrow n\text{-}C_4H_{10} + M$	$k_\infty = 1.9 \times 10^{-11}$	300–1200	± 0.3
$CH_3CO + O_2 + M \rightarrow CH_3CO_3 + M$	2×10^{-12} for $p = 1$–4 Torr.	300	± 0.3

ELECTRICAL CONDUCTIVITY OF WATER

This table gives the electrical conductivity of highly purified water over a range of temperature and pressure. The first column of conductivity data refers to water at its own vapor pressure. Equations for calculating the conductivity at any temperature and pressure may be found in the reference.

REFERENCE

Marshall, W. L., *J. Chem. Eng. Data* 32, 221, 1987.

Conductivity in μS/cm at the indicated pressure

t/°C	Sat. vapor	50 MPa	100 MPa	200 MPa	400 MPa	600 MPa
0	0.0115	0.0150	0.0189	0.0275	0.0458	0.0667
25	0.0550	0.0686	0.0836	0.117	0.194	0.291
100	0.765	0.942	1.13	1.53	2.45	3.51
200	2.99	4.08	5.22	7.65	13.1	19.5
300	2.41	4.87	7.80	14.1	28.9	46.5
400		1.17	4.91	14.3	39.2	71.3
600			0.134	4.65	33.8	85.7

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THERMODYNAMIC PROPERTIES OF AIR

These tables summarize the thermodynamic properties of air in the liquid and gaseous states, as well as along the saturation line. In the table for the saturation state, *P*(boil) is the bubble point temperature (i.e., the pressure at which boiling begins as the temperature of the liquid is raised), and *P*(con) is the dew point temperature (pressure at which condensation begins as the temperature of the gas is lowered). The other properties tabulated are density (ρ), enthalpy (*H*), entropy (*S*), and isobaric heat capacity (C_p). More detailed tables may be found in the references.

REFERENCES

1. Vasserman, A.A., and Rabinovich, V.A., *Thermophysical Properties of Liquid Air and its Components*, Izdatel'stvo Komiteta, Standartov, Moscow, 1968.
2. Vasserman, A.A., et al., *Thermophysical Properties of Air and Air Components,* Izdatel'stvo Nauka, Moscow, 1966.

Properties in the saturation state:

T K	*P*(boil) bar	*P*(con) bar	ρ (liq) g/cm³	ρ (gas) g/L
65	0.1468	0.0861	0.939	0.464
70	0.3234	0.2052	0.917	1.033
75	0.6366	0.4321	0.894	2.048
80	1.146	0.8245	0.871	3.709
85	1.921	1.453	0.845	6.258
90	3.036	2.397	0.819	9.980
95	4.574	3.748	0.792	15.21
100	6.621	5.599	0.763	22.39
110	12.59	11.22	0.699	45.15
120	21.61	20.14	0.622	87.34
130	34.16	33.32	0.487	184.33
132.55	37.69	37.69	0.313	312.89

Properties of liquid air:

P bar	*T* K	ρ g/cm³	*H* J/g	*S* J/g K	C_p J/g K
1	75	0.8935	–131.7	2.918	1.843
5	75	0.8942	–131.4	2.916	1.840
5	80	0.8718	–122.3	3.031	1.868
5	85	0.8482	–112.9	3.143	1.901
5	90	0.8230	–103.3	3.250	1.941
5	95	0.7962	–93.5	3.356	1.991
10	75	0.8952	–131.1	2.913	1.836
10	80	0.8729	–122.0	3.028	1.863
10	90	0.8245	–103.1	3.246	1.932
10	100	0.7695	–83.2	3.452	2.041
50	75	0.9025	–128.2	2.892	1.806
50	100	0.7859	–81.8	3.415	1.939
50	125	0.6222	–28.3	3.889	2.614
50	150	0.1879	91.9	4.764	2.721
100	75	0.9111	–124.5	2.867	1.774
100	100	0.8033	–79.4	3.376	1.852
100	125	0.6746	–31.4	3.805	2.062
100	150	0.4871	32.8	4.271	2.832

Properties of air in the gaseous state:

P bar	*T* K	ρ g/L	*H* J/g	*S* J/g K	C_p J/g K
1	100	3.556	98.3	5.759	1.032
1	200	1.746	199.7	6.463	1.007
1	300	1.161	300.3	6.871	1.007

THERMODYNAMIC PROPERTIES OF AIR (continued)

P bar	*T* K	ρ g/L	*H* J/g	*S* J/g K	C_p J/g K
1	500	0.696	503.4	7.389	1.030
1	1000	0.348	1046.6	8.138	1.141
10	200	17.835	195.2	5.766	1.049
10	300	11.643	298.3	6.204	1.021
10	500	6.944	502.9	6.727	1.034
10	1000	3.471	1047.2	7.477	1.142
100	200	213.950	148.8	4.949	1.650
100	300	116.945	279.9	5.486	1.158
100	500	66.934	499.0	6.048	1.073
100	1000	33.613	1052.4	6.812	1.151

PROPERTIES OF WATER IN THE RANGE 0 — 100 °C

This table summarizes the best available values of the density, specific heat capacity at constant pressure (C_p), vapor pressure, viscosity, thermal conductivity, dielectric constant, and surface tension for liquid water in the range 0 — 100 °C. All values (except vapor pressure) refer to a pressure of 100 kPa (1 bar). The temperature scale is IPTS-68.

t °C	Density g/cm^3	C_p J/g K	Vap. pres. kPa	Visc. μPa s	Ther. cond. mW/K m	Diel. const.	Surf. ten. mN/m
0	0.99984	4.2176	0.6113	1793	561.0	87.90	75.64
10	0.99970	4.1921	1.2281	1307	580.0	83.96	74.23
20	0.99821	4.1818	2.3388	1002	598.4	80.20	72.75
30	0.99565	4.1784	4.2455	797.7	615.4	76.60	71.20
40	0.99222	4.1785	7.3814	653.2	630.5	73.17	69.60
50	0.98803	4.1806	12.344	547.0	643.5	69.88	67.94
60	0.98320	4.1843	19.932	466.5	654.3	66.73	66.24
70	0.97778	4.1895	31.176	404.0	663.1	63.73	64.47
80	0.97182	4.1963	47.373	354.4	670.0	60.86	62.67
90	0.96535	4.2050	70.117	314.5	675.3	58.12	60.82
100	0.95840	4.2159	101.325	281.8	679.1	55.51	58.91
Ref.	1—3	2	1, 3	3	3	4	5

REFERENCES

1. L. Harr, J. S. Gallagher, and G. S. Kell, *NBS/NRC Steam Tables*, Hemisphere Publishing Corp., 1984.
2. K. N. Marsh, Ed., *Recommended Reference Materials for the Realization of Physicochemical Properties*, Blackwell Scientific Publications, Oxford, 1987.
3. J. V. Sengers and J. T. R. Watson, Improved international formulations for the viscosity and thermal conductivity of water substance, *J. Phys. Chem. Ref. Data*, 15, 1291, 1986.
4. D. G. Archer and P. Wang, The dielectric constant of water and Debye-Hückel limiting law slopes, *J. Phys. Chem. Ref. Data*, 19, 371, 1990.
5. N. B. Vargaftik, et al., International tables of the surface tension of water, *J. Phys. Chem. Ref. Data*, 12, 817, 1983.

ENTHALPY OF VAPORIZATION OF WATER

The enthalpy (heat) of vaporization of water is tabulated as a function of temperature on the IPTS-68 scale.

REFERENCE

Marsh, K. N., Ed., *Recommended Reference Materials for the Realization of Physicochemical Properties,* Blackwell, Oxford, 1987.

t °C	$\Delta_{vap}H$ kJ/mol	t °C	$\Delta_{vap}H$ kJ/mol
0	45.054	200	34.962
25	43.990	220	33.468
40	43.350	240	31.809
60	42.482	260	29.930
80	41.585	280	27.795
100	40.657	300	25.300
120	39.684	320	22.297
140	38.643	340	18.502
160	37.518	360	12.966
180	36.304	374	2.066

FIXED POINT PROPERTIES OF H_2O AND D_2O

Temperatures are given on the IPTS-68 scale.

REFERENCES

1. Haar, L., Gallagher, J.S., and Kell, G.S., *NBS/NRC Steam Tables*, Hemisphere Publishing Corp., 1984.
2. Levelt Sengers, J.M.H., Straub, J., Watanabe, K., and Hill, P.G., Assessment of critical parameter values for H_2O and D_2O, *J. Phys. Chem. Ref. Data*, 14, 193, 1985.
3. Kestin, J. et. al., Thermophysical properties of fluid D_2O, *J. Phys. Chem. Ref. Data*, 13, 601, 1984.
4. Kestin, J. et. al., Thermophysical properties of fluid H_2O, *J. Phys. Chem. Ref. Data*, 13, 175, 1984.
5. Hill, P.G., MacMillan, R.D.C., and Lee, V., A fundamental equation of state for heavy water, *J. Phys. Chem. Ref. Data*, 11, 1, 1982.

	Unit	H_2O	D_2O
Molar mass	g/mol	18.01528	20.02748
Melting point(101.325 kPa)	°C	0.00	3.82
Boiling point(101.325 kPa)	°C	100.00	101.42
Triple point temperature	°C	0.01	3.82
Triple point pressure	Pa	611.73	661
Triple point density(l)	g/cm^3	0.99978	1.1055
Triple point density(g)	mg/L	4.885	5.75
Critical temperature	°C	373.99	370.74
Critical pressure	MPa	22.064	21.671
Critical density	g/cm^3	0.322	0.356
Critical specific volume	cm^3/g	3.11	2.81
Maximum density(saturated liquid)	g/cm^3	0.99995	1.1053
Temperature of maximum density	°C	4.0	11.2

THERMAL CONDUCTIVITY OF SATURATED H_2O AND D_2O

This table gives the thermal conductivity λ for water (H_2O or D_2O) in equilibrium with its vapor. Values for the liquid (λ_l) and vapor (λ_v) are listed, as well as the vapor pressure.

REFERENCES

1. Sengers, J.V. and Watson, J.T.R., Improved international formulations for the viscosity and thermal conductivity of water substance, *J. Phys. Chem. Ref. Data*, 15, 1291, 1986.
2. Matsunaga, N. and Nagashima, A., Transport properties of liquid and gaseous D_2O over a wide range of temperature and pressure, *J. Phys. Chem. Ref. Data*, 12, 933, 1983.

		H_2O			D_2O	
***t*/°C**	***P*/kPa**	**λ_l/(mW/K m)**	**λ_v/(mW/K m)**	***P*/kPa**	**λ_l/(mW/K m)**	**λ_v/(mW/K m)**
0	0.6	561.0	16.49			
10	1.2	580.0	17.21	1.0	575	17.0
20	2.3	598.4	17.95	2.0	589	17.8
30	4.2	615.4	18.70	3.7	600	18.5
40	7.4	630.5	19.48	6.5	610	19.3
50	12.3	643.5	20.28	11.1	618	20.2
60	19.9	654.3	21.10	18.2	625	21.0
70	31.2	663.1	21.96	28.8	629	21.9
80	47.4	670.0	22.86	44.2	633	22.8
90	70.1	675.3	23.80	66.1	635	23.8
100	101.3	679.1	24.79	96.2	636	24.8
150	476	682.1	30.77	465	625	30.8
200	1555	663.4	39.10	1546	592	39.0
250	3978	621.4	51.18	3995	541	52.0
300	8593	547.7	71.78	8688	473	75.2
350	16530	447.6	134.59	16820	391	143.0

STANDARD DENSITY OF WATER

This table gives the density ρ of standard mean ocean water (SMOW), free from dissolved salts and gases, at a pressure of 101325 Pa. SMOW is a standard water sample of high purity and known isotopic composition. Methods of correcting for different isotopic compositions are discussed in the reference. The table below is reprinted with the permission of IUPAC. Note that the temperature scale is IPTS-68.

REFERENCE

Marsh, K. N., Ed., *Recommended Reference Materials for the Realization of Physicochemical Properties*, Blackwell Scientific Publications, Oxford, 1987.

					ρ/kg m^{-3}					
t_{68}/°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	999.8426	8493	8558	8622	8683	8743	8801	8857	8912	8964
1	999.9015	9065	9112	9158	9202	9244	9284	9323	9360	9395
2	999.9429	9461	9491	9519	9546	9571	9595	9616	9636	9655
3	999.9672	9687	9700	9712	9722	9731	9738	9743	9747	9749
4	999.9750	9748	9746	9742	9736	9728	9719	9709	9696	9683
5	999.9668	9651	9632	9612	9591	9568	9544	9518	9490	9461
6	999.9430	9398	9365	9330	9293	9255	9216	9175	9132	9088
7	999.9043	8996	8948	8898	8847	8794	8740	8684	8627	8569
8	999.8509	8448	8385	8321	8256	8189	8121	8051	7980	7908
9	999.7834	7759	7682	7604	7525	7444	7362	7279	7194	7108
10	999.7021	6932	6842	6751	6658	6564	6468	6372	6274	6174
11	999.6074	5972	5869	5764	5658	5551	5443	5333	5222	5110
12	999.4996	4882	4766	4648	4530	4410	4289	4167	4043	3918
13	999.3792	3665	3536	3407	3276	3143	3010	2875	2740	2602
14	999.2464	2325	2184	2042	1899	1755	1609	1463	1315	1166
15	999.1016	0864	0712	0558	0403	0247	0090	9932*	9772*	9612*
16	998.9450	9287	9123	8957	8791	8623	8455	8285	8114	7942
17	998.7769	7595	7419	7243	7065	6886	6706	6525	6343	6160
18	998.5976	5790	5604	5416	5228	5038	4847	4655	4462	4268
19	998.4073	3877	3680	3481	3282	3081	2880	2677	2474	2269
20	998.2063	1856	1649	1440	1230	1019	0807	0594	0380	0164
21	997.9948	9731	9513	9294	9073	8852	8630	8406	8182	7957
22	997.7730	7503	7275	7045	6815	6584	6351	6118	5883	5648
23	997.5412	5174	4936	4697	4456	4215	3973	3730	3485	3240
24	997.2994	2747	2499	2250	2000	1749	1497	1244	0990	0735
25	997.0480	0223	9965*	9707*	9447*	9186*	8925*	8663*	8399*	8135*
26	996.7870	7604	7337	7069	6800	6530	6259	5987	5714	5441
27	996.5166	4891	4615	4337	4059	3780	3500	3219	2938	2655
28	996.2371	2087	1801	1515	1228	0940	0651	0361	0070	9778*
29	995.9486	9192	8898	8603	8306	8009	7712	7413	7113	6813
30	995.6511	6209	5906	5602	5297	4991	4685	4377	4069	3760
31	995.3450	3139	2827	2514	2201	1887	1572	1255	0939	0621
32	995.0302	9983*	9663*	9342*	9020*	8697*	8373*	8049*	7724*	7397*
33	994.7071	6743	6414	6085	5755	5423	5092	4759	4425	4091
34	994.3756	3420	3083	2745	2407	2068	1728	1387	1045	0703
35	994.0359	0015	9671*	9325*	8978*	8631*	8283*	7934*	7585*	7234*
36	993.6883	6531	6178	5825	5470	5115	4759	4403	4045	3687
37	993.3328	2968	2607	2246	1884	1521	1157	0793	0428	0062
38	992.9695	9328	8960	8591	8221	7850	7479	7107	6735	6361
39	992.5987	5612	5236	4860	4483	4105	3726	3347	2966	2586
40	992.2204									

* The leading figure decreases by 1.

VOLUMETRIC PROPERTIES OF AQUEOUS SODIUM CHLORIDE SOLUTIONS

This table gives the following properties of aqueous solutions of NaCl as a function of temperature and concentration:

Specific volume v (reciprocal of density) in cm^3/g
Isothermal compressibility $\kappa_T = -(1/v)(\partial v/\partial P)_T$ in GPa^{-1}
Cubic expansion coefficient $\alpha_v = (1/v)(\partial v/\partial T)_P$ in kK^{-1}

All data refer to a pressure of 100 kPa (1 bar). The reference gives properties over a wider range of temperature and pressure.

REFERENCE

Rogers, P. S. Z., and Pitzer, K. S., *J. Phys. Chem. Ref. Data*, 11, 15, 1982.

	Molality in mol/kg								
***T*/°C**	**0.100**	**0.250**	**0.500**	**0.750**	**1.000**	**2.000**	**3.000**	**4.000**	**5.000**
	Specific volume *v* in cm³/g								
0	0.995732	0.989259	0.978889	0.968991	0.959525	0.925426	0.896292	0.870996	0.848646
10	0.995998	0.989781	0.979804	0.970256	0.961101	0.927905	0.899262	0.874201	0.851958
20	0.997620	0.991564	0.981833	0.972505	0.963544	0.930909	0.902565	0.877643	0.855469
25	0.998834	0.992832	0.983185	0.973932	0.965038	0.932590	0.904339	0.879457	0.857301
30	1.000279	0.994319	0.984735	0.975539	0.966694	0.934382	0.906194	0.881334	0.859185
40	1.003796	0.997883	0.988374	0.979243	0.970455	0.938287	0.910145	0.885276	0.863108
50	1.008064	1.002161	0.992668	0.983551	0.974772	0.942603	0.914411	0.889473	0.867241
60	1.0130	1.0071	0.9976	0.9885	0.9797	0.9474	0.9191	0.8940	0.8716
70	1.0186	1.0127	1.0031	0.9939	0.9851	0.9526	0.9240	0.8987	0.8762
80	1.0249	1.0188	1.0092	0.9999	0.9909	0.9581	0.9293	0.9037	0.8809
90	1.0317	1.0256	1.0157	1.0063	0.9972	0.9640	0.9348	0.9089	0.8858
100	1.0391	1.0329	1.0228	1.0133	1.0040	0.9703	0.9406	0.9144	0.8910
	Compressibility κ_T in GPa⁻¹								
0	0.503	0.492	0.475	0.459	0.443	0.389	0.346	0.315	0.294
10	0.472	0.463	0.449	0.436	0.423	0.377	0.341	0.313	0.294
20	0.453	0.446	0.433	0.422	0.411	0.371	0.338	0.313	0.294
25	0.447	0.440	0.428	0.417	0.407	0.369	0.337	0.313	0.294
30	0.443	0.436	0.425	0.414	0.404	0.367	0.337	0.313	0.294
40	0.438	0.432	0.421	0.411	0.401	0.367	0.338	0.315	0.296
50	0.438	0.431	0.421	0.411	0.402	0.369	0.340	0.317	0.299
60	0.44	0.44	0.43	0.42	0.41	0.38	0.35	0.32	0.30
70	0.45	0.44	0.43	0.42	0.42	0.38	0.36	0.33	0.31
80	0.46	0.45	0.44	0.43	0.43	0.39	0.37	0.34	0.32
90	0.47	0.47	0.46	0.45	0.44	0.41	0.38	0.35	0.33
100	0.49	0.48	0.47	0.46	0.45	0.42	0.39	0.37	0.34
	Cubic expansion coefficient α_V in kK⁻¹								
0	-0.058	-0.026	0.024	0.069	0.110	0.237	0.313	0.355	
10	0.102	0.123	0.156	0.186	0.213	0.297	0.349	0.380	
20	0.218	0.232	0.254	0.274	0.292	0.349	0.384	0.406	
25	0.267	0.278	0.296	0.312	0.327	0.373	0.401	0.420	
30	0.311	0.320	0.334	0.347	0.359	0.395	0.418	0.433	
40	0.389	0.394	0.402	0.410	0.417	0.438	0.451	0.460	
50	0.458	0.460	0.464	0.467	0.470	0.479	0.484	0.486	
60	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	
70	0.58	0.58	0.58	0.57	0.57	0.56	0.55	0.54	
80	0.64	0.63	0.63	0.62	0.61	0.60	0.58	0.56	
90	0.69	0.68	0.67	0.67	0.66	0.63	0.61	0.59	
100	0.74	0.73	0.72	0.71	0.70	0.66	0.64	0.61	

DENSITY OF D_2O

Density of liquid D_2O in g/cm^3 at a pressure of 100 kPa (1 bar).

REFERENCE

Kirillin, V.A., Ed., *Heavy Water: Thermophysical Properties*, Gosudarstvennoe Energeticheskoe Izdatel'stvo, Moscow, 1963.

t/°C	3.8	5	10	15	20	25	30
Density	1.1053	1.1055	1.1057	1.1056	1.105	1.1044	1.1034
t/°C	35	40	45	50	55	60	65
Density	1.1019	1.1001	1.0979	1.0957	1.0931	1.0905	1.0875
t/°C	70	75	80	85	90	95	100
Density	1.0847	1.0815	1.0783	1.0748	1.0712	1.0673	1.0635

VAPOR PRESSURE OF ICE

The values of the vapor (sublimation) pressure of ice in this table were calculated from the equation recommended by the International Association for the Properties of Steam (IAPS) in 1993. Temperature values correspond to the ITS-90 temperature scale. The uncertainty in the pressure is estimated to be 0.1% for $t > -25$°C and 0.5% for $t < -25$°C. The first entry in the table is the triple point of water.

REFERENCE

Wagner, W., Saul, A., and Pruss, A., *J. Phys. Chem. Ref. Data*, 23, 515, 1994.

t/°C	*p*/Pa	*t*/°C	*p*/Pa	*t*/°C	*p*/Pa
0.01	611.657	–16	150.68	–33	27.71
0	611.15	–17	137.25	–34	24.90
–1	562.67	–18	124.92	–35	22.35
–2	517.72	–19	113.62	–36	20.04
–3	476.06	–20	103.26	–37	17.96
–4	437.47	–21	93.77	–38	16.07
–5	401.76	–22	85.10	–39	14.37
–6	368.73	–23	77.16	–40	12.84
–7	338.19	–24	69.91	–45	7.202
–8	309.98	–25	63.29	–50	3.936
–9	283.94	–26	57.25	–55	2.093
–10	259.90	–27	51.74	–60	1.080
–11	237.74	–28	46.73	–65	0.540
–12	217.32	–29	42.16	–70	0.261
–13	198.52	–30	38.01	–75	0.122
–14	181.22	–31	34.24	–80	0.055
–15	165.30	–32	30.82		

VAPOR PRESSURE OF WATER FROM 0 TO 370° C

This table gives the vapor pressure of water at intervals of 1° C from the melting point to the critical point.

REFERENCE

Haar, L., Gallagher, J.S., and Kell, G.S., *NBS/NRC Steam Tables*, Hemisphere Publishing Corp., New York, 1984.

t/°C	*P*/kPa	*t*/°C	*P*/kPa	*t*/°C	*P*/kPa	*t*/°C	*P*/kPa
0	0.61129	53	14.303	106	125.03	159	602.11
1	0.65716	54	15.012	107	129.39	160	617.66
2	0.70605	55	15.752	108	133.88	161	633.53
3	0.75813	56	16.522	109	138.50	162	649.73
4	0.81359	57	17.324	110	143.24	163	666.25
5	0.87260	58	18.159	111	148.12	164	683.10
6	0.93537	59	19.028	112	153.13	165	700.29
7	1.0021	60	19.932	113	158.29	166	717.83
8	1.0730	61	20.873	114	163.58	167	735.70
9	1.1482	62	21.851	115	169.02	168	753.94
10	1.2281	63	22.868	116	174.61	169	772.52
11	1.3129	64	23.925	117	180.34	170	791.47
12	1.4027	65	25.022	118	186.23	171	810.78
13	1.4979	66	26.163	119	192.28	172	830.47
14	1.5988	67	27.347	120	198.48	173	850.53
15	1.7056	68	28.576	121	204.85	174	870.98
16	1.8185	69	29.852	122	211.38	175	891.80
17	1.9380	70	31.176	123	218.09	176	913.03
18	2.0644	71	32.549	124	224.96	177	934.64
19	2.1978	72	33.972	125	232.01	178	956.66
20	2.3388	73	35.448	126	239.24	179	979.09
21	2.4877	74	36.978	127	246.66	180	1001.9
22	2.6447	75	38.563	128	254.25	181	1025.2
23	2.8104	76	40.205	129	262.04	182	1048.9
24	2.9850	77	41.905	130	270.02	183	1073.0
25	3.1690	78	43.665	131	278.20	184	1097.5
26	3.3629	79	45.487	132	286.57	185	1122.5
27	3.5670	80	47.373	133	295.15	186	1147.9
28	3.7818	81	49.324	134	303.93	187	1173.8
29	4.0078	82	51.342	135	312.93	188	1200.1
30	4.2455	83	53.428	136	322.14	189	1226.9
31	4.4953	84	55.585	137	331.57	190	1254.2
32	4.7578	85	57.815	138	341.22	191	1281.9
33	5.0335	86	60.119	139	351.09	192	1310.1
34	5.3229	87	62.499	140	361.19	193	1338.8
35	5.6267	88	64.958	141	371.53	194	1368.0
36	5.9453	89	67.496	142	382.11	195	1397.6
37	6.2795	90	70.117	143	392.92	196	1427.8
38	6.6298	91	72.823	144	403.98	197	1458.5
39	6.9969	92	75.614	145	415.29	198	1489.7
40	7.3814	93	78.494	146	426.85	199	1521.4
41	7.7840	94	81.465	147	438.67	200	1553.6
42	8.2054	95	84.529	148	450.75	201	1586.4
43	8.6463	96	87.688	149	463.10	202	1619.7
44	9.1075	97	90.945	150	475.72	203	1653.6
45	9.5898	98	94.301	151	488.61	204	1688.0
46	10.094	99	97.759	152	501.78	205	1722.9
47	10.620	100	101.32	153	515.23	206	1758.4
48	11.171	101	104.99	154	528.96	207	1794.5
49	11.745	102	108.77	155	542.99	208	1831.1
50	12.344	103	112.66	156	557.32	209	1868.4
51	12.970	104	116.67	157	571.94	210	1906.2
52	13.623	105	120.79	158	586.87	211	1944.6

VAPOR PRESSURE OF WATER FROM 0 TO 370° C (continued)

t/°C	*P*/kPa	*t*/°C	*P*/kPa	*t*/°C	*P*/kPa	*t*/°C	*P*/kPa
212	1983.6	253	4178.9	294	7881.3	335	13701
213	2023.2	254	4249.1	295	7995.2	336	13876
214	2063.4	255	4320.2	296	8110.3	337	14053
215	2104.2	256	4392.2	297	8226.8	338	14232
216	2145.7	257	4465.1	298	8344.5	339	14412
217	2187.8	258	4539.0	299	8463.5	340	14594
218	2230.5	259	4613.7	300	8583.8	341	14778
219	2273.8	260	4689.4	301	8705.4	342	14964
220	2317.8	261	4766.1	302	8828.3	343	15152
221	2362.5	262	4843.7	303	8952.6	344	15342
222	2407.8	263	4922.3	304	9078.2	345	15533
223	2453.8	264	5001.8	305	9205.1	346	15727
224	2500.5	265	5082.3	306	9333.4	347	15922
225	2547.9	266	5163.8	307	9463.1	348	16120
226	2595.9	267	5246.3	308	9594.2	349	16320
227	2644.6	268	5329.8	309	9726.7	350	16521
228	2694.1	269	5414.3	310	9860.5	351	16725
229	2744.2	270	5499.9	311	9995.8	352	16931
230	2795.1	271	5586.4	312	10133	353	17138
231	2846.7	272	5674.0	313	10271	354	17348
232	2899.0	273	5762.7	314	10410	355	17561
233	2952.1	274	5852.4	315	10551	356	17775
234	3005.9	275	5943.1	316	10694	357	17992
235	3060.4	276	6035.0	317	10838	358	18211
236	3115.7	277	6127.9	318	10984	359	18432
237	3171.8	278	6221.9	319	11131	360	18655
238	3228.6	279	6317.0	320	11279	361	18881
239	3286.3	280	6413.2	321	11429	362	19110
240	3344.7	281	6510.5	322	11581	363	19340
241	3403.9	282	6608.9	323	11734	364	19574
242	3463.9	283	6708.5	324	11889	365	19809
243	3524.7	284	6809.2	325	12046	366	20048
244	3586.3	285	6911.1	326	12204	367	20289
245	3648.8	286	7014.1	327	12364	368	20533
246	3712.1	287	7118.3	328	12525	369	20780
247	3776.2	288	7223.7	329	12688	370	21030
248	3841.2	289	7330.2	330	12852	371	21283
249	3907.0	290	7438.0	331	13019	372	21539
250	3973.6	291	7547.0	332	13187	373	21799
251	4041.2	292	7657.2	333	13357	373.98	22055
252	4109.6	293	7768.6	334	13528		

BOILING POINT OF WATER AT VARIOUS PRESSURES

Data are based on the equation of state recommended by the International Association for the Properties of Steam in 1984, as presented in Haar, Gallagher, and Kell, *NBS-NRC Steam Tables* (Hemisphere Publishing Corp., New York, 1984). The temperature scale is IPTS-68.
Note that: 1 mbar = 100 Pa = 0.000986923 atmos = 0.750062 mmHg.

***P*/mbar**	***T*/°C**	***P*/mbar**	***T*/°C**	***P*/mbar**	***T*/°C**	***P*/mbar**	***T*/°C**
50	32.88	915	97.17	1013.25	100.00	1200	104.81
100	45.82	920	97.32	1015	100.05	1250	105.99
150	53.98	925	97.47	1020	100.19	1300	107.14
200	60.07	930	97.62	1025	100.32	1350	108.25
250	64.98	935	97.76	1030	100.46	1400	109.32
300	69.11	940	97.91	1035	100.60	1450	110.36
350	72.70	945	98.06	1040	100.73	1500	111.38
400	75.88	950	98.21	1045	100.87	1550	112.37
450	78.74	955	98.35	1050	101.00	1600	113.33
500	81.34	960	98.50	1055	101.14	1650	114.26
550	83.73	965	98.64	1060	101.27	1700	115.18
600	85.95	970	98.78	1065	101.40	1750	116.07
650	88.02	975	98.93	1070	101.54	1800	116.94
700	89.96	980	99.07	1075	101.67	1850	117.79
750	91.78	985	99.21	1080	101.80	1900	118.63
800	93.51	990	99.35	1085	101.93	1950	119.44
850	95.15	995	99.49	1090	102.06	2000	120.24
900	96.71	1000	99.63	1095	102.19	2050	121.02
905	96.87	1005	99.77	1100	102.32	2100	121.79
910	97.02	1010	99.91	1150	103.59	2150	122.54

MELTING POINT OF ICE AS A FUNCTION OF PRESSURE

This table gives values of the melting temperature of ice at various pressures, as calculated from the equation for the ice I - liquid water phase boundary recommended by the International Association for the Properties of Steam (IAPS). Temperatures are on the ITS-90 scale. See the Reference for information on forms of ice that exist at higher pressures. The transition points for transformations of the various forms of ice (in each case in equilibrium with liquid water) are:

ice I - ice III	209.9 MPa	–21.985°C
ice III - ice V	350.1	–16.986
ice V - ice VI	632.4	0.16
ice VI - ice VII	2216	82

REFERENCE

Wagner, W., Saul, A., and Pruss, A., *J. Phys. Chem. Ref. Data,* 23, 515, 1994.

***p*/MPa**	***t*/°C**	***p*/MPa**	***t*/°C**	***p*/MPa**	***t*/°C**
0.1	0.00	40	-3.15	130	-12.07
1	-0.06	50	-4.02	140	-13.22
2	-0.14	60	-4.91	150	-14.40
3	-0.21	70	-5.83	160	-15.62
4	-0.29	80	-6.79	170	-16.85
5	-0.36	90	-7.78	180	-18.11
10	-0.74	100	-8.80	190	-19.39
20	-1.52	110	-9.86	200	-20.69
30	-2.32	120	-10.95	210	-22.00

PROPERTIES OF WATER AND STEAM AS A FUNCTION OF TEMPERATURE AND PRESSURE

This table gives properties of compressed water and superheated steam at selected pressures and temperatures. The properties included are density ρ, enthalpy H, entropy S, heat capacity at constant pressure C_p, and static dielectric constant (relative permittivity). The table was generated from the formulation approved by the International Association for the Properties of Water and Steam for general and scientific use. The reference state for this table is the liquid at the triple point, at which the internal energy and entropy are taken as zero. A duplicate entry in the temperature column indicates a phase transition (liquid-vapor) at that temperature; property values are then given for both phases. In the 100 MPa section of the table, an entry is given at the critical temperature, 647.10 K. Temperatures refer to the ITS-90 scale, on which the normal boiling point of water is 373.12 K (99.97°C).

REFERENCES

1. Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use, September 1996; available from Executive Secretary of IAPWS, Electric Power Research Institute, 3412 Hillview Ave., Palo Alto, CA 94304-1395.
2. NIST Chemistry WebBook, NIST Standard Reference Database Number 69, Mallard, W. G., and Linstrom, P. J., Eds., March 1998, National Institute of Standards and Technology, Gaithersburg, MD, 20899 (http://webbook.nist.gov).
3. Pruss, A. and Wagner, W., to be published.
4. Fernandez, D. P., Goodwin, A. R. H., Lemmon, E. W., Levelt Sengers, J. M. H., and Williams, R. C., *J. Phys. Chem. Ref. Data*, 26, 1125, 1997. [Dielectric constant]

p/MPa	*T*/K	ρ/kg m^{-3}	*H*/J g^{-1}	*S*/J g^{-1}K^{-1}	C_p/J g^{-1}K^{-1}	Diel. const.
0.1	273.16	999.84	0.10	0.0000	4.2194	87.90
0.1	300	996.56	112.65	0.3931	4.1806	77.75
0.1	325	987.19	217.15	0.7276	4.1819	69.32
0.1	350	973.73	321.84	1.0380	4.1945	61.79
0.1	372.76	958.63	417.50	1.3028	4.2152	55.61
0.1	372.76	0.59034	2674.9	7.3588	2.0784	1.006
0.1	375	0.58653	2679.6	7.3713	2.0686	1.006
0.1	400	0.54761	2730.4	7.5025	2.0078	1.005
0.1	450	0.48458	2829.7	7.7365	1.9752	1.004
0.1	500	0.43514	2928.6	7.9447	1.9813	1.003
0.1	550	0.39507	3028.1	8.1344	2.0010	1.003
0.1	600	0.36185	3128.8	8.3096	2.0268	1.002
0.1	650	0.33384	3230.8	8.4730	2.0557	1.002
0.1	700	0.30988	3334.4	8.6264	2.0867	1.002
0.1	750	0.28915	3439.5	8.7715	2.1191	1.002
0.1	800	0.27102	3546.3	8.9093	2.1525	1.001
0.1	850	0.25504	3654.8	9.0408	2.1868	1.001
0.1	900	0.24085	3765.0	9.1668	2.2216	1.001
0.1	950	0.22815	3876.9	9.2879	2.2568	1.001
0.1	1000	0.21673	3990.7	9.4045	2.2921	1.001
0.1	1050	0.20640	4106.1	9.5172	2.3273	1.001
0.1	1100	0.19701	4223.4	9.6263	2.3621	1.001
0.1	1150	0.18844	4342.3	9.7321	2.3965	1.001
0.1	1200	0.18058	4463.0	9.8348	2.4302	1.001
1	273.16	1000.3	1.02	0.0000	4.2150	87.93
1	300	996.96	113.48	0.3928	4.1781	77.78
1	325	987.58	217.93	0.7272	4.1798	69.36
1	350	974.13	322.56	1.0374	4.1925	61.82
1	375	957.43	427.64	1.3274	4.2158	55.09
1	400	937.87	533.47	1.6005	4.2535	49.06
1	450	890.39	749.20	2.1086	4.3924	38.81
1	453.03	887.13	762.51	2.1381	4.4045	38.23
1	453.03	5.1450	2777.1	6.5850	2.7114	1.042
1	500	4.5323	2891.2	6.8250	2.2795	1.034

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PROPERTIES OF WATER AND STEAM AS A FUNCTION OF TEMPERATURE AND PRESSURE (continued)

p/MPa	*T*/K	ρ/kg m^{-3}	*H*/J g^{-1}	*S*/J $g^{-1}K^{-1}$	C_p/J $g^{-1}K^{-1}$	Diel. const.
1	550	4.0581	3001.8	7.0359	2.1647	1.028
1	600	3.6871	3109.0	7.2224	2.1292	1.024
1	650	3.3843	3215.2	7.3925	2.1254	1.020
1	700	3.1305	3321.7	7.5504	2.1368	1.017
1	750	2.9140	3429.0	7.6984	2.1566	1.015
1	800	2.7265	3537.5	7.8384	2.1816	1.013
1	850	2.5624	3647.3	7.9715	2.2098	1.012
1	900	2.4174	3758.5	8.0986	2.2402	1.011
1	950	2.2882	3871.3	8.2206	2.2721	1.010
1	1000	2.1723	3985.7	8.3380	2.3048	1.009
1	1050	2.0678	4101.8	8.4512	2.3380	1.008
1	1100	1.9729	4219.5	8.5608	2.3713	1.007
1	1150	1.8865	4338.9	8.6669	2.4044	1.007
1	1200	1.8074	4460.0	8.7699	2.4371	1.006
10	273.16	1004.8	10.1	0.000	4.173	88.30
10	300	1001.0	121.7	0.390	4.153	78.11
10	325	991.46	225.6	0.723	4.160	69.67
10	350	978.09	329.7	1.031	4.173	62.13
10	375	961.62	434.4	1.320	4.195	55.40
10	400	942.42	539.6	1.592	4.230	49.39
10	450	896.16	753.9	2.096	4.355	39.17
10	500	838.02	977.1	2.566	4.602	30.79
10	550	761.82	1218	3.027	5.140	23.53
10	584.15	688.42	1408	3.360	6.123	18.70
10	584.15	55.463	2725	5.616	7.140	1.404
10	600	49.773	2820	5.775	5.136	1.365
10	650	40.479	3022	6.100	3.396	1.267
10	700	35.355	3177	6.330	2.874	1.214
10	750	31.810	3314	6.520	2.645	1.179
10	800	29.107	3443	6.686	2.531	1.154
10	850	26.933	3568	6.838	2.473	1.134
10	900	25.123	3691	6.978	2.445	1.118
10	950	23.580	3813	7.110	2.436	1.105
10	1000	22.241	3935	7.235	2.439	1.095
10	1050	21.063	4057	7.354	2.450	1.086
10	1100	20.017	4180	7.469	2.466	1.078
10	1150	19.078	4304	7.579	2.485	1.072
10	1200	18.230	4429	7.685	2.507	1.066
100	273.16	1045.3	95.4	-0.008	3.905	91.83
100	300	1037.2	201.4	0.362	3.979	81.22
100	325	1026.6	301.3	0.682	4.008	72.58
100	350	1013.6	401.7	0.979	4.025	64.95
100	375	998.59	502.6	1.258	4.040	58.19
100	400	981.82	603.7	1.518	4.056	52.20
100	450	943.51	807.8	1.999	4.110	42.15
100	500	899.21	1015	2.436	4.196	34.15
100	550	848.78	1228	2.842	4.323	27.67
100	600	791.49	1448	3.225	4.501	22.29
100	647.10	730.24	1665	3.573	4.733	17.97
100	650	726.21	1679	3.595	4.750	17.72
100	700	651.77	1925	3.958	5.083	13.75
100	750	568.52	2188	4.322	5.449	10.34
100	800	482.23	2466	4.681	5.610	7.562
100	850	404.66	2742	5.016	5.380	5.571
100	900	343.61	3000	5.310	4.887	4.284
100	950	298.61	3231	5.560	4.382	3.477
100	1000	265.45	3440	5.774	3.978	2.956
100	1050	240.32	3631	5.961	3.683	2.601
100	1100	220.62	3809	6.127	3.471	2.347
100	1150	204.71	3979	6.278	3.319	2.158
100	1200	191.53	4142	6.417	3.209	2.011

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PERMITTIVITY (DIELECTRIC CONSTANT) OF WATER AT VARIOUS FREQUENCIES

The permittivity of liquid water in the radiofrequency and microwave regions can be represented by the Debye equation (References 1 and 2):

$$\varepsilon' = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1+\omega^2\tau^2}$$

$$\varepsilon'' = \frac{(\varepsilon_s - \varepsilon_\infty)\omega\tau}{1+\omega^2\tau^2}$$

where $\varepsilon = \varepsilon' + i\,\varepsilon''$ is the (complex) relative permittivity (i.e., the absolute permittivity divided by the permittivity of free space $\varepsilon_0 = 8.854 \cdot 10^{-12}$ F m^{-1}). Here ε_s is the static permittivity (see Reference 3 and the table "Properties of Water in the Range 0—100°C" in this Section); ε_∞ is a parameter describing the permittivity in the high frequency limit; τ is the relaxation time for molecular orientation; and $\omega = 2\pi f$ is the angular frequency. The values in this table have been calculated from parameters given in Reference 2:

	0°C	**25°C**	**50°C**
ε_∞	5.7	5.2	4.0
τ/ps	17.67	8.27	4.75

Other useful quantities that can be calculated from the values in the table are the loss tangent:

$$\tan\delta = \varepsilon''/\varepsilon'$$

and the absorption coefficient α which describes the power attentuation per unit length ($P = P_0\, e^{-\alpha l}$):

$$\alpha = \frac{\pi f\, \varepsilon''}{c\sqrt{\varepsilon'}}$$

and c is the speed of light. The last equation is valid when $\varepsilon''/\varepsilon' << 1$.

REFERENCES

1. Fernendez, D.P., Mulev, Y., Goodwin, A.R.H., and Levelt Sengers, J.M.H., *J. Phys. Chem. Ref. Data*, 24, 33, 1995.
2. Kaatze, U., *J. Chem. Eng. Data*, 34, 371, 1989.
3. Archer, D.G., and Wang, P., *J. Phys. Chem. Ref. Data*, 12, 817, 1983.

	0°C		**25°C**		**50°C**	
Frequency	ε′	ε″	ε′	ε″	ε′	ε″
0	87.90	0.00	78.36	0.00	69.88	0.00
1 kHz	87.90	0.00	78.36	0.00	69.88	0.00
1 MHz	87.90	0.01	78.36	0.00	69.88	0.00
10 MHz	87.90	0.09	78.36	0.04	69.88	0.02
100 MHz	87.89	0.91	78.36	0.38	69.88	0.20
200 MHz	87.86	1.82	78.35	0.76	69.88	0.39
500 MHz	87.65	4.55	78.31	1.90	69.87	0.98
1 GHz	86.90	9.01	78.16	3.79	69.82	1.96
2 GHz	84.04	17.39	77.58	7.52	69.65	3.92
3 GHz	79.69	24.64	76.62	11.13	69.36	5.85
4 GHz	74.36	30.49	75.33	14.58	68.95	7.75
5 GHz	68.54	34.88	73.73	17.81	68.45	9.62
10 GHz	42.52	40.88	62.81	29.93	64.49	18.05
20 GHz	19.56	30.78	40.37	36.55	52.57	28.99
30 GHz	12.50	22.64	26.53	33.25	40.57	32.74
40 GHz	9.67	17.62	18.95	28.58	31.17	32.43
50 GHz	8.28	14.34	14.64	24.53	24.42	30.47

THERMOPHYSICAL PROPERTIES OF FLUIDS

These tables give thermodynamic and transport properties of some important fluids, as generated from the equations of state presented in the references below. The properties tabulated are density (ρ), energy (*E*), enthalpy (*H*), entropy (*S*), isochoric heat capacity (C_v), isobaric heat capacity (C_p), speed of sound (v_s), viscosity (η), thermal conductivity (λ), and dielectric constant (*D*). All extensive properties are given on a molar basis. Not all properties are included for every substance. The references should be consulted for information on the uncertainties and the reference states for *E*, *H*, and *S*.

Values are given as a function of temperature for several isobars. The phase can be determined by noting the sharp decrease in density between two successive temperature entries; all lines above this point refer to the liquid phase, and all lines below refer to the gas phase. If there is no sharp discontinuity in density, all data in the table refer to the supercritical region (i.e., the isobar is above the critical pressure).

REFERENCES

1. Younglove, B.A., *Thermophysical Properties of Fluids. Part I, J. Phys. Chem. Ref. Data*, 11, Suppl. 1, 1982.
2. Younglove, B.A., and Ely, J.F., *Thermophysical Properties of Fluids. Part II, J. Phys. Chem. Ref. Data,* 16, 577, 1987.
3. McCarty, R.D., *Thermodynamic Properties of Helium, J. Phys. Chem. Ref. Data,* 2, 923, 1973.

Nitrogen (N_2)

T K	**ρ** mol/L	***E*** J/mol	***H*** J/mol	***S*** J/mol K	C_v J/mol K	C_p J/mol K	**η** μPa s	**λ** mW/m K	***D***
P = 0.1 MPa (1 bar)									
70	30.017	–3828	–3824	73.8	28.5	57.2	203.9	143.5	1.45269
77.25	28.881	–3411	–3407	79.5	27.8	57.8	152.2	133.8	1.43386
77.25	0.163	1546	2161	151.6	21.6	31.4	5.3	7.6	1.00215
100	0.123	2041	2856	159.5	21.1	30.0	6.8	9.6	1.00162
200	0.060	4140	5800	179.9	20.8	29.2	12.9	18.4	1.00079
300	0.040	6223	8717	191.8	20.8	29.2	18.0	25.8	1.00053
400	0.030	8308	11635	200.2	20.9	29.2	22.2	32.3	1.00040
500	0.024	10414	14573	206.7	21.2	29.6	26.1	38.5	1.00032
600	0.020	12563	17554	212.2	21.8	30.1	29.5	44.5	1.00026
700	0.017	14770	20593	216.8	22.4	30.7	32.8	50.5	1.00023
800	0.015	17044	23698	221.0	23.1	31.4	35.8	56.3	1.00020
900	0.013	19383	26869	224.7	23.7	32.0	38.7	62.0	1.00017
1000	0.012	21786	30103	228.1	24.3	32.6	41.5	67.7	1.00016
1500	0.008	34530	47004	241.8	26.4	34.7	54.0	93.3	1.00010
P = 1 MPa									
70	30.070	–3838	–3805	73.6	28.9	56.9	205.9	144.1	1.45355
80	28.504	–3267	–3232	81.3	27.8	57.7	139.5	130.7	1.42760
90	26.721	–2685	–2648	88.2	26.7	59.4	100.1	115.3	1.39824
100	24.634	–2073	–2032	94.6	26.2	64.4	73.1	98.5	1.36417
103.75	23.727	–1828	–1786	97.1	26.2	67.8	64.8	91.8	1.34947
103.75	1.472	1788	2467	138.1	24.1	45.0	7.6	12.5	1.01954
200	0.614	4048	5675	160.3	21.0	30.4	13.2	19.3	1.00812
300	0.402	6171	8661	172.5	20.9	29.6	18.1	26.3	1.00529
400	0.300	8273	11609	180.9	20.9	29.5	22.4	32.7	1.00395
500	0.240	10389	14563	187.5	21.3	29.7	26.1	38.8	1.00315
600	0.200	12544	17554	193.0	21.8	30.2	29.6	44.8	1.00262
700	0.171	14756	20600	197.7	22.4	30.8	32.8	50.7	1.00224
800	0.150	17032	23709	201.8	23.1	31.4	35.9	56.5	1.00196
900	0.133	19374	26884	205.6	23.7	32.1	38.8	62.2	1.00174
1000	0.120	21778	30121	209.0	24.3	32.7	41.5	67.8	1.00157
1500	0.080	34527	47029	222.7	26.4	34.8	54.0	93.4	1.00104
P = 10 MPa									
65.32	31.120	–4176	–3855	68.6	31.8	53.8	275.7	153.8	1.47067
100	26.201	–2328	–1946	92.0	27.4	56.3	90.2	112.3	1.38942
200	7.117	3037	4442	136.4	22.7	45.5	17.6	30.4	1.09698
300	3.989	5667	8174	151.7	21.4	33.4	20.1	31.9	1.05347
400	2.898	7941	11392	161.0	21.3	31.3	23.7	36.7	1.03860
500	2.302	10148	14492	167.9	21.5	30.8	27.1	42.0	1.03055

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	η μPa s	λ mW/m K	*D*
600	1.918	12361	17575	173.5	21.9	30.9	30.4	47.4	1.02538
700	1.647	14613	20683	178.3	22.5	31.3	33.5	53.0	1.02175
800	1.445	16919	23837	182.5	23.2	31.8	36.4	58.6	1.01904
900	1.288	19283	27046	186.3	23.8	32.4	39.3	64.1	1.01694
1000	1.162	21705	30308	189.8	24.4	32.9	42.0	69.6	1.01526
1500	0.783	34504	47283	203.5	26.5	34.8	54.3	94.7	1.01020

Oxygen (O_2)

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	η μPa s	λ mW/m K	*D*
P = 0.1 MPa (1 bar)									
60	40.049	–5883	–5880	72.4	34.9	53.4	425.2	188.2	1.55619
80	37.204	–4814	–4812	87.7	31.0	53.6	251.7	166.1	1.51114
100	0.123	2029	2840	172.9	21.4	30.5	7.5	9.3	1.00146
120	0.102	2458	3442	178.4	21.0	29.8	9.0	11.2	1.00121
140	0.087	2881	4035	182.9	20.9	29.5	10.5	13.1	1.00103
160	0.076	3301	4624	186.9	20.9	29.4	11.9	15.0	1.00090
180	0.067	3720	5210	190.3	20.8	29.3	13.3	16.7	1.00080
200	0.060	4138	5796	193.4	20.8	29.3	14.6	18.4	1.00072
220	0.055	4556	6381	196.2	20.8	29.3	15.9	20.1	1.00065
240	0.050	4974	6966	198.8	20.9	29.3	17.2	21.7	1.00060
260	0.046	5393	7552	201.1	20.9	29.3	18.4	23.2	1.00055
280	0.043	5812	8138	203.3	21.0	29.4	19.5	24.8	1.00051
300	0.040	6234	8726	205.3	21.1	29.4	20.6	26.3	1.00048
320	0.038	6657	9316	207.2	21.2	29.5	21.7	27.8	1.00045
340	0.035	7082	9908	209.0	21.3	29.7	22.8	29.3	1.00042
360	0.033	7510	10503	210.7	21.5	29.8	23.8	30.8	1.00040
380	0.032	7941	11100	212.3	21.6	30.0	24.8	32.2	1.00038
P = 1 MPa									
60	40.084	–5887	–5863	72.3	34.9	53.3	428.5	188.4	1.55674
80	37.254	–4822	–4795	87.6	31.0	53.5	253.8	166.4	1.51192
100	34.153	–3741	–3712	99.7	28.5	55.2	155.6	137.9	1.46381
120	1.198	2163	2997	156.7	24.0	40.6	9.4	13.9	1.01429
140	0.950	2683	3735	162.4	22.2	34.4	10.8	14.9	1.01133
160	0.802	3151	4398	166.8	21.5	32.2	12.2	16.3	1.00955
180	0.698	3598	5030	170.5	21.2	31.2	13.5	17.7	1.00831
200	0.620	4035	5647	173.8	21.1	30.6	14.8	19.3	1.00738
220	0.559	4466	6255	176.7	21.0	30.3	16.1	20.8	1.00665
240	0.509	4894	6858	179.3	21.0	30.1	17.3	22.3	1.00606
260	0.468	5321	7458	181.7	21.0	29.9	18.5	23.8	1.00556
280	0.433	5748	8056	183.9	21.1	29.9	19.6	25.2	1.00515
300	0.403	6174	8654	186.0	21.1	29.9	20.7	26.7	1.00479
320	0.377	6602	9252	187.9	21.2	29.9	21.8	28.2	1.00448
340	0.355	7032	9851	189.7	21.4	30.0	22.8	29.6	1.00421
360	0.335	7463	10452	191.4	21.5	30.1	23.9	31.1	1.00397
380	0.317	7898	11056	193.1	21.7	30.2	24.9	32.6	1.00376
P = 10 MPa									
60	40.419	–5931	–5684	71.5	35.1	53.0	461.8	189.9	1.56210
80	37.727	–4893	–4628	86.7	31.6	52.7	274.4	168.6	1.51936
100	34.881	–3856	–3570	98.5	29.1	53.4	171.0	141.2	1.47500
120	31.721	–2796	–2481	108.4	27.3	55.9	113.0	115.1	1.42677
140	27.890	–1662	–1304	117.5	26.2	62.9	76.3	91.8	1.36972
160	22.379	-322	125	127.0	26.1	84.8	48.6	71.2	1.29037
180	13.232	1489	2245	139.5	26.6	105.9	26.2	46.8	1.16560
200	8.666	2681	3835	147.9	24.0	60.6	21.2	34.0	1.10650

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	η μPa s	λ mW/m K	*D*
220	6.868	3424	4880	152.9	22.6	46.4	20.5	30.8	1.08380
240	5.836	4029	5742	156.6	22.0	40.6	20.8	30.1	1.07090
260	5.134	4573	6521	159.7	21.8	37.6	21.4	30.2	1.06219
280	4.613	5086	7254	162.5	21.6	35.8	22.1	30.8	1.05575
300	4.205	5581	7959	164.9	21.6	34.7	22.9	31.6	1.05073
320	3.874	6063	8645	167.1	21.7	33.9	23.7	32.6	1.04667
340	3.598	6538	9318	169.1	21.8	33.4	24.6	33.7	1.04329
360	3.363	7009	9982	171.0	21.9	33.0	25.4	34.9	1.04043
380	3.161	7477	10641	172.8	22.0	32.8	26.3	36.1	1.03796

Hydrogen (H_2)

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	v_s m/s	*D*
P = 0.1 MPa (1 bar)								
15	37.738	–605	–603	11.2	9.7	14.4	1319	1.24827
20	35.278	–524	–521	15.8	11.3	19.1	1111	1.23093
40	0.305	491	818	75.6	12.5	21.3	521	1.00186
60	0.201	748	1244	84.3	13.1	21.6	636	1.00122
80	0.151	1030	1694	90.7	15.3	23.7	714	1.00091
100	0.120	1370	2202	96.4	18.7	27.1	773	1.00073
120	0.100	1777	2776	101.6	21.8	30.2	827	1.00061
140	0.086	2237	3401	106.4	23.8	32.2	883	1.00052
160	0.075	2723	4054	110.8	24.6	33.0	940	1.00046
180	0.067	3216	4714	114.7	24.6	32.9	998	1.00041
200	0.060	3703	5367	118.1	24.1	32.4	1054	1.00037
220	0.055	4179	6009	121.2	23.4	31.8	1110	1.00033
240	0.050	4641	6638	123.9	22.8	31.2	1163	1.00030
260	0.046	5093	7256	126.4	22.3	30.6	1214	1.00028
280	0.043	5535	7865	128.6	21.9	30.2	1263	1.00026
300	0.040	5970	8466	130.7	21.6	29.9	1310	1.00024
400	0.030	8093	11421	139.2	21.0	29.3	1518	1.00018
P = 1 MPa								
15	38.109	–609	–583	10.9	10.1	14.1	1315	1.25089
20	35.852	–532	–504	15.5	11.4	18.4	1155	1.23496
40	3.608	399	676	54.1	12.9	28.4	498	1.02209
60	2.098	697	1173	64.3	13.2	23.5	635	1.01280
80	1.523	994	1651	71.1	15.4	24.7	719	1.00928
100	1.204	1343	2174	77.0	18.8	27.7	779	1.00733
120	0.999	1756	2758	82.3	21.9	30.6	835	1.00608
140	0.854	2219	3390	87.1	23.9	32.5	891	1.00520
160	0.747	2709	4048	91.5	24.7	33.2	949	1.00454
180	0.663	3204	4712	95.4	24.6	33.1	1006	1.00404
200	0.597	3693	5368	98.9	24.1	32.5	1063	1.00363
220	0.543	4170	6012	102.0	23.5	31.9	1118	1.00330
240	0.498	4634	6643	104.7	22.9	31.2	1171	1.00303
260	0.460	5087	7263	107.2	22.3	30.7	1222	1.00279
280	0.427	5530	7873	109.5	21.9	30.3	1271	1.00259
300	0.399	5966	8475	111.5	21.6	30.0	1317	1.00242
400	0.299	8091	11433	120.1	21.0	29.4	1525	1.00182
P = 10 MPa								
20	39.669	–568	–316	13.0	10.9	15.0	1458	1.26198
40	31.344	–209	110	27.3	13.2	27.0	1171	1.20354
60	21.273	255	725	39.7	13.8	32.5	931	1.13527
80	14.830	686	1360	48.8	15.9	31.1	886	1.09303
100	11.417	1110	1986	55.8	19.3	31.9	904	1.07109

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	v_s m/s	*D*
120	9.357	1571	2640	61.8	22.4	33.5	941	1.05801
140	7.969	2068	3323	67.0	24.3	34.6	989	1.04925
160	6.963	2583	4020	71.7	25.0	34.9	1042	1.04294
180	6.195	3099	4713	75.7	24.9	34.4	1096	1.03814
200	5.588	3604	5393	79.3	24.4	33.6	1150	1.03436
220	5.094	4094	6057	82.5	23.7	32.8	1203	1.03129
240	4.683	4569	6704	85.3	23.1	32.0	1254	1.02874
260	4.336	5030	7336	87.8	22.6	31.3	1302	1.02659
280	4.038	5481	7958	90.1	22.1	30.8	1349	1.02475
300	3.780	5924	8570	92.3	21.8	30.4	1394	1.02315
400	2.869	8073	11559	100.9	21.2	29.6	1592	1.01753

Helium (He-4)

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	v_s m/s	η μPa s	*D*
P = 0.1 MPa (1 bar)									
3	35.794	–39	–36	9.8	7.6	9.4	222	3.85	1.05646
4	32.477	–27	–24	13.3	9.1	16.3	185	3.33	1.05114
5	2.935	52	86	39.1	12.7	27.1	120	1.39	1.00456
10	1.238	120	201	55.2	12.5	21.7	185	2.26	1.00192
20	0.602	247	413	69.9	12.5	21.0	264	3.58	1.00093
50	0.240	623	1039	89.0	12.5	20.8	417	6.36	1.00037
100	0.120	1247	2079	103.4	12.5	20.8	589	9.78	1.00019
200	0.060	2494	4158	117.8	12.5	20.8	833	15.14	1.00009
300	0.040	3741	6237	126.3	12.5	20.8	1020	19.93	1.00006
400	0.030	4988	8315	132.3	12.5	20.8	1177	24.29	1.00005
500	0.024	6236	10394	136.9	12.5	20.8	1316	28.36	1.00004
600	0.020	7483	12472	140.7	12.5	20.8	1441	32.22	1.00003
700	0.017	8730	14551	143.9	12.5	20.8	1557	35.89	1.00003
800	0.015	9977	16630	146.7	12.5	20.8	1664	39.43	1.00002
900	0.013	11224	18708	149.1	12.5	20.8	1765	42.85	1.00002
1000	0.012	12471	20787	151.3	12.5	20.8	1861	46.16	1.00002
1500	0.008	18707	31179	159.7	12.5	20.8	2279	61.55	1.00001
P = 1 MPa									
3	39.703	–42	–16	8.6	7.1	7.8	300	5.63	1.06274
4	38.210	–34	–7	11.2	8.3	10.9	290	5.01	1.06034
5	35.818	–22	6	14.0	9.7	15.1	269	4.38	1.05650
10	15.378	78	143	32.2	12.3	30.5	198	3.07	1.02402
20	6.067	228	393	49.8	12.6	22.9	274	3.94	1.00943
50	2.353	617	1042	69.8	12.5	21.1	428	6.53	1.00365
100	1.186	1245	2089	84.3	12.5	20.9	597	9.89	1.00184
200	0.597	2495	4170	98.7	12.5	20.8	838	15.21	1.00093
300	0.399	3742	6249	107.1	12.5	20.8	1024	19.96	1.00062
400	0.300	4990	8327	113.1	12.5	20.8	1180	24.32	1.00046
500	0.240	6237	10406	117.8	12.5	20.8	1319	28.38	1.00037
600	0.200	7485	12484	121.5	12.5	20.8	1444	32.23	1.00031
700	0.172	8732	14562	124.7	12.5	20.8	1559	35.91	1.00027
800	0.150	9979	16641	127.5	12.5	20.8	1666	39.44	1.00023
900	0.133	11227	18719	130.0	12.5	20.8	1767	42.86	1.00021
1000	0.120	12474	20798	132.2	12.5	20.8	1862	46.17	1.00019
1500	0.080	18710	31190	140.6	12.5	20.8	2280	61.55	1.00012
P = 10 MPa									
4	51.978	–24	169	6.7	6.0	7.3	586	24.27	1.08262
5	51.118	–18	177	8.5	7.9	9.3	576	18.16	1.08122
10	46.872	23	236	16.6	11.0	14.5	546	9.31	1.07432

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	v_s m/s	η μPa s	*D*
20	37.092	154	423	29.5	12.6	20.7	498	6.99	1.05854
50	19.192	572	1093	49.9	12.9	22.4	541	8.07	1.03003
100	10.525	1231	2181	65.0	12.8	21.3	674	10.93	1.01640
200	5.605	2500	4284	79.6	12.6	20.9	889	15.82	1.00871
300	3.829	3755	6367	88.0	12.6	20.8	1063	20.25	1.00595
400	2.908	5006	8445	94.0	12.6	20.8	1212	24.54	1.00452
500	2.344	6256	10522	98.6	12.5	20.8	1346	28.56	1.00364
600	1.963	7505	12599	102.4	12.5	20.8	1467	32.38	1.00305
700	1.689	8754	14676	105.6	12.5	20.8	1580	36.04	1.00262
800	1.481	10003	16753	108.4	12.5	20.8	1685	39.56	1.00230
900	1.320	11252	18830	110.9	12.5	20.8	1784	42.96	1.00205
1000	1.189	12500	20907	113.0	12.5	20.8	1877	46.26	1.00185
1500	0.797	18742	31294	121.5	12.5	20.8	2289	61.62	1.00124

Argon (Ar)

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	v_s m/s	η μPa s	λ mW/m K
P = 0.1 MPa (1 bar)									
85	35.243	–4811	–4808	53.6	23.1	44.7	820	278.8	132.4
90	0.138	1077	1802	129.4	13.1	22.5	174	7.5	6.0
100	0.123	1211	2024	131.8	12.9	21.9	184	8.2	6.6
120	0.102	1471	2456	135.7	12.6	21.4	203	9.8	7.8
140	0.087	1727	2881	139.0	12.6	21.1	220	11.4	9.0
160	0.076	1980	3302	141.8	12.5	21.0	235	13.0	10.2
180	0.067	2232	3722	144.3	12.5	21.0	250	14.5	11.4
200	0.060	2483	4141	146.5	12.5	20.9	263	16.0	12.5
220	0.055	2734	4559	148.5	12.5	20.9	276	17.5	13.7
240	0.050	2984	4976	150.3	12.5	20.9	289	18.9	14.8
260	0.046	3234	5394	152.0	12.5	20.9	300	20.3	15.8
280	0.043	3484	5811	153.5	12.5	20.8	312	21.6	16.9
300	0.040	3734	6227	155.0	12.5	20.8	323	22.9	17.9
320	0.038	3984	6644	156.3	12.5	20.8	333	24.2	18.9
340	0.035	4234	7060	157.6	12.5	20.8	344	25.4	19.9
360	0.033	4484	7477	158.7	12.5	20.8	354	26.6	20.8
380	0.032	4734	7893	159.9	12.5	20.8	363	27.8	21.7
P = 1 MPa									
85	35.307	–4820	–4792	53.5	23.1	44.6	823	281.3	133.0
90	34.542	–4598	–4569	56.1	21.6	44.7	808	242.7	124.2
100	32.909	–4145	–4115	60.9	19.9	46.2	753	185.0	109.2
120	1.181	1210	2057	114.3	14.7	30.1	189	10.3	9.3
140	0.945	1544	2603	118.5	13.5	25.4	212	11.8	10.1
160	0.799	1838	3089	121.8	13.0	23.6	231	13.3	11.1
180	0.697	2116	3551	124.5	12.8	22.7	247	14.8	12.1
200	0.619	2384	3999	126.9	12.7	22.2	262	16.3	13.2
220	0.559	2648	4438	128.9	12.6	21.8	275	17.7	14.2
240	0.509	2908	4873	130.8	12.6	21.6	288	19.1	15.3
260	0.468	3167	5304	132.6	12.6	21.5	301	20.4	16.3
280	0.433	3423	5732	134.2	12.6	21.4	312	21.8	17.3
300	0.403	3679	6159	135.6	12.5	21.3	324	23.1	18.3
320	0.377	3934	6583	137.0	12.5	21.2	334	24.3	19.2
340	0.355	4188	7007	138.3	12.5	21.2	345	25.5	20.2
360	0.335	4441	7429	139.5	12.5	21.1	355	26.7	21.1
380	0.317	4694	7851	140.6	12.5	21.1	365	27.9	22.0
P = 10 MPa									
90	35.208	–4694	–4410	55.0	21.9	43.2	846	265.2	129.5

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	v_s m/s	η μPa s	λ mW/m K
100	33.744	–4271	–3974	59.6	20.4	44.0	800	205.0	115.1
120	30.525	–3396	–3069	67.8	18.8	46.9	672	131.2	92.1
140	26.609	–2447	–2072	75.5	17.6	54.1	526	85.9	71.7
160	20.816	–1279	–799	83.9	17.4	78.6	357	51.3	52.8
180	12.296	228	1042	94.8	17.3	83.6	257	27.8	32.0
200	8.442	1118	2302	101.4	15.3	48.6	268	23.3	23.6
220	6.776	1661	3137	105.4	14.2	36.8	284	22.8	21.6
240	5.787	2087	3815	108.4	13.7	31.6	300	23.2	21.3
260	5.105	2458	4416	110.8	13.4	28.8	314	23.9	21.4
280	4.596	2798	4974	112.9	13.2	27.1	327	24.8	21.8
300	4.195	3119	5503	114.7	13.1	25.9	339	25.7	22.3
320	3.869	3427	6012	116.3	13.0	25.0	350	26.7	22.9
340	3.596	3726	6506	117.8	13.0	24.4	361	27.7	23.5
360	3.364	4017	6989	119.2	12.9	23.9	372	28.7	24.2
380	3.164	4303	7464	120.5	12.9	23.5	381	29.7	24.9

Methane (CH_4)

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	η μPa s	λ mW/m K	*D*
P = 0.1 MPa (1 bar)									
100	27.370	–5258	–5254	73.0	33.4	54.1	156.3	208.1	1.65504
125	0.099	3026	4039	156.5	25.4	34.6	5.0	13.4	1.00193
150	0.081	3667	4896	162.7	25.2	34.0	5.9	16.2	1.00159
175	0.069	4301	5743	168.0	25.2	33.8	6.9	19.1	1.00136
200	0.061	4935	6587	172.5	25.3	33.8	7.8	21.9	1.00119
225	0.054	5571	7434	176.5	25.5	34.0	8.7	24.8	1.00105
250	0.048	6216	8288	180.1	26.0	34.4	9.6	27.8	1.00095
275	0.044	6875	9156	183.4	26.6	35.0	10.4	30.9	1.00086
300	0.040	7552	10042	186.4	27.5	35.9	11.2	34.1	1.00079
325	0.037	8252	10951	189.4	28.5	36.9	12.0	37.6	1.00073
350	0.034	8979	11887	192.1	29.7	38.0	12.8	41.2	1.00068
375	0.032	9737	12853	194.8	30.9	39.3	13.5	45.1	1.00063
400	0.030	10528	13852	197.4	32.3	40.7	14.3	49.1	1.00059
425	0.028	11354	14886	199.9	33.7	42.1	15.0	53.3	1.00056
450	0.027	12215	15956	202.3	35.2	43.5	15.7	57.6	1.00053
500	0.024	14047	18204	207.1	38.0	46.4	17.0	66.5	1.00047
600	0.020	18111	23101	216.0	42.9	51.3	19.4	84.1	1.00039
P = 1 MPa									
100	27.413	–5268	–5231	72.9	33.4	54.0	158.1	208.9	1.65617
125	25.137	–3882	–3842	85.3	32.4	57.4	89.2	168.2	1.59261
150	0.969	3282	4315	140.9	27.9	45.2	6.2	18.4	1.01911
175	0.765	4041	5348	147.3	26.4	38.9	7.1	20.6	1.01507
200	0.644	4736	6289	152.3	25.9	36.8	8.0	23.1	1.01268
225	0.560	5410	7197	156.6	25.9	36.0	8.9	25.8	1.01102
250	0.497	6081	8093	160.4	26.2	35.8	9.7	28.7	1.00979
275	0.448	6758	8991	163.8	26.8	36.1	10.6	31.7	1.00882
300	0.408	7449	9901	167.0	27.6	36.7	11.4	34.9	1.00803
325	0.375	8160	10829	169.9	28.6	37.6	12.1	38.3	1.00738
350	0.347	8897	11781	172.8	29.7	38.6	12.9	41.9	1.00683
375	0.323	9662	12760	175.5	31.0	39.8	13.6	45.7	1.00636
400	0.302	10460	13770	178.1	32.4	41.1	14.4	49.6	1.00595
425	0.284	11291	14814	180.6	33.8	42.4	15.1	53.8	1.00559
450	0.268	12157	15892	183.1	35.2	43.8	15.7	58.1	1.00527
500	0.241	13997	18153	187.8	38.1	46.6	17.0	66.9	1.00474
600	0.200	18073	23070	196.8	43.0	51.4	19.5	84.5	1.00394

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	η μPa s	λ mW/m K	*D*
P = 10 MPa									
100	27.815	–5362	–5003	72.0	33.8	53.2	175.4	217	1.66668
125	25.754	–4036	–3648	84.1	32.7	55.3	100.4	178.8	1.60895
150	23.441	–2655	–2229	94.4	31.4	58.6	65.7	144.6	1.54553
175	20.613	–1175	–689	103.9	30.3	65.5	44.9	113.4	1.47021
200	16.602	542	1144	113.6	30.1	84.7	29.4	85.8	1.36789
225	10.547	2680	3628	125.3	30.8	102.2	17.6	61.0	1.22352
250	7.013	4289	5714	134.1	29.3	67.4	14.3	47.6	1.14481
275	5.530	5387	7195	139.8	28.7	53.4	13.8	44.1	1.11297
300	4.685	6320	8454	144.2	28.9	48.0	13.9	44.6	1.09513
325	4.115	7192	9622	147.9	29.6	45.8	14.3	46.6	1.08322
350	3.695	8047	10753	151.3	30.5	44.9	14.7	49.2	1.07450
375	3.366	8903	11874	154.4	31.7	44.8	15.2	52.3	1.06773
400	3.101	9774	12999	157.3	32.9	45.2	15.8	55.7	1.06227
425	2.880	10666	14138	160.0	34.3	46.0	16.3	59.4	1.05775
450	2.692	11584	15298	162.7	35.7	46.9	16.9	63.3	1.05392
500	2.389	13507	17692	167.7	38.5	48.9	18.0	71.6	1.04775
600	1.963	17700	22795	177.0	43.3	52.9	20.2	88.3	1.03911

Ethane (C_2H_6)

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	v_s m/s	*D*
P = 0.1 MPa (1 bar)								
95	21.50	–14555	–14550	80.2	47.2	68.7	1970	1.93480
100	21.32	–14210	–14205	83.8	47.1	69.3	1943	1.92500
125	20.41	–12468	–12463	99.3	45.0	69.8	1775	1.87634
150	19.47	–10717	–10712	112.1	43.4	70.4	1587	1.82726
175	18.49	–8938	-8933	123.1	42.7	72.1	1396	1.77671
200	0.062	5503	7123	210.1	34.5	43.8	258	1.00208
225	0.054	6401	8238	215.4	36.5	45.5	273	1.00183
250	0.049	7349	9401	220.3	38.9	47.7	287	1.00164
275	0.044	8360	10624	224.9	41.6	50.2	300	1.00148
300	0.040	9439	11914	229.4	44.5	53.1	312	1.00136
325	0.037	10592	13278	233.8	47.6	56.1	324	1.00125
350	0.035	11823	14719	238.1	50.7	59.2	335	1.00116
375	0.032	13133	16240	242.3	54.0	62.4	345	1.00108
400	0.030	14525	17841	246.4	57.2	65.6	355	1.00101
450	0.027	17548	21282	254.5	63.6	72.0	375	1.00090
500	0.024	20883	25035	262.4	69.7	78.1	393	1.00081
600	0.020	28429	33415	277.6	80.9	89.3	428	1.00067
P = 1 MPa								
95	21.514	–14562	–14515	80.2	47.3	68.7	1972	1.93537
100	21.334	–14217	–14170	83.7	47.2	69.3	1946	1.92560
125	20.427	–12478	–12429	99.2	45.0	69.8	1778	1.87709
150	19.494	–10731	–10679	112.0	43.4	70.3	1592	1.82823
175	18.515	–8957	–8903	123.0	42.7	72.0	1402	1.77800
200	17.464	–7127	–7070	132.7	42.9	74.9	1209	1.72513
225	16.288	–5199	–5137	141.8	43.8	80.2	1008	1.66733
250	0.564	6762	8534	198.7	41.6	57.5	260	1.01909
275	0.489	7902	9949	204.1	43.2	56.2	280	1.01650
300	0.435	9063	11363	209.0	45.5	57.2	297	1.01467
325	0.393	10273	12815	213.7	48.3	59.1	311	1.01327
350	0.360	11546	14321	218.1	51.3	61.5	325	1.01214
375	0.333	12889	15893	222.5	54.4	64.2	337	1.01121
400	0.310	14306	17534	226.7	57.5	67.1	349	1.01043

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	v_s m/s	*D*
450	0.272	17367	21038	234.9	63.8	73.0	370	1.00917
500	0.244	20730	24836	242.9	69.9	78.9	390	1.00819
600	0.201	28313	33278	258.3	81.0	89.8	427	1.00677
P = 10 MPa								
95	21.624	–14626	–14163	79.5	47.4	68.5	2000	1.94104
100	21.448	–14286	–13819	83.0	47.4	69.1	1974	1.93146
125	20.570	–12572	–12086	98.5	45.5	69.3	1814	1.88436
150	19.678	–10858	–10350	111.1	43.9	69.6	1637	1.83753
175	18.758	–9130	–8596	121.9	43.3	70.8	1459	1.79010
200	17.793	–7363	–6801	131.5	43.5	73.0	1284	1.74134
225	16.760	–5535	–4938	140.3	44.3	76.4	1110	1.69017
250	15.620	–3609	–2969	148.6	45.8	81.5	935	1.63488
275	14.301	–1539	–839	156.7	47.9	89.4	758	1.57249
300	12.666	757	1547	165.0	50.8	102.7	577	1.49740
325	10.398	3443	4404	174.1	54.7	129.1	399	1.39745
350	7.292	6643	8015	184.8	58.8	150.1	290	1.26832
375	5.182	9419	11349	194.1	60.0	115.7	289	1.18570
400	4.182	11577	13968	200.8	61.4	96.9	310	1.14797
450	3.204	15379	18500	211.5	65.8	87.5	347	1.11193
500	2.677	19135	22870	220.7	71.2	88.0	378	1.09288
600	2.076	27160	31978	237.3	81.8	94.7	427	1.07142

Propane (C_3H_8)

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	v_s m/s	*D*
P = 0.1 MPa (1 bar)								
90	16.526	–21486	–21426	87.3	59.2	84.5	2126	2.07988
100	16.295	–20639	–20577	96.2	59.6	85.2	2041	2.05806
125	15.726	–18495	–18432	115.4	59.2	86.5	1856	2.00674
150	15.156	–16319	–16253	131.3	58.9	88.0	1685	1.95796
175	14.577	–14096	–14028	145.0	59.5	90.3	1521	1.91036
200	13.982	–11806	–11735	157.3	61.0	93.5	1359	1.86300
225	13.339	–9395	–9387	168.5	63.4	97.9	1197	1.81487
250	0.050	9194	11213	257.6	57.2	66.8	228	1.00238
275	0.045	10691	12930	264.1	61.6	70.7	239	1.00215
300	0.041	12297	14752	270.5	66.2	75.1	249	1.00195
325	0.037	14019	16689	276.7	71.1	79.8	259	1.00179
350	0.035	15862	18744	282.8	76.0	84.6	269	1.00166
375	0.032	17827	20921	288.8	80.9	89.5	278	1.00154
400	0.030	19912	23217	294.7	85.7	94.3	286	1.00144
450	0.027	24441	28166	306.4	95.2	103.6	303	1.00128
500	0.024	29428	33573	317.7	104.1	112.6	318	1.00115
600	0.020	40677	45658	339.7	120.4	128.8	347	1.00095
P = 1 MPa								
90	16.526	–21486	–21426	87.2	59.3	84.5	2128	2.08034
100	16.295	–20639	–20577	96.2	59.7	85.2	2043	2.05856
125	15.726	–18495	–18432	115.3	59.2	86.4	1859	2.00736
150	15.156	–16319	–16253	131.2	59.0	88.0	1690	1.95873
175	14.577	–14096	–14028	144.9	59.6	90.2	1526	1.91132
200	13.982	–11806	–11735	157.2	61.1	93.4	1365	1.86421
225	13.361	–9424	–9349	168.4	63.4	97.7	1205	1.81642
250	12.696	–6919	–6840	179.0	66.4	103.3	1045	1.76672
275	11.962	–4252	–4169	189.1	70.0	110.8	881	1.71316
300	11.102	–1360	–1270	199.2	74.1	121.9	708	1.65216
325	0.428	13278	15614	255.2	74.1	89.6	233	1.02067

T K	ρ mol/L	*E* J/mol	*H* J/mol	*S* J/mol K	C_v J/mol K	C_p J/mol K	v_s m/s	*D*
350	0.383	15259	17869	261.9	78.0	91.2	248	1.01846
375	0.349	17318	20183	268.3	82.2	94.2	261	1.01678
400	0.322	19472	22582	274.4	86.7	97.8	272	1.01544
450	0.279	24092	27672	286.4	95.7	105.9	293	1.01337
500	0.248	29137	33172	298.0	104.4	114.1	312	1.01184
600	0.203	40455	45374	320.2	120.5	129.7	344	1.00968
P = 10 MPa								
90	16.590	–21553	–20951	86.5	59.9	84.4	2146	2.08489
100	16.364	–20714	–20103	95.4	60.1	85.1	2068	2.06350
125	15.810	–18595	–17962	114.5	59.6	86.1	1895	2.01342
150	15.259	–16448	–15793	130.3	59.3	87.5	1733	1.96617
175	14.705	–14261	–13581	144.0	59.9	89.5	1577	1.92048
200	14.141	–12016	–11309	156.1	61.4	92.4	1425	1.87557
225	13.562	–9692	–8955	167.2	63.7	96.1	1277	1.83076
250	12.960	–7268	–6496	177.5	66.7	100.7	1133	1.78529
275	12.322	–4721	–3909	187.4	70.2	106.4	991	1.73826
300	11.631	–2027	–1167	196.9	74.1	113.2	851	1.68849
325	10.860	843	1764	206.3	78.4	121.5	715	1.63437
350	9.973	3924	4927	215.7	82.9	132.0	582	1.57361
375	8.905	7270	8393	225.2	87.7	146.1	455	1.50271
400	7.561	10957	12279	235.3	93.0	165.7	339	1.41671
450	4.614	18845	21013	255.8	101.8	167.8	249	1.24060
500	3.241	25567	28652	272.0	107.8	142.7	276	1.16439
600	2.242	38131	42591	297.4	121.7	140.5	332	1.11122

VIRIAL COEFFICIENTS OF SELECTED GASES

Henry V. Kehiaian

This table gives second virial coefficients of about 110 inorganic and organic gases as a function of temperature. Selected data from the literature have been fitted by least squares to the equation

$$B/\text{cm}^3\,\text{mol}^{-1} = \sum_{i=1}^{n} a(i)\left[\left(T_o/T\right)-1\right]^{i-1}$$

where T_o = 298.15 K. The table gives the coefficients $a(i)$ and values of B at fixed temperature increments, as calculated from this smoothing equation.

The equation may be used with the tabulated coefficients for interpolation within the indicated temperature range. It should not be used for extrapolation beyond this range.

Compounds are listed in the modified Hill order (see Introduction), with carbon-containing compounds following those compounds not containing carbon.

A useful compilation of virial coefficient data from the literature may be found in:

J. H. Dymond and E. B. Smith, *The Virial Coefficients of Pure Gases and Mixtures, A Critical Compilation*, Oxford University Press, Oxford, 1980.

Compounds Not Containing Carbon

Mol. form.	**Name**	***T*/K**	***B*/cm³ mol⁻¹**
Ar	Argon	100	–184
		120	–131
		140	–98
	a(1) = –16	160	–76
	a(2) = –60	80	–60
	a(3) = –10	200	–48
		300	–16
		400	–1
		500	7
		600	12
		700	15
		800	18
		900	20
		1000	22
BF_3	Boron trifluoride	200	–338
		240	–202
		280	–129
	a(1) = –106	320	–85
	a(2) = –330	360	–56
	a(3) = –251	400	–37
	a(4) = –80	440	–23
ClH	Hydrogen chloride	190	–451
		230	–269
		270	–181
	a(1) = –144	310	–132
	a(2) = –325	350	–102
	a(3) = –277	390	–81
	a(4) = –170	430	–66
		470	–54
Cl_2	Chlorine	210	–508
		220	–483

Mol. form.	Name	*T*/K	*B*/cm^3 mol^{-1}
		230	–457
	a(1) = –303	240	–432
	a(2) = –555	250	–407
	a(3) = 9	260	–383
	a(4) = 329	270	–360
	a(5) = 68	280	–339
		290	–318
		300	–299
		350	–221
		400	–166
		450	–126
		500	–97
		600	–59
		700	–36
		800	–22
		900	–12
F_2	Fluorine	80	–386
		110	–171
		140	–113
	a(1) = –25	170	–73
	a(2) = 21	200	–47
	a(3) = –185	230	–32
	a(4) = 113	260	–25
F_4Si	Silicon tetrafluoride	210	–268
		240	–213
		270	–170
	a(1) = –138	300	–136
	a(2) = –312	330	–108
		360	–84
		390	–64
		420	–47
		450	–32
F_5I	Iodine pentafluoride	320	–2540
		330	–2344
		340	–2172
	a(1) = –3077	350	–2021
	a(2) = –8474	360	–1890
	a(3) = –9116	370	–1775
		380	–1674
		390	–1587
		400	–1510
		410	–1443
F_5P	Phosphorus pentafluoride	320	–162
		340	–143
		360	–127
	a(1) = –186	380	–112
	a(2) = –345	400	–98
		420	–86
		440	–75
		460	–64
F_6Mo	Molybdenum hexafluoride	300	–896
		310	–810
		320	–737

VIRIAL COEFFICIENTS OF SELECTED GASES (continued)

Mol. form.	Name	*T*/K	*B*/cm³ mol⁻¹
	a(1) = –914	330	–677
	a(2) = –2922	340	–627
	a(3) = –4778	350	–586
		360	–553
		370	–527
		380	–506
		390	–491
F_6S	Sulfur hexafluoride	200	–685
		250	–416
		300	–275
	a(1) = –279	350	–190
	a(2) = –647	400	–135
	a(3) = –335	450	–96
	a(4) = –72	500	–68
F_6U	Uranium hexafluoride	320	–1030
		340	–905
		360	–805
	a(1) = –1204	380	–724
	a(2) = –2690	400	–658
	a(3) = –2144	420	–604
		440	–560
F_6W	Tungsten hexafluoride	320	–641
		340	–578
		360	–523
	a(1) = –719	380	–473
	a(2) = –1143	400	–428
		420	–387
		440	–350
		460	–317
H_2	Hydrogen	15	–230
		20	–151
		25	–108
	a(1) = 15.4	30	–82
	a(2) = –9.0	35	–64
	a(3) = –0.2	40	–52
		45	–42
		50	–35
		60	–24
		70	–16
		80	–11
		90	–7
		100	–3
		200	11
		300	15
		400	18
H_2O	Water	300	–1126
		320	–850
		340	–660
	a(1) = –1158	360	–526
	a(2) = –5157	380	–428
	a(3) = –10301	400	–356
	a(4) =–10597	420	–301
	a(5) = –4415	440	–258

Mol. form.	Name	*T*/K	*B*/cm^3 mol^{-1}
		460	–224
		480	–197
		500	–175
		600	–104
		700	–67
		800	–44
		900	–30
		1000	–20
		1100	–14
		1200	–11
H_3N	Ammonia	290	–302
		300	–265
		310	–236
	a(1) = –271	320	–213
	a(2) = –1022	330	–194
	a(3) = –2715	340	–179
	a(4) = –4189	350	–166
		360	–154
		370	–144
		380	–135
		400	–118
		420	–101
H_3P	Phosphine	190	–457
		200	–404
		210	–364
	a(1) = –146	220	–332
	a(2) = –733	230	–305
	a(3) = 1022	240	–281
	a(4) = –1220	250	–258
		260	–235
		270	–213
		280	–190
		290	–166
He	Helium	2	–172
		6	–48
		10	–24
	a(1) = 12	14	–13
	a(2) = –1	18	–7
		22	–3
		26	–1
		30	1
		50	6
		70	8
		90	10
		110	10
		150	11
		250	12
		650	13
		700	13
Kr	Krypton	110	–363
		120	–307
		130	–263
	a(1) = –51	140	–229
	a(2) = –118	150	–201

Mol. form.	Name	*T*/K	*B*/cm^3 mol^{-1}
	a(3) = –29	160	–178
	a(4) = –5	170	–159
		180	–143
		190	–129
		200	–117
		250	–75
		300	–51
		400	–23
		500	–8
		600	2
		700	8
NO	Nitric oxide	120	–232
		130	–176
		140	–138
	a(1) = –12	150	–113
	a(2) = –119	160	–96
	a(3) = 89	170	–83
	a(4) = –73	180	–73
		190	–65
		200	–58
		210	–52
		230	–42
		250	–32
		270	–24
N_2	Nitrogen	75	–274
		100	–161
		125	–104
	a(1) = –4	150	–71
	a(2) = –56	175	–49
	a(3) = –12	200	–34
		225	–24
		250	–15
		300	–4
		400	9
		500	16
		600	21
		700	24
N_2O	Nitrous oxide	240	–219
		260	–181
		280	–151
	a(1) = –130	300	–128
	a(2) = –307	320	–110
	a(3) = –248	340	–96
		360	–85
		380	–76
		400	–68
Ne	Neon	60	–25
		80	–13
		100	–6
	a(1) = 10.8	120	–1
	a(2) = –7.5	140	2
	a(3) = 0.4	160	4
		180	6
		200	7

Mol. form.	Name	*T*/K	*B*/cm^3 mol^{-1}
		300	11
		400	13
		500	14
		600	15
O_2	Oxygen	90	–241
		110	–161
		130	–117
	a(1) = –16	150	–88
	a(2) = –62	170	–69
	a(3) = –8	190	–55
	a(4) = –3	210	–44
		230	–36
		250	–29
		270	–23
		290	–18
		310	–14
		330	–10
		350	–7
		400	–1
O_2S	Sulfur dioxide	290	–465
		320	–354
		350	–276
	a(1) = –430	380	–221
	a(2) = –1193	410	–181
	a(3) = –1029	440	–153
		470	–132
Xe	Xenon	160	–421
		170	–377
		180	–340
	a(1) = –130	190	–307
	a(2) = –262	200	–280
	a(3) = –87	210	–255
		220	–234
		230	–215
		240	–199
		250	–184
		300	–129
		350	–93
		400	–69
		500	–39
		600	–21
		650	–14

Compounds Containing Carbon

Mol. form.	Name	*T*/K	*B*/cm^3 mol^{-1}
$CClF_3$	Chlorotrifluoromethane	240	–369
		290	–237
		340	–165
	a(1) = –223	390	–119
	a(2) = –504	440	–86
	a(3) = –340	490	–60
	a(4) = –291	540	–39

VIRIAL COEFFICIENTS OF SELECTED GASES (continued)

Mol. form.	Name	*T*/K	*B*/cm^3 mol^{-1}
CCl_2F_2	Dichlorodifluoromethane	250	–769
		280	–570
		310	–441
	a(1) = –486	340	–353
	a(2) = –1217	370	–289
	a(3) = –1188	400	–241
	a(4) = –698	430	–204
		460	–174
CCl_3F	Trichlorofluoromethane	240	–1140
		280	–879
		320	–689
	a(1) = –786	360	–545
	a(2) = –1428	400	–431
	a(3) = –142	440	–340
		480	–265
CCl_4	Tetrachloromethane	320	–1345
		340	–1171
		360	–1040
	a(1) = –1600	380	–942
	a(2) = –4059	400	–868
	a(3) = –4653	420	–814
CF_4	Tetrafluoromethane	250	–137
		300	–87
		350	–55
	a(1) = –88	400	–32
	a(2) = –238	450	–16
	a(3) = –70	500	–4
		600	14
		700	25
		800	33
$CHClF_2$	Chlorodifluoromethane	300	–343
		325	–298
		350	–257
	a(1) = –347	375	–221
	a(2) = –575	400	–188
	a(3) = 187	425	–158
$CHCl_2F$	Dichlorofluoromethane	250	–728
		275	–634
		300	–557
	a(1) = –562	325	–491
	a(2) = –862	350	–434
		375	–385
		400	–343
		425	–305
		450	–271
$CHCl_3$	Trichloromethane	320	–1001
		330	–926
		340	–858
	a(1) = –1193	350	–797
	a(2) = –2936	360	–740
	a(3) = –1751	370	–689
		380	–642

VIRIAL COEFFICIENTS OF SELECTED GASES (continued)

Mol. form.	Name	*T*/K	*B*/cm³ mol⁻¹
		390	–599
		400	–559
CHF_3	Trifluoromethane	200	–433
		220	–350
		240	–288
	a(1) = –177	260	–241
	a(2) = –399	280	–204
	a(3) = –250	300	–174
		320	–151
		340	–132
		360	–116
		380	–103
		400	–91
CH_2Cl_2	Dichloromethane	320	–706
		330	–634
		340	–574
	a(1) = –913	350	–524
	a(2) = –3371	360	–482
	a(3) = –5013	370	–447
		380	–420
		400	–380
		420	–357
CH_2F_2	Difluoromethane	280	–375
		290	–343
		300	–316
	a(1) = –321	310	–294
	a(2) = –754	320	–275
	a(3) = –1300	330	–260
		340	–248
		350	–238
CH_3Br	Bromomethane	280	–645
		290	–596
		300	–551
	a(1) = –559	310	–509
	a(2) = –1324	320	–469
		340	–396
		360	–332
		380	–274
CH_3Cl	Chloromethane	280	–466
		300	–402
		320	–348
	a(1) = –407	340	–304
	a(2) = –887	360	–266
	a(3) = –385	380	–234
		400	–206
		420	–182
		440	–161
		460	–142
		480	–126
		500	–112
		600	–58
CH_3F	Fluoromethane	280	–244

VIRIAL COEFFICIENTS OF SELECTED GASES (continued)

Mol. form.	Name	*T*/K	*B*/cm³ mol⁻¹
		300	–205
		320	–174
	a(1) = –209	340	–150
	a(2) = –525	360	–129
	a(3) = –365	380	–112
		400	–99
		420	–87
CH_3I	Iodomethane	310	–725
		320	–646
		330	–582
	a(1) = –844	340	–531
	a(2) = –3353	350	–492
	a(3) = –6590	360	–462
		370	–441
		380	–427
CH_4	Methane	110	–328
		120	–276
		130	–237
	a(1) = –43	140	–206
	a(2) = –114	150	–181
	a(3) = –19	160	–160
	a(4) = –7	170	–143
		180	–128
		190	–116
		200	–105
		250	–66
		300	–43
		350	–27
		400	–16
		500	0
		600	10
CH_4O	Methanol	320	–1431
		330	–1299
		340	–1174
	a(1) = –1752	350	–1056
	a(2) = –4694	360	–945
		370	–840
		380	–741
		390	–646
		400	–557
CH_5N	Methylamine	300	–451
		325	–367
		350	–304
	a(1) = –459	375	–257
	a(2) = –1191	400	–220
	a(3) = –995	425	–192
		450	–170
		500	–140
		550	–122
CO	Carbon monoxide	210	–36
		240	–24
		270	–15
	a(1) = –9	300	–8

VIRIAL COEFFICIENTS OF SELECTED GASES (continued)

Mol. form.	Name	T/K	B/cm^3 mol^{-1}
	a(2) = –58	330	–3
	a(3) = –18	360	1
		420	7
		480	11
CO_2	Carbon dioxide	220	–244
		240	–204
		260	–172
	a(1) = –127	280	–146
	a(2) = –288	300	–126
	a(3) = –118	320	–108
		340	–94
		360	–81
		380	–71
		400	–62
		500	–30
		600	–13
		700	–1
		800	7
		900	12
		1000	16
		1100	19
CS_2	Carbon disulfide	280	–932
		310	–740
		340	–603
	a(1) = –807	370	–504
	a(2) = –1829	400	–431
	a(3) = –1371	430	–375
$C_2Cl_2F_4$	1,2-Dichloro-1,1,2,2-tetrafluoroethane	300	–801
		320	–695
		340	–608
	a(1) = –812	360	–536
	a(2) = –1773	380	–475
	a(3) = –963	400	–423
		420	–379
		440	–341
		460	–307
		480	–279
		500	–253
$C_2Cl_3F_3$	1,1,2-Trichloro-1,2,2-trifluoroethane	290	–1041
		310	–943
		330	–856
	a(1) = –999	350	–780
	a(2) = –1479	370	–712
		390	–651
		410	–596
		430	–546
		450	–500
C_2H_2	Ethyne	200	–573
		210	–500
		220	–440
	a(1) = –216	230	–390
	a(2) = –375	240	–349
	a(3) = –716	250	–315

Mol. form.	Name	*T*/K	*B*/cm³ mol⁻¹
		260	–287
		270	–263
C_2H_3N	Ethanenitrile	330	–3468
		340	–2971
		350	–2563
	a(1) = –5840	360	–2233
	a(2) = –29175	370	–1970
	a(3) = –47611	380	–1765
		390	–1610
		400	–1499
		410	–1425
C_2H_4	Ethene	240	–218
		270	–172
		300	–139
	a(1) = –140	330	–113
	a(2) = –296	360	–92
	a(3) = –101	390	–76
		420	–63
		450	–52
$C_2H_4Cl_2$	1,2-Dichloroethane	370	–812
		390	–716
		410	–635
	a(1) = –1362	430	–566
	a(2) = –3240	450	–508
	a(3) = –2100	470	–458
		490	–416
		510	–379
		530	–347
		550	–319
		570	–295
C_2H_4O	Ethanal	290	–1352
		320	–927
		350	–654
	a(1) = –1217	380	–482
	a(2) = –4647	410	–375
	a(3) = –5725	440	–314
		470	–283
$C_2H_4O_2$	Methyl methanoate	320	–821
		330	–744
		340	–677
	a(1) = –1035	350	–620
	a(2) = –3425	360	–571
	a(3) = –4203	370	–528
		380	–492
		390	–461
		400	–435
C_2H_5Cl	Chloroethane	320	–634
		360	–450
		400	–330
	a(1) = –777	440	–249
	a(2) = –2205	480	–195
	a(3) = –1764	520	–157

VIRIAL COEFFICIENTS OF SELECTED GASES (continued)

Mol. form.	Name	*T*/K	*B*/cm^3 mol^{-1}
		560	–131
		600	–114
C_2H_6	Ethane	200	–409
		220	–337
		240	–284
	a(1) = –184	260	–242
	a(2) = –376	280	–209
	a(3) = –143	300	–181
	a(4) = –54	320	–159
		340	–140
		360	–123
		380	–109
		400	–96
		500	–52
		600	–24
C_2H_6O	Ethanol	320	–2710
		330	–2135
		340	–1676
	a(1) = –4475	350	–1317
	a(2) = –29719	360	–1043
	a(3) = –56716	370	–843
		380	–705
		390	–622
C_2H_6O	Dimethyl ether	275	–536
		280	–517
		285	–499
	a(1) = –455	290	–482
	a(2) = –965	295	–465
		300	–449
		305	–433
		310	–418
C_2H_7N	Dimethylamine	310	–606
		320	–563
		330	–523
	a(1) = –662	340	–487
	a(2) = –1504	350	–454
	a(3) = –667	360	–423
		370	–395
		380	–369
		390	–345
		400	–322
C_2H_7N	Ethylamine	300	–773
		310	–710
		320	–654
	a(1) = –785	330	–604
	a(2) = –2012	340	–558
	a(3) = –1397	350	–517
		360	–480
		370	–447
		380	–416
		390	–389
		400	–363
C_3H_6	Cyclopropane	300	–383

Mol. form.	Name	*T*/K	*B*/cm³ mol⁻¹
		310	–356
		320	–332
	a(1) = –388	330	–310
	a(2) = –861	340	–290
	a(3) = –538	350	–272
		360	–256
		370	–241
		380	–227
		390	–215
		400	–204
C_3H_6	Propene	280	–395
		300	–342
		320	–299
	a(1) = –347	340	–262
	a(2) = –727	360	–232
	a(3) = –325	380	–205
		400	–183
		420	–163
		440	–146
		460	–131
		480	–118
		500	–106
C_3H_6O	2-Propanone	300	–1996
		320	–1522
		340	–1198
	a(1) = –2051	360	–971
	a(2) = –8903	380	–806
	a(3) = –18056	400	–683
	a(4) = –16448	420	–586
		440	–506
		460	–437
		480	–375
C_3H_6O	Ethyl methanoate	330	–1003
		340	–916
		350	–839
	a(1) = –1371	360	–771
	a(2) = –4231	370	–712
	a(3) = –4312	380	–660
		390	–614
C_3H_6O	Methyl ethanoate	320	–1320
		330	–1186
		340	–1074
	a(1) = –1709	350	–980
	a(2) = –6348	360	–903
	a(3) = –9650	370	–840
		380	–789
		390	–749
C_3H_7Cl	1-Chloropropane	310	–1001
		340	–772
		370	–614
	a(1) = –1121	400	–501
	a(2) = –3271	430	–417
	a(3) = –3786	460	–352
	a(4) = –1974	490	–302

Mol. form.	Name	*T*/K	*B*/cm^3 mol^{-1}
		520	–261
		550	–227
		580	–198
C_3H_8	Propane	240	–641
		260	–527
		280	–444
	a(1) = –386	300	–381
	a(2) = –844	320	–331
	a(3) = –720	340	–292
	a(4) = –574	360	–259
		380	–232
		400	–208
		440	–169
		480	–138
		520	–112
		560	–90
C_3H_8O	1-Propanol	380	–873
		385	–826
		390	–783
	a(1) = –2690	395	–744
	a(2) = –12040	400	–709
	a(3) = –16738	405	–679
		410	–651
		415	–627
		420	–606
C_3H_8O	2-Propanol	380	–821
		385	–766
		390	–717
	a(1) = –3165	395	–674
	a(2) = –16092	400	–636
	a(3) = –24197	405	–604
		410	–576
		415	–552
		420	–533
C_3H_9N	Trimethylamine	310	–675
		320	–628
		330	–585
	a(1) = –737	340	–547
	a(2) = –1669	350	–512
	a(3) = –986	360	–480
		370	–450
C_4H_8	1-Butene	300	–624
		320	–539
		340	–470
	a(1) = –633	360	–413
	a(2) = –1442	380	–366
	a(3) = –932	400	–327
		420	–294
C_4H_8O	2-Butanone	310	–2056
		320	–1878
		330	–1712
	a(1) = –2282	340	–1555

VIRIAL COEFFICIENTS OF SELECTED GASES (continued)

Mol. form.	Name	*T*/K	*B*/cm^3 mol^{-1}
	a(2) = –5907	350	–1407
		360	–1267
		370	–1135
$C_4H_8O_2$	Propyl methanoate	330	–1496
		340	–1354
		350	–1231
	a(1) = –2118	360	–1126
	a(2) = –7299	370	–1035
	a(3) = –8851	380	–957
		390	–890
		400	–834
$C_4H_8O_2$	Ethyl ethanoate	330	–1543
		340	–1385
		350	–1254
	a(1) = –2272	360	–1144
	a(2) = –8818	370	–1055
	a(3) = –13130	380	–982
		390	–923
		400	–878
$C_4H_8O_2$	Methyl propanoate	330	–1588
		340	–1444
		350	–1319
	a(1) = –2216	360	–1211
	a(2) = –7339	370	–1117
	a(3) = –8658	380	–1037
		390	–968
		400	–908
C_4H_9Cl	1-Chlorobutane	330	–1224
		370	–898
		410	–691
	a(1) = –1643	450	–551
	a(2) = –4897	490	–449
	a(3) = –6178	530	–371
	a(4) = –3718	570	–309
C_4H_{10}	Butane	250	–1170
		280	–863
		310	–668
	a(1) = –735	340	–536
	a(2) = –1835	370	–442
	a(3) = –1922	400	–371
	a(4) = –1330	430	–315
		460	–270
		490	–232
		520	–199
		550	–171
C_4H_{10}	2-Methylpropane	270	–900
		300	–697
		330	–553
	a(1) = –707	360	–450
	a(2) = –1719	390	–374
	a(3) = –1282	420	–317
		450	–273

Mol. form.	Name	*T*/K	*B*/cm³ mol⁻¹
		480	–240
		510	–215
$C_4H_{10}O$	1-Butanol	350	–1693
		360	–1544
		370	–1402
	a(1) = –2629	380	–1268
	a(2) = –6315	390	–1141
		400	–1021
		420	–796
		440	–593
$C_4H_{10}O$	2-Methyl-1-propanol	390	–1076
		400	–979
		410	–887
	a(1) = –2269	420	–800
	a(2) = –5065	430	–716
		440	–636
$C_4H_{10}O$	2-Butanol	380	–1110
		390	–1005
		400	–906
	a(1) = –2232	410	–811
	a(2) = –5209	420	–721
$C_4H_{10}O$	2-Methyl-2-propanol	380	–924
		390	–827
		400	–736
	a(1) = –1952	410	–649
	a(2) = –4775	420	–567
$C_4H_{10}O$	Diethyl ether	280	–1550
		300	–1199
		320	–954
	a(1) = –1226	340	–776
	a(2) = –4458	360	–638
	a(3) = –7746	380	–525
	a(4) = –10005	400	–428
		420	–340
$C_4H_{11}N$	Diethylamine	320	–1228
		330	–1134
		340	–1056
	a(1) = –1522	350	–988
	a(2) = –5204	360	–926
	a(3) = –15047	370	–868
	a(4) = –28835	380	–812
		390	–755
		400	–697
C_5H_5N	Pyridine	350	–1257
		360	–1176
		370	–1099
	a(1) = –1765	380	–1026
	a(2) = –3431	390	–957
		400	–892
		420	–770
		440	–659

Mol. form.	Name	*T*/K	*B*/cm³ mol⁻¹
C_5H_{10}	Cyclopentane	300	–1049
		305	–1015
		310	–981
	a(1) = –1062	315	–949
	a(2) = –2116	320	–918
C_5H_{10}	1-Pentene	310	–966
		320	–898
		330	–836
	a(1) = –1055	340	–780
	a(2) = –2377	350	–729
	a(3) = –1189	360	–681
		370	–638
		380	–598
		390	–561
		400	–527
		410	–495
$C_5H_{10}O$	2-Pentanone	330	–2850
		340	–2420
		350	–2076
	a(1) = –4962	360	–1804
	a(2) = –26372	370	–1595
	a(3) = –46537	380	–1440
		390	–1332
C_5H_{12}	Pentane	300	–1234
		310	–1130
		320	–1038
	a(1) = –1254	330	–957
	a(2) = –3345	340	–884
	a(3) = –2726	350	–818
		400	–579
		450	–436
		500	–348
		550	–294
C_5H_{12}	2-Methylbutane	280	–1263
		290	–1166
		300	–1079
	a(1) = –1095	310	–1001
	a(2) = –2503	320	–931
	a(3) = –1534	330	–867
		340	–810
		350	–757
		400	–557
		450	–424
C_5H_{12}	2,2-Dimethylpropane	300	–916
		310	–843
		320	–780
	a(1) = –931	330	–724
	a(2) = –2387	340	–674
	a(3) = –2641	350	–629
	a(4) = –1810	360	–590
		370	–554
		380	–521
		390	–492

Mol. form.	Name	T/K	B/cm^3 mol^{-1}
		400	–464
		450	–357
		500	–279
		550	–218
C_6H_6	Benzene	290	–1588
		300	–1454
		310	–1335
	a(1) = –1477	320	–1231
	a(2) = –3851	330	–1139
	a(3) = –3683	340	–1056
	a(4) = –1423	350	–983
		400	–712
		450	–542
		500	–429
		550	–349
		600	–291
C_6H_7N	2-Methylpyridine	360	–1656
		370	–1523
		380	–1404
	a(1) = –2940	390	–1297
	a(2) = –8813	400	–1202
	a(3) = –7809	410	–1117
		420	–1040
		430	–972
C_6H_7N	3-Methylpyridine	380	–1819
		390	–1612
		400	–1448
	a(1) = –6304	410	–1322
	a(2) = –30415	420	–1230
	a(3) = –44549	430	–1166
C_6H_7N	4-Methylpyridine	380	–1787
		390	–1578
		400	–1417
	a(1) = –6553	410	–1297
	a(2) = –32873	420	–1214
	a(3) = –49874	430	–1163
C_6H_{12}	Cyclohexane	300	–1698
		320	–1391
		340	–1170
	a(1) = –1733	360	–1007
	a(2) = –5618	380	–883
	a(3) = –9486	400	–786
	a(4) = –7936	420	–707
		440	–641
		460	–584
		480	–534
		500	–488
		520	–446
		540	–406
		560	–368
C_6H_{12}	Methylcyclopentane	305	–1447
		315	–1357

Mol. form.	Name	*T*/K	*B*/cm³ mol⁻¹
		325	–1272
	a(1) = –1512	335	–1192
	a(2) = –2910	345	–1117
C_6H_{14}	Hexane	300	–1920
		310	–1724
		320	–1561
	a(1) = –1961	330	–1424
	a(2) = –6691	340	–1309
	a(3) = –13167	350	–1209
	a(4) = –15273	360	–1123
		370	–1046
		380	–978
		390	–916
		400	–859
		410	–806
		430	–707
		450	–616
$C_6H_{15}N$	Triethylamine	330	–1562
		340	–1444
		350	–1340
	a(1) = –2061	360	–1249
	a(2) = –5735	370	–1169
	a(3) = –5899	380	–1099
		390	–1037
		400	–983
C_7H_8	Toluene	350	–1641
		360	–1511
		370	–1394
	a(1) = –2620	380	–1289
	a(2) = –7548	390	–1195
	a(3) = –6349	400	–1110
		410	–1034
		420	–965
		430	–903
C_7H_{14}	1-Heptene	340	–1781
		350	–1651
		360	–1532
	a(1) = –2491	370	–1424
	a(2) = –6230	380	–1324
	a(3) = –3780	390	–1233
		400	–1150
		410	–1073
C_7H_{16}	Heptane	300	–2782
		320	–2297
		340	–1928
	a(1) = –2834	360	–1641
	a(2) = –8523	380	–1415
	a(3) = –10068	400	–1233
	a(4) = –5051	420	–1085
		440	–963
		460	–862
		480	–775
		500	–702

VIRIAL COEFFICIENTS OF SELECTED GASES (continued)

Mol. form.	Name	*T*/K	*B*/cm³ mol⁻¹
		540	–583
		580	–490
		620	–416
		660	–355
		700	–304
C_8H_{10}	1,2-Dimethylbenzene	380	–2046
		390	–1848
		400	–1681
	a(1) = –5632	410	–1543
	a(2) = –22873	420	–1428
	a(3) = –28900	430	–1335
		440	–1261
C_8H_{10}	1,3-Dimethylbenzene	380	–2082
		390	–1865
		400	–1679
	a(1) = –5808	410	–1521
	a(2) = –23244	420	–1388
	a(3) = –27607	430	–1276
		440	–1184
C_8H_{10}	1,4-Dimethylbenzene	380	–2043
		390	–1851
		400	–1680
	a(1) = –4921	410	–1529
	a(2) = –16843	420	–1395
	a(3) = –16159	430	–1276
		440	–1171
C_8H_{16}	1-Octene	360	–2147
		370	–2000
		380	–1861
	a(1) = –3273	390	–1729
	a(2) = –6557	400	–1604
		410	–1485
C_8H_{18}	Octane	300	–4042
		350	–2511
		400	–1704
	a(1) = –4123	450	–1234
	a(2) = –13120	500	–936
	a(3) = –16408	550	–732
	a(4) = –8580	600	–583
		650	–468
		700	–375

VAN DER WAALS CONSTANTS FOR GASES

The van der Waals equation of state for a real gas is

$$(P + n^2a/V^2)(V - nb) = nRT$$

where P is the pressure, V the volume, T the temperature, n the amount of substance (in moles), and R the gas constant. The van der Waals constants a and b are characteristic of the substance and are independent of temperature. They are related to the critical temperature and pressure, T_c and P_c, by

$$a = 27R^2T_c^2/64P_c \quad b = RT_c/8P_c$$

This table gives values of a and b for some common gases. Most of the values have been calculated from the critical temperature and pressure values given in the table "Critical Constants" in this section. Van der Waals constants for other gases may easily be calculated from the data in that table.

To convert the van der Waals constants to SI units, note that 1 bar L^2/mol^2 = 0.1 Pa m^6/mol^2 and 1 L/mol = 0.001 m^3/mol.

REFERENCE

Reid, R.C, Prausnitz, J. M., and Poling, B.E., *The Properties of Gases and Liquids, Fourth Edition*, McGraw-Hill, New York, 1987.

Substance	*a* bar L^2/mol^2	*b* L/mol
Acetic acid	17.71	0.1065
Acetone	16.02	0.1124
Acetylene	4.516	0.0522
Ammonia	4.225	0.0371
Aniline	29.14	0.1486
Argon	1.355	0.0320
Benzene	18.82	0.1193
Bromine	9.75	0.0591
Butane	13.89	0.1164
1-Butanol	20.94	0.1326
2-Butanone	19.97	0.1326
Carbon dioxide	3.658	0.0429
Carbon disulfide	11.25	0.0726
Carbon monoxide	1.472	0.0395
Chlorine	6.343	0.0542
Chlorobenzene	25.80	0.1454
Chloroethane	11.66	0.0903
Chloromethane	7.566	0.0648
Cyclohexane	21.92	0.1411
Cyclopropane	8.34	0.0747
Decane	52.74	0.3043
1-Decanol	59.51	0.3086
Diethyl ether	17.46	0.1333
Dimethyl ether	8.690	0.0774
Dodecane	69.38	0.3758
1-Dodecanol	75.70	0.3750
Ethane	5.580	0.0651
Ethanol	12.56	0.0871
Ethylene	4.612	0.0582
Fluorine	1.171	0.0290
Furan	12.74	0.0926
Helium	0.0346	0.0238
Heptane	31.06	0.2049
1-Heptanol	38.17	0.2150
Hexane	24.84	0.1744
1-Hexanol	31.79	0.1856
Hydrazine	8.46	0.0462
Hydrogen	0.2452	0.0265
Hydrogen bromide	4.500	0.0442
Hydrogen chloride	3.700	0.0406
Hydrogen cyanide	11.29	0.0881
Hydrogen fluoride	9.565	0.0739
Hydrogen iodide	6.309	0.0530
Hydrogen sulfide	4.544	0.0434
Isobutane	13.32	0.1164
Krypton	5.193	0.0106
Methane	2.303	0.0431
Methanol	9.476	0.0659
Methylamine	7.106	0.0588
Neon	0.208	0.0167
Neopentane	17.17	0.1411
Nitric oxide	1.46	0.0289
Nitrogen	1.370	0.0387
Nitrogen dioxide	5.36	0.0443
Nitrogen trifluoride	3.58	0.0545
Nitrous oxide	3.852	0.0444
Octane	37.88	0.2374
1-Octanol	44.71	0.2442
Oxygen	1.382	0.0319
Ozone	3.570	0.0487
Pentane	19.09	0.1449
1-Pentanol	25.88	0.1568
Phenol	22.93	0.1177
Propane	9.39	0.0905
1-Propanol	16.26	0.1079
2-Propanol	15.82	0.1109
Propene	8.442	0.0824
Pyridine	19.77	0.1137
Pyrrole	18.82	0.1049
Silane	4.38	0.0579
Sulfur dioxide	6.865	0.0568
Sulfur hexafluoride	7.857	0.0879
Tetrachloromethane	20.01	0.1281
Tetrachlorosilane	20.96	0.1470
Tetrafluoroethylene	6.954	0.0809
Tetrafluoromethane	4.040	0.0633
Tetrafluorosilane	5.259	0.0724
Tetrahydrofuran	16.39	0.1082
Thiophene	17.21	0.1058
Toluene	24.86	0.1497
1,1,1-Trichloroethane	20.15	0.1317
Trichloromethane	15.34	0.1019
Trifluoromethane	5.378	0.0640
Trimethylamine	13.37	0.1101
Water	5.537	0.0305
Xenon	4.192	0.0516

MEAN FREE PATH AND RELATED PROPERTIES OF GASES

In the simplest version of the kinetic theory of gases, molecules are treated as hard spheres of diameter d which make binary collisions only. In this approximation the mean distance traveled by a molecule between successive collisions, the mean free path l, is related to the collision diameter by:

$$l = \frac{kT}{\pi\sqrt{2}Pd^2}$$

where P is the pressure, T the absolute temperature, and k the Boltzmann constant. At standard conditions (P = 100 000 Pa and T = 298.15 K) this relation becomes:

$$l = \frac{9.27 \cdot 10^{-27}}{d^2}$$

where l and d are in meters.

Using the same model and the same standard pressure, the collision diameter can be calculated from the viscosity η by the kinetic theory relation:

$$\eta = \frac{2.67 \cdot 10^{-20}(MT)^{1/2}}{d^2}$$

where η is in units of μPa s and M is the molar mass in g/mol. Kinetic theory also gives a relation for the mean velocity $\bar{v}$ of molecules of mass m:

$$\bar{v} = \left(\frac{8kT}{\pi m}\right)^{1/2} = 145.5(T/M)^{1/2} \text{ m/s}$$

Finally, the mean time τ between collisions can be calculated from the relation $\tau\bar{v} = l$.

The table below gives values of l, $\bar{v}$, and τ for some common gases at 25°C and atmospheric pressure, as well as the value of d, all calculated from measured gas viscosities (see References 2 and 3 and the table "Viscosity of Gases" in this section). It is seen from the above equations that the mean free path varies directly with T and inversely with P, while the mean velocity varies as the square root of T and, in this approximation, is independent of P.

A more accurate model, in which molecular interactions are described by a Lennard-Jones potential, gives mean free path values about 5% lower than this table (see Reference 4).

REFERENCES

1. Reid, R.C., Prausnitz, J.M., and Poling, B.E., *The Properties of Gases and Liquids, Fourth Edition* , McGraw-Hill, New York, 1987.
2. Lide, D.R., and Kehiaian, H.V., *CRC Handbook of Thermophysical and Thermochemical Data,* CRC Press, Boca Raton, FL, 1994.
3. Vargaftik, N.B., *Tables of Thermophysical Properties of Liquids and Gases, Second Edition,* John Wiley, New York, 1975.
4. Kaye, G.W.C., and Laby, T.H., *Tables of Physical and Chemical Constants, 15th Edition,* Longman, London, 1986.

Gas	d	l	$\bar{v}$	τ
Air	$3.66 \cdot 10^{-10}$ m	$6.91 \cdot 10^{-8}$ m	467 m/s	148 ps
Ar	3.58	7.22	397	182
CO_2	4.53	4.51	379	119
H_2	2.71	12.6	1769	71
He	2.15	20.0	1256	159
Kr	4.08	5.58	274	203
N_2	3.70	6.76	475	142
NH_3	4.32	4.97	609	82
Ne	2.54	14.3	559	256
O_2	3.55	7.36	444	166
Xe	4.78	4.05	219	185

INFLUENCE OF PRESSURE ON FREEZING POINTS

This table illustrates the variation of the freezing point of representative types of liquids with pressure. Substances are listed in alphabetical order. Note that 1 MPa = 0.01 kbar = 9.87 atm.

REFERENCES

1. Isaacs, N.S., *Liquid Phase High Pressure Chemistry*, John Wiley, New York, 1981.
2. Merrill, L., *J. Phys. Chem. Ref. Data*, 6, 1205, 1977; 11, 1005, 1982.

Substance	Molecular formula	Freezing point in °C at:		
		0.1 MPa	100 MPa	1000 MPa
Acetic acid	$C_2H_4O_2$	16.6	37	
Acetophenone	C_8H_8O	20.0	41.2	
Aniline	C_6H_7N	–6.0	13.5	140
Benzene	C_6H_6	5.5	33.4	
Benzonitrile	C_7H_5N	–12.8	7.6	
Benzyl alcohol	C_7H_8O	–15.2	0.2	
Bromobenzene	C_6H_5Br	–30.6	–12	108
Bromoethane	C_2H_5Br	–118.6	–108	
1-Bromonaphthalene	$C_{10}H_7Br$	–1.8	6.1	
1-Bromopropane	C_3H_7Br	–110	–98	
p-Bromotoluene	C_7H_7Br	28.0	56.7	
Butanoic acid	$C_4H_8O_2$	–5.7	13.8	
1-Butanol	$C_4H_{10}O$	–89.8	–77.2	
Carbon disulfide	CS_2	–111.5	–98	
Chlorobenzene	C_6H_5Cl	–45.2	–28	84
p-Chlorotoluene	C_7H_7Cl	6.9	33.1	
o-Cresol	C_7H_8O	29.8	47.7	
m-Cresol	C_7H_8O	11.8	25.6	
p-Cresol	C_7H_8O	35.8	56.2	
Cyclohexane	C_6H_{12}	6.6	32.5	
Cyclohexanol	$C_6H_{12}O$	25.5	62.3	
1,2-Dibromoethane	$C_2H_4Br_2$	9.9	34.0	
p-Dichlorobenzene	$C_6H_4Cl_2$	52.7	79.1	
Dichloromethane	CH_2Cl_2	–95.1	–83	
N,*N*-Dimethylaniline	$C_8H_{11}N$	2.5	26.3	
1,4-Dioxane	$C_4H_8O_2$	11	23	
Ethanol	C_2H_6O	–114.1	–108	
Formamide	CH_3NO	–15.5	10.8	
Formic acid	CH_2O_2	8.3	20.6	
Furan	C_4H_4O	–85.6	–73	
Hexamethyldisiloxane	$C_6H_{18}OSi_2$	–66	–37	
Menthol	$C_{10}H_{20}O$	42	60	
Methyl benzoate	$C_8H_8O_2$	–15	31.8	
2-Methyl-2-butanol	$C_5H_{12}O$	–8.8	13.4	
2-Methyl-2-propanol	$C_4H_{10}O$	25.4	58.1	
Naphthalene	$C_{10}H_8$	78.2	115.7	
Nitrobenzene	$C_6H_5NO_2$	5.7	13.5	
m-Nitrotoluene	$C_7H_7NO_2$	15.5	40.6	
Pentachloroethane	C_2HCl_5	–29.0	–6.3	
Potassium	K	63.7	78	170
Potassium chloride	ClK	771		945
Propanoic acid	$C_3H_6O_2$	–20.7	–1.2	
Silver chloride	AgCl	455		545
Sodium	Na	97.8	106	167
Sodium chloride	ClNa	800.7		997
Sodium fluoride	FNa	996		1115
Tetrachloromethane	CCl_4	–23.0	14.2	
Tribromomethane	$CHBr_3$	8.1	31.5	
Trichloromethane	$CHCl_3$	–63.6	–45.2	
Water	H_2O	0.0	–9.0	
o-Xylene	C_8H_{10}	–25.2	–3.5	
m-Xylene	C_8H_{10}	–47.8	–25.2	
p-Xylene	C_8H_{10}	13.2	46.0	

CRITICAL CONSTANTS

This table gives the liquid–gas critical constants and normal boiling points of about 750 inorganic and organic substances. The properties tabulated are:

- T_b: Normal boiling point in K at a pressure of 101.325 kPa (1 atmosphere); an "s" following the value indicates a sublimation point (temperature at which the solid is in equilibrium with the gas at a pressure of 101.325 kPa)
- T_c: Critical temperature in K
- P_c: Critical pressure in MPa
- V_c: Critical molar volume in cm^3/mol

The number of digits given for T_b, T_c, and P_c indicates the estimated accuracy of these quantities; however, values of T_c greater than 750 K may be in error by 10 K or more. Although most V_c values are given to three figures, they cannot be assumed accurate to better than a few percent.

Many of the critical constants in this table are taken from reviews produced by the IUPAC Commission on Thermodynamics (References 2-6) and from the publications of the Design Institute for Physical Property Data (References 8-9). Compounds are listed by molecular formula in modified Hill order, with compounds not containing carbon preceding those that do contain carbon.

* An asterisk following an entry indicates the value was obtained by extrapolation.

REFERENCES

1. Ambrose, D., "Vapor-Liquid Constants of Fluids", in Stevenson, R. M., and Malanowski, S., *Handbook of the Thermodynamics of Organic Compounds*, Elsevier, New York, 1987.
2. Ambrose, D., and Tsonopoulos, C., *J. Chem. Eng. Data*, 40, 531, 1995.
3. Tsonopoulos, C., and Ambrose, D., *J. Chem. Eng. Data*, 40, 547, 1995.
4. Gude, M., and Teja, A. S., *J. Chem. Eng. Data*, 40, 1025, 1995.
5. Daubert, T. E., *J. Chem. Eng. Data*, 41, 365, 1966.
6. Tsonopoulos, C., and Ambrose, D., *J. Chem. Eng. Data*, 41, 645, 1996.
7. Das, A., Frenkel, M., Gadalla, N. A. M., Kudchadker, S., Marsh, K. N., Rodgers, A. S., and Wilhoit, R. C., *J. Phys. Chem. Ref. Data*, 22, 659, 1993.
8. Wilson, L. C., Wilson, H. L., Wilding, W. V., and Wilson, G. M., *J. Chem. Eng. Data*, 41, 1252, 1997.
9. Daubert, T. E., Danner, R. P., Sibul, H. M., and Stebbins, C. C., *Physical and Thermodynamic Properties of Pure Compounds: Data Compilation*, extant 1996 (core with 6 supplements), Taylor & Francis, Bristol, PA.
10. Reid, R. C., Prausnitz, J. M., and Poling, B. E., *The Properties of Gases and Liquids, Fourth Edition,* McGraw-Hill, New York, 1987.
11. Vargaftik, N.B., Vinogradov, Y. K., and Yargin, V. S., *Handbook of Physical Properties of Liquids and Gases, Third Edition*, Begell House, New York, 1996.
12. Morton, D. W., Lui, M. P. W., Tran, C. A., and Young, C. L., *J. Chem. Eng. Data*, 45, 437, 2000.
13. VonNiederhausern, D. M., Wilson, L. C., Giles, N. F., and Wilson, G. M., *J. Chem. Eng. Data*, 45, 154, 2000.
14. VonNiederhausern, D. M., Wilson, G. M., and Giles, N. F., *J. Chem. Eng. Data*, 45, 157, 2000.

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
$AlBr_3$	Aluminum bromide	528	763	2.89	310
$AlCl_3$	Aluminum chloride	453 s	620	2.63	257
AlI_3	Aluminum iodide	655	983		408
Ar	Argon	87.30	150.87	4.898	75
As	Arsenic	876 s	1673		35
$AsCl_3$	Arsenic(III) chloride	403	654		252
AsH_3	Arsine	210.7	373.1		
BBr_3	Boron tribromide	364	581		272
BCl_3	Boron trichloride	285.80	455	3.87	239
BF_3	Boron trifluoride	172	260.8	4.98	115
BI_3	Boron triiodide	482.7	773		356
B_2H_6	Diborane	180.8	289.8	4.05	
$BiBr_3$	Bismuth tribromide	726	1220		301
$BiCl_3$	Bismuth trichloride	720	1179	12.0	261
BrH	Hydrogen bromide	206.77	363.2	8.55	
BrI	Iodine bromide	389	719		139
Br_2	Bromine	332.0	588	10.34	127

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
Br_2Hg	Mercury(II) bromide	595	1012		
Br_3Ga	Gallium(III) bromide	552	806.7		303
Br_3HSi	Tribromosilane	382	610.0		305
Br_3P	Phosphorus(III) bromide	446.4	711		300
Br_3Sb	Antimony(III) bromide	553	904		300
Br_4Ge	Germanium(IV) bromide	459.50	718		392
Br_4Hf	Hafnium(IV) bromide	596 s	746		415
Br_4Si	Tetrabromosilane	427	663		382
Br_4Sn	Tin(IV) bromide	478	744		417
Br_4Ti	Titanium(IV) bromide	503	795.7		391
Br_4Zr	Zirconium(IV) bromide	633 s	805		424
Br_5Ta	Tantalum(V) bromide	622	974		461
$ClFO_3$	Perchloryl fluoride	226.40	368.4	5.37	161
ClF_2N	Nitrogen chloride difluoride	206	337.5	5.15	
ClF_2P	Phosphorus(III) chloride difluoride	225.9	362.4	4.52	
ClF_2PS	Phosphorothioc chloride difluoride	279.5	439.2	4.14	
ClF_3Si	Chlorotrifluorosilane	203.2	307.7	3.46	
ClF_5	Chlorine pentafluoride	260.1	416	5.27	233
ClF_5S	Sulfur chloride pentafluoride	254.10	390.9		
ClH	Hydrogen chloride	188	324.7	8.31	81
ClH_4N	Ammonium chloride	611 s	1155	163.5	
ClH_4P	Phosphonium chloride	246	322.3	7.37	
$ClNO$	Nitrosyl chloride	267.7	440		
$ClOV$	Vanadyl chloride	400	636		171
Cl_2	Chlorine	239.11	416.9	7.991	123
Cl_2FP	Phosphorus(III) dichloride fluoride	287.00	463.0	4.96	
Cl_2F_2Si	Dichlorodifluorosilane	241	369.0	3.5	
Cl_2Hg	Mercury(II) chloride	577	973		174
Cl_2OSe	Selenium oxychloride	450	730	7.09	235
Cl_3FSi	Trichlorofluorosilane	285.40	438.6	3.58	
Cl_3Ga	Gallium(III) chloride	474	694		263
Cl_3HSi	Trichlorosilane	306	479		268
Cl_3P	Phosphorus(III) chloride	349.3	563		264
Cl_3Sb	Antimony(III) chloride	493.5	794		272
Cl_4Ge	Germanium(IV) chloride	359.70	553.2	3.861	330
Cl_4Hf	Hafnium(IV) chloride	590 s	725.7	5.42	314
Cl_4ORe	Rhenium(VI) oxytetrachloride	496	781		362
Cl_4OW	Tungsten(VI) oxytetrachloride	500.70	782		338
Cl_4Si	Tetrachlorosilane	330.80	508.1	3.593	326
Cl_4Sn	Tin(IV) chloride	387.30	591.9	3.75	351
Cl_4Te	Tellurium tetrachloride	660	1002	8.56	310
Cl_4Ti	Titanium(IV) chloride	409.60	638	4.66	339
Cl_4Zr	Zirconium(IV) chloride	604 s	778	5.77	319
Cl_5Mo	Molybdenum(V) chloride	541	850		369
Cl_5Nb	Niobium(V) chloride	527.2	803.5	4.88	397
Cl_5P	Phosphorus(V) chloride	433 s	646		
Cl_5Ta	Tantalum(V) chloride	512.50	767		402
Cl_6W	Tungsten(VI) chloride	619.90	923		422
Cs	Cesium	944	1938	9.4	341
FH	Hydrogen fluoride	293	461	6.48	69
FNO_2	Nitryl fluoride	200.8	349.5		
F_2	Fluorine	85.03	144.13	5.172	66
F_2HN	Difluoramine	250	403		
F_2N_2	*cis*-Difluorodiazine	167.40	272	7.09	
F_2N_2	*trans*-Difluorodiazine	161.70	260	5.57	
F_2O	Fluorine monoxide	128.40	215		
F_2Xe	Xenon difluoride	387.50 s	631	9.32	148

CRITICAL CONSTANTS (continued)

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
F_3N	Nitrogen trifluoride	144.40	234.0	4.46	126
F_3NO	Trifluoramine oxide	185.7	303	6.43	147
F_3P	Phosphorus(III) fluoride	171.4	271.2	4.33	
F_3PS	Phosphorothioc trifluoride	220.90	346.0	3.82	
F_4N_2	Tetrafluorohydrazine	199	309	3.75	
F_4S	Sulfur tetrafluoride	232.70	364		
F_4Si	Tetrafluorosilane	187	259.0	3.72	
F_4Xe	Xenon tetrafluoride	388.90 s	612	7.04	188
F_5Nb	Niobium(V) fluoride	502	737	6.28	155
F_6Mo	Molybdenum(VI) fluoride	307.2	473	4.75	226
F_6S	Sulfur hexafluoride	209.35 s	318.69	3.77	199
F_6Se	Selenium hexafluoride	226.55 s	345.5		
F_6Te	Tellurium hexafluoride	234.25 s	356		
F_6U	Uranium(VI) fluoride	329.65 s	505.8	4.66	250
F_6W	Tungsten(VI) fluoride	290.3	444	4.34	233
GaI_3	Gallium(III) iodide	613	951		395
GeH_4	Germane	185.1	312.2	4.95	147
GeI_4	Germanium(IV) iodide	650	973		500
HI	Hydrogen iodide	237.60	424.0	8.31	
H_2	Hydrogen	20.28	32.97	1.293	65
H_2O	Water	373.2	647.14	22.06	56
H_2O_2	Hydrogen peroxide	423.4	728*	22*	
H_2S	Hydrogen sulfide	213.60	373.2	8.94	99
H_2Se	Hydrogen selenide	231.90	411	8.92	
H_3N	Ammonia	239.82	405.5	11.35	72
H_3P	Phosphine	185.40	324.5	6.54	
H_4N_2	Hydrazine	386.70	653	14.7	
He	Helium	4.22	5.19	0.227	57
HfI_4	Hafnium iodide	667 s	916		528
Hg	Mercury	629.88	1750	172.00	43
HgI_2	Mercury(II) iodide	627	1072		
I_2	Iodine	457.6	819		155
I_3Sb	Antimony(III) iodide	674	1102		
I_4Si	Tetraiodosilane	560.50	944		558
I_4Sn	Tin(IV) iodide	637.50	968		531
I_4Ti	Titanium(IV) iodide	650	1040		505
I_4Zr	Zirconium(IV) iodide	704 s	960		530
K	Potassium	1032	2223*	16*	209*
Kr	Krypton	119.93	209.41	5.50	91
Li	Lithium	1615	3223*	67*	66*
NO	Nitric oxide	121.41	180	6.48	58
N_2	Nitrogen	77.36	126.21	3.39	90
N_2O	Nitrous oxide	184.67	309.57	7.255	97
N_2O_4	Nitrogen tetroxide	294.30	431	10.1	167
Na	Sodium	1156	2573*	35*	116*
Ne	Neon	27.07	44.4	2.76	42
O_2	Oxygen	90.20	154.59	5.043	73
O_2S	Sulfur dioxide	263.10	430.8	7.884	122
O_3	Ozone	161.80	261.1	5.57	89
O_3S	Sulfur trioxide	318	491.0	8.2	127
O_4Os	Osmium(VIII) oxide	408	678		
O_7Re_2	Rhenium(VII) oxide	633	942		334
P	Phosphorus	553.7	994		
Rb	Rubidium	961	2093*	16*	247*
Rn	Radon	211.5	377	6.28	
S	Sulfur	717.75	1314	20.7	
Se	Selenium	958	1766	27.2	
Xe	Xenon	165.03	289.77	5.841	118

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
$CBrClF_2$	Bromochlorodifluoromethane	269.5	426.88	4.254	246
$CBrF_3$	Bromotrifluoromethane	215.4	340.2	3.97	196
CBr_2F_2	Dibromodifluoromethane	298	471.3		
$CClF_3$	Chlorotrifluoromethane	191.8	302	3.870	180
CCl_2F_2	Dichlorodifluoromethane	243.4	384.95	4.136	217
CCl_2O	Carbonyl chloride	281	455	5.67	190
CCl_3F	Trichlorofluoromethane	296.9	471.1	4.47	247
CCl_4	Tetrachloromethane	350.0	556.6	4.516	276
CF_3I	Trifluoroiodomethane	250.7	396.44	3.953	
CF_4	Tetrafluoromethane	145.2	227.6	3.74	140
$CHClF_2$	Chlorodifluoromethane	232.5	369.5	5.035	164
$CHCl_2F$	Dichlorofluoromethane	282.1	451.58	5.18	196
$CHCl_3$	Trichloromethane	334.32	536.4	5.47	239
CHF_3	Trifluoromethane	191.1	299.3	4.858	133
CHN	Hydrogen cyanide	299	456.7	5.39	139
CH_2Cl_2	Dichloromethane	313	510	6.10	
CH_2F_2	Difluoromethane	221.6	351.6	5.830	121
CH_2O_2	Formic acid	374	588		
CH_3Cl	Chloromethane	249.06	416.25	6.679	139
CH_3Cl_3Si	Methyltrichlorosilane	338.8	517	3.28	348
CH_3F	Fluoromethane	194.8	317.8	5.88	113
CH_3I	Iodomethane	315.58	528		
CH_3NO_2	Nitromethane	374.34	588	5.87	173
CH_4	Methane	111.67	190.56	4.599	98.60
CH_4O	Methanol	337.8	512.5	8.084	117
CH_4S	Methanethiol	279.1	470.0	7.23	145
CH_5ClSi	Chloromethylsilane	280	517.8		
CH_5N	Methylamine	266.83	430.7	7.614	
CH_6N_2	Methylhydrazine	360.7	567	8.24	271
CH_6Si	Methylsilane	215.7	352.5		
CO	Carbon monoxide	81.7	132.91	3.499	93
COS	Carbon oxysulfide	223	375	5.88	137
CO_2	Carbon dioxide	194.65 s	304.13	7.375	94
CS_2	Carbon disulfide	319	552	7.90	173
$C_2Br_2ClF_3$	1,2-Dibromo-1-chloro-1,2,2-trifluoroethane	366	560.7	3.61	368
$C_2Br_2F_4$	1,2-Dibromotetrafluoroethane	320.50	487.8	3.393	341
C_2ClF_3	Chlorotrifluoroethene	245.4	379	4.05	212
C_2ClF_5	Chloropentafluoroethane	235.20	353.2	3.229	252
$C_2Cl_2F_4$	1,1-Dichloro-1,2,2,2-tetrafluoroethane	277	418.6	3.30	294
$C_2Cl_2F_4$	1,2-Dichloro-1,1,2,2-tetrafluoroethane	277.0	418.78	3.252	297
$C_2Cl_3F_3$	1,1,2-Trichloro-1,2,2-trifluoroethane	320.9	487.3	3.42	325
C_2Cl_4	Tetrachloroethene	394.5	620.2		
$C_2Cl_4F_2$	1,1,2,2-Tetrachloro-1,2-difluoroethane	366.0	551		
C_2F_3N	Trifluoroacetonitrile	204.4	311.11	3.618	202
C_2F_4	Tetrafluoroethene	197.3	306.5	3.94	172
C_2F_6	Hexafluoroethane	195.1	293		222
C_2HClF_2	1-Chloro-2,2-difluoroethene	254.7	400.6	4.46	197
C_2HClF_4	1-Chloro-1,1,2,2-tetrafluoroethane	263	399.9	3.72	244
C_2HClF_4	1-Chloro-1,2,2,2-tetrafluoroethane	261	395.4	3.66	
$C_2HCl_2F_3$	1,2-Dichloro-1,1,2-trifluoroethane	301	461.6		278
$C_2HCl_2F_3$	2,2-Dichloro-1,1,1-trifluoroethane	300.97	456.83	3.661	278
C_2HCl_3	Trichloroethene	360.36	544.2	5.02	
$C_2HF_3O_2$	Trifluoroacetic acid	346	491.3	3.258	204
C_2HF_5	Pentafluoroethane	224.7	339.41	3.639	209.7
C_2HF_5O	Trifluoromethyl difluoromethyl ether	237	354.49	3.33	
C_2H_2	Acetylene	188.45 s	308.3	6.138	112.2
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethene	333.3	544.2		
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethene	321.9	516.5	5.51	

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane	419.7	661.15		
$C_2H_2F_2$	1,1-Difluoroethene	187.5	302.9	4.46	154
$C_2H_2F_4$	1,1,1,2-Tetrafluoroethane	247.07	374.18	4.065	198
$C_2H_2F_4$	1,1,2,2-Tetrafluoroethane	253.3	391.8		191
$C_2H_3ClF_2$	1-Chloro-1,1-difluoroethane	263.5	410.34	4.048	225
$C_2H_3Cl_2F$	1,1-Dichloro-1-fluoroethane	305.2	477.5	4.194	255
$C_2H_3Cl_3$	1,1,1-Trichloroethane	347.24	545	4.30	
C_2H_3F	Fluoroethene	201	327.9	5.24	144
$C_2H_3F_3$	1,1,1-Trifluoroethane	225.90	345.86	3.764	194
$C_2H_3F_3O$	Methyl trifluoromethyl ether	249	378.0	3.680	228
C_2H_3N	Acetonitrile	354.80	545.5	4.85	173
C_2H_3N	Acetonitrile	354.80	545.6	4.884	173
C_2H_4	Ethylene	169.38	282.34	5.041	131.1
$C_2H_4Br_2$	1,2-Dibromoethane	404.8	583.0	7.2	
$C_2H_4Cl_2$	1,1-Dichloroethane	330.5	523	5.07	236
$C_2H_4Cl_2$	1,2-Dichloroethane	356.7	561	5.4	225
$C_2H_4F_2$	1,1-Difluoroethane	248.20	386.7	4.50	181
C_2H_4O	Acetaldehyde	293.3	466		154
C_2H_4O	Ethylene oxide	283.8	469	7.19	140
$C_2H_4O_2$	Acetic acid	391.1	592.71	5.786	171
$C_2H_4O_2$	Methyl formate	304.9	487.2	5.998	172
C_2H_5Br	Bromoethane	311.7	503.9	6.23	215
C_2H_5Cl	Chloroethane	285.5	460.4	5.3	
C_2H_5F	Fluoroethane	235.5	375.31	5.028	
C_2H_6	Ethane	184.6	305.32	4.872	145.5
$C_2H_6Cl_2Si$	Dichlorodimethylsilane	343.5	520.4	3.49	350
C_2H_6O	Ethanol	351.44	514.0	6.137	168
C_2H_6O	Dimethyl ether	248.4	400.0	5.37	190
$C_2H_6O_2$	Ethylene glycol	470.5	719	8.2	
C_2H_6S	Ethanethiol	308.3	499	5.49	207
C_2H_6S	Dimethyl sulfide	310.48	503.0	5.53	201
C_2H_7N	Ethylamine	289.7	456	5.62	182
C_2H_7N	Dimethylamine	280.03	437.22	5.340	
$C_2H_8N_2$	1,2-Ethanediamine	390	613.1	6.707	
C_2N_2	Cyanogen	252.1	400	5.98	
C_3ClF_5O	Chloropentafluoroacetone	281	410.6	2.878	
C_3F_6O	Perfluoroacetone	245.8	357.14	2.84	329
C_3F_6O	Perfluorooxetane	244	361.8	3.094	272
C_3F_8	Perfluoropropane	236.6	345.1	2.680	299
$C_3F_8O_2$	Perfluorodimethoxymethane	263	372.3	2.333	363
C_3HF_7O	Trifluoromethyl 1,1,2,2-tetrafluoroethyl ether	270	387.7	2.640	337
$C_3H_2F_6$	1,1,1,2,3,3-Hexafluoropropane	279.3	412.38	3.412	269
$C_3H_2F_6O$	1,2,2,2-Tetrafluoroethyl difluoromethyl ether	296.50	428.95	3.050	315
$C_3H_3F_3$	3,3,3-Trifluoropropene	256	376.2	3.80	211
$C_3H_3F_5$	1,1,1,2,2-Pentafluoropropane	255.8	380.11	3.137	273
$C_3H_3F_5O$	Perfluoroethyl methyl ether	278.74	406.80	2.887	301
C_3H_3N	Acrylonitrile	350.5	540	4.660	
C_3H_3NO	Isoxazole	368	552.0		
C_3H_4	Allene	238.8	394	5.25	
C_3H_4	Propyne	250.0	402.4	5.63	163.5
C_3H_5Cl	3-Chloropropene	318.3	514		
$C_3H_5F_3O$	2,2,2-Trifluoroethyl methyl ether	304.77	448.98	3.513	277
C_3H_5N	Propanenitrile	370.29	561.3	4.26	229
C_3H_6	Propene	225.46	364.9	4.60	184.6
C_3H_6	Cyclopropane	240.34	398.0	5.54	162
$C_3H_6Cl_2$	1,2-Dichloropropane	369.6	578.5		
$C_3H_6Cl_2$	1,3-Dichloropropane	394.1	614.6		
C_3H_6O	Allyl alcohol	370.2	545.1		

CRITICAL CONSTANTS (continued)

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
C_3H_6O	Propanal	321	504.4	5.27	204
C_3H_6O	Acetone	329.20	508.1	4.700	209
C_3H_6O	Methyloxirane	308	482.2	4.92	186
$C_3H_6O_2$	Propanoic acid	414.30	604	4.53	222
$C_3H_6O_2$	Ethyl formate	327.6	508.5	4.74	229
$C_3H_6O_2$	Methyl acetate	330.02	506.55	4.75	228
C_3H_7Cl	1-Chloropropane	319.7	503	4.58	
C_3H_7Cl	2-Chloropropane	308.9	484		
C_3H_7NO	*N,N*-Dimethylformamide	426	649.6		262
C_3H_8	Propane	231.1	369.83	4.248	200
C_3H_8O	1-Propanol	370.4	536.8	5.169	218
C_3H_8O	2-Propanol	355.5	508.3	4.764	222
C_3H_8O	Ethyl methyl ether	280.6	437.8	4.40	221
$C_3H_8O_2$	1,2-Propylene glycol	460.8	676.4	5.941	
$C_3H_8O_2$	1,3-Propylene glycol	487.6	722	6.3	
$C_3H_8O_2$	Ethylene glycol monomethyl ether	397.3	597.6	5.285	263
C_3H_8S	1-Propanethiol	341.0	536.6		286
C_3H_8S	Ethyl methyl sulfide	339.9	533	4.26	
$C_3H_9BO_3$	Trimethyl borate	340.7	501.7	3.59	
C_3H_9ClSi	Trimethylchlorosilane	333	497.8	3.20	366
C_3H_9N	Propylamine	320.37	497.0	4.72	
C_3H_9N	Isopropylamine	304.91	471.8	4.54	221
C_3H_9N	Trimethylamine	276.02	432.79	4.087	254
$C_4Br_2F_8$	1,4-Dibromooctafluorobutane	370	532.5	2.39	
C_4F_8	Perfluorocyclobutane	267.3	388.46	2.784	324
C_4F_{10}	Perfluorobutane	271.3	386.4	2.323	378
C_4F_{10}	Perfluoroisobutane	273	395.4		
$C_4H_2F_8O$	Perfluoroethyl 2,2,2-trifluoroethyl ether	301.04	421.68	2.330	409
$C_4H_3F_7O$	Perfluoropropyl methyl ether	307.38	437.70	2.481	377
$C_4H_3F_7O$	Perfluoroisopropyl methyl ether	302.56	433.30	2.553	369
C_4H_4O	Furan	304.7	490.2	5.50	218
C_4H_4S	Thiophene	357.2	579.4	5.69	219
$C_4H_5F_5O$	Perfluoroethyl ethyl ether	301.26	431.23	2.533	366
C_4H_5N	Pyrrole	402.94	639.7	6.34	200
C_4H_6	1,3-Butadiene	268.74	425	4.32	221
C_4H_6	1-Butyne	281.23	440	4.60	208
C_4H_6	2-Butyne	300.1	488.7		
$C_4H_6O_2$	γ-Butyrolactone	477	731.0	5.131	
$C_4H_6O_3$	Acetic anhydride	412.7	606	4.0	
C_4H_7N	Butanenitrile	390.8	585.4	3.88	
C_4H_8	1-Butene	266.89	419.5	4.02	240.8
C_4H_8	*cis*-2-Butene	276.86	435.5	4.21	233.8
C_4H_8	*trans*-2-Butene	274.03	428.6	4.10	237.7
C_4H_8	Isobutene	266.3	417.9	4.000	238.8
C_4H_8	Cyclobutane	285.8	460.0	4.98	210
C_4H_8O	Ethyl vinyl ether	308.7	475	4.07	
C_4H_8O	Butanal	348.0	537.2	4.32	258
C_4H_8O	2-Butanone	352.74	536.78	4.207	267
C_4H_8O	Tetrahydrofuran	338	540.1	5.19	224
C_4H_8OS	Ethyl thioacetate	389.6	590.55	4.075	319
$C_4H_8O_2$	Butanoic acid	436.90	624	4.03	290
$C_4H_8O_2$	2-Methylpropanoic acid	427.60	605	3.7	292
$C_4H_8O_2$	Propyl formate	354.1	538.0	4.06	285
$C_4H_8O_2$	Ethyl acetate	350.26	523.3	3.882	286
$C_4H_8O_2$	Methyl propanoate	353.0	530.6	4.004	282
$C_4H_8O_2$	1,4-Dioxane	374.7	587	5.21	238
C_4H_8S	Tetrahydrothiophene	394.2	632.0		
C_4H_9Cl	1-Chlorobutane	351.6	539.2		

CRITICAL CONSTANTS (continued)

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
C_4H_9Cl	2-Chlorobutane	341.4	518.6		
C_4H_9Cl	2-Chloro-2-methylpropane	324.1	500		
C_4H_9N	Pyrrolidine	359.71	568	6.00	238
C_4H_{10}	Butane	272.7	425.12	3.796	255
C_4H_{10}	Isobutane	261.42	407.8	3.640	259
$C_4H_{10}O$	1-Butanol	390.88	563.0	4.414	274
$C_4H_{10}O$	2-Butanol	372.66	536.2	4.202	269
$C_4H_{10}O$	2-Methyl-1-propanol	381.04	547.8	4.295	274
$C_4H_{10}O$	2-Methyl-2-propanol	355.6	506.2	3.972	275
$C_4H_{10}O$	Diethyl ether	307.7	466.74	3.638	280
$C_4H_{10}O$	Methyl propyl ether	312.3	476.25	3.801	
$C_4H_{10}O$	Isopropyl methyl ether	303.92	464.48	3.762	
$C_4H_{10}O_2$	1,2-Butanediol	463.7	680	5.21	303
$C_4H_{10}O_2$	1,3-Butanediol	480.7	676	4.02	305
$C_4H_{10}O_2$	1,4-Butanediol	508	727	6.22	
$C_4H_{10}O_2$	Ethylene glycol dimethyl ether	358	536	3.87	271
$C_4H_{10}O_2$	Propylene glycol monomethyl ether	392	579.8	4.113	
$C_4H_{10}S$	1-Butanethiol	371.7	570.1		324
$C_4H_{10}S$	Diethyl sulfide	365.3	557.8	3.897	318
$C_4H_{11}N$	Butylamine	350.15	531.9	4.25	277
$C_4H_{11}N$	*sec*-Butylamine	335.88	514.3	4.20	278
$C_4H_{11}N$	*tert*-Butylamine	317.19	483.9	3.84	292
$C_4H_{11}N$	Isobutylamine	340.90	519	4.07	278
$C_4H_{11}N$	Diethylamine	328.7	499.99	3.758	
$C_4H_{12}Si$	Tetramethylsilane	299.8	448.64	2.821	362
$C_4H_{12}Sn$	Tetramethylstannane	351	521.8	2.981	
$C_4H_{13}N_3$	Bis(2-amimoethyl)amine	480	709	4.3	
C_5F_{12}	Perfluoropentane	302.4	420.59	2.045	473
$C_5H_2F_6O_2$	Hexafluoroacetylacetone	327.30	485.1	2.767	
$C_5H_4O_2$	Furfural	434.9	670	5.89	
C_5H_5N	Pyridine	388.38	620.0	5.67	243
$C_5H_6N_2$	2-Methylpyrazine	410	634.3	5.01	283
C_5H_6O	2-Methylfuran	337.9	527	4.72	247
C_5H_7N	1-Methylpyrrole	385.96	596.0	4.86	271
C_5H_7N	2-Methylpyrrole	420.8	654	5.08	266
C_5H_7N	3-Methylpyrrole	416.1	647	5.08	266
C_5H_8	1-Pentyne	313.3	493.5		
C_5H_8	Cyclopentene	317.4	506.5	4.80	245
C_5H_8O	Cyclopentanone	403.72	624.5	4.60	
C_5H_8O	3,4-Dihydro-2*H*-pyran	359	561.7	4.56	268
C_5H_9N	Pentanenitrile	414.5	610.3	3.58	
C_5H_9NO	*N*-Methyl-2-pyrrolidone	475	721.8		311
C_5H_{10}	1-Pentene	303.11	464.8	3.56	298.4
C_5H_{10}	*cis*-2-Pentene	310.08	475	3.69	
C_5H_{10}	*trans*-2-Pentene	309.49	471	3.52	
C_5H_{10}	2-Methyl-1-butene	304.4	470	3.8	
C_5H_{10}	3-Methyl-1-butene	293.3	452.7	3.53	304.9
C_5H_{10}	2-Methyl-2-butene	311.71	470	3.42	
C_5H_{10}	Cyclopentane	322.5	511.7	4.51	259
$C_5H_{10}O$	Cyclopentanol	413.57	619.5	4.9	
$C_5H_{10}O$	Allyl ethyl ether	340.8	518		
$C_5H_{10}O$	Pentanal	376	566.1	3.97	313
$C_5H_{10}O$	2-Pentanone	375.41	561.08	3.694	301
$C_5H_{10}O$	3-Pentanone	374.9	561.46	3.729	336
$C_5H_{10}O$	3-Methyl-2-butanone	367.48	553.4	3.85	310
$C_5H_{10}O$	Tetrahydropyran	361	572.2	4.77	263
$C_5H_{10}O$	2-Methyltetrahydrofuran	351	537	3.76	267
$C_5H_{10}O_2$	Pentanoic acid	459.3	643	3.58	340

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
$C_5H_{10}O_2$	3-Methylbutanoic acid	449.7	629	3.40	
$C_5H_{10}O_2$	Isobutyl formate	371.4	551	3.88	352
$C_5H_{10}O_2$	Propyl acetate	374.69	549.7	3.36	345
$C_5H_{10}O_2$	Isopropyl acetate	361.8	531		
$C_5H_{10}O_2$	Ethyl propanoate	372.3	546.0	3.362	345
$C_5H_{10}O_2$	Methyl butanoate	376.0	554.4	3.47	340
$C_5H_{10}O_2$	Methyl isobutanoate	365.7	540.8	3.43	339
$C_5H_{11}Cl$	1-Chloropentane	381.6	571.2		
$C_5H_{11}Cl$	2-Chloro-2-methylbutane	358.8	509.1		
$C_5H_{11}N$	Piperidine	379.37	594	4.94	288
C_5H_{12}	Pentane	309.21	469.7	3.370	311
C_5H_{12}	Isopentane	301.03	460.4	3.38	306
C_5H_{12}	Neopentane	282.63	433.8	3.196	307
$C_5H_{12}O$	1-Pentanol	411.13	588.1	3.897	326
$C_5H_{12}O$	2-Pentanol	392.5	560.3	3.675	329
$C_5H_{12}O$	3-Pentanol	389.40	559.6		325
$C_5H_{12}O$	2-Methyl-1-butanol	400.7	575.4	3.94	
$C_5H_{12}O$	3-Methyl-1-butanol	404.3	577.2	3.93	
$C_5H_{12}O$	2-Methyl-2-butanol	375.6	543.7	3.71	
$C_5H_{12}O$	3-Methyl-2-butanol	386.1	556.1	3.87	
$C_5H_{12}O$	Butyl methyl ether	343.31	512.78	3.371	329
$C_5H_{12}O$	Methyl *tert*-butyl ether	328.4	497.1	3.430	
$C_5H_{12}O$	Ethyl propyl ether	336.36	500.23	3.370	339
$C_5H_{12}O_2$	Ethylene glycol monopropyl ether	423.0	614.6		364
$C_5H_{12}O_3$	Diethylene glycol monomethyl ether	466	672	3.67	
$C_5H_{12}S$	3-Methyl-1-butanethiol	393	604		
C_6BrF_5	Bromopentafluorobenzene	410	601	3.0	
C_6ClF_5	Chloropentafluorobenzene	391.11	570.81	3.238	376
$C_6Cl_2F_4$	1,2-Dichloro-3,4,5,6-tetrafluorobenzene	430.9	626	5.32	
$C_6Cl_3F_3$	1,3,5-Trichloro-2,4,6-trifluorobenzene	471.6	684.8	3.27	448
C_6F_6	Hexafluorobenzene	353.41	516.73	3.273	335
C_6F_{10}	Perfluorocyclohexene	325.2	461.8		
C_6F_{12}	Perfluoro-1-hexene	330.2	454.4		
C_6F_{12}	Perfluorocyclohexane	325.95 s	457.2	2.43	
C_6F_{14}	Perfluorohexane	329.8	448.77	1.868	606
C_6F_{14}	Perfluoro-2-methylpentane	330.8	455.3	1.923	532
C_6F_{14}	Perfluoro-3-methylpentane	331.6	450	1.69	
C_6F_{14}	Perfluoro-2,3-dimethylbutane	333.0	463	1.87	525
C_6HF_5	Pentafluorobenzene	358.89	530.97	3.531	324
C_6HF_5O	Pentafluorophenol	418.8	609	4.0	348
C_6HF_{11}	Undecafluorocyclohexane	335.2	477.7		
$C_6H_2F_4$	1,2,3,4-Tetrafluorobenzene	367.5	550.83	3.791	313
$C_6H_2F_4$	1,2,3,5-Tetrafluorobenzene	357.6	535.25	3.747	
$C_6H_2F_4$	1,2,4,5-Tetrafluorobenzene	363.4	543.35	3.801	
$C_6H_3ClF_2$	1-Chloro-2,4-difluorobenzene	400	609.6		
$C_6H_3ClF_2$	1-Chloro-2,5-difluorobenzene	401	612.5		
$C_6H_3ClF_2$	1-Chloro-3,4-difluorobenzene	400	609.2		
$C_6H_3ClF_2$	1-Chloro-3,5-difluorobenzene	391.7	592.0		
$C_6H_3F_3$	1,2,3-Trifluorobenzene		560.3		
$C_6H_3F_3$	1,2,4-Trifluorobenzene	363	551.1		
$C_6H_3F_3$	1,3,5-Trifluorobenzene	348.7	530.9		
C_6H_4BrF	1-Bromo-2-fluorobenzene	427	669.6		
C_6H_4BrF	1-Bromo-3-fluorobenzene	423	652.0		
C_6H_4BrF	1-Bromo-4-fluorobenzene	424.7	654.8		
C_6H_4ClF	1-Chloro-2-fluorobenzene	410.8	633.8		
C_6H_4ClF	1-Chloro-3-fluorobenzene	400.8	615.9		
C_6H_4ClF	1-Chloro-4-fluorobenzene	403	620.1		
$C_6H_4Cl_2$	*m*-Dichlorobenzene	446	685.7		

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
$C_6H_4F_2$	*o*-Difluorobenzene	367	566.0		
$C_6H_4F_2$	*m*-Difluorobenzene	355.8	548.4		
$C_6H_4F_2$	*p*-Difluorobenzene	362	556.9	4.40	
C_6H_5Br	Bromobenzene	429.21	670	4.52	324
C_6H_5Cl	Chlorobenzene	404.87	633.4	4.52	308
C_6H_5F	Fluorobenzene	357.88	560.09	4.551	269
C_6H_5I	Iodobenzene	461.6	721	4.52	351
C_6H_6	Benzene	353.24	562.05	4.895	256
C_6H_6O	Phenol	455.02	694.2	6.13	
C_6H_7N	Aniline	457.32	699	4.89	287
C_6H_7N	2-Methylpyridine	402.53	621.0	4.60	292
C_6H_7N	3-Methylpyridine	417.29	645.0	4.65	288
C_6H_7N	4-Methylpyridine	418.51	645.7	4.70	292
C_6H_{10}	1,5-Hexadiene	332.6	508		
C_6H_{10}	Cyclohexene	356.13	560.4		
$C_6H_{10}O$	Cyclohexanone	428.58	653.0	4.0	
$C_6H_{10}O_2$	Ethyl *trans*-2-butenoate	411	599		
$C_6H_{10}S$	Diallyl sulfide	411.8	653		
$C_6H_{11}Cl$	Chlorocyclohexane	415	586		
$C_6H_{11}N$	Hexanenitrile	436.80	633.8	3.30	
C_6H_{12}	1-Hexene	336.63	504.0	3.21	355.1
C_6H_{12}	Cyclohexane	353.88	553.8	4.08	308
C_6H_{12}	Methylcyclopentane	345.0	532.7	3.79	318
$C_6H_{12}O$	Hexanal	404	591	3.46	
$C_6H_{12}O$	2-Hexanone	400.8	587.0	3.32	
$C_6H_{12}O$	3-Hexanone	396.7	582.82	3.320	
$C_6H_{12}O$	4-Methyl-2-pentanone	389.7	571	3.27	
$C_6H_{12}O$	Cyclohexanol	433.99	647.1	4.401	
$C_6H_{12}O_2$	Hexanoic acid	478.4	662	3.20	
$C_6H_{12}O_2$	Pentyl formate	403.6	576	3.46	
$C_6H_{12}O_2$	Isopentyl formate	396.7	578		
$C_6H_{12}O_2$	Butyl acetate	399.3	579		
$C_6H_{12}O_2$	Isobutyl acetate	389.7	561	3.16	
$C_6H_{12}O_2$	Propyl propanoate	395.7	578		
$C_6H_{12}O_2$	Ethyl butanoate	394.7	566	3.06	421
$C_6H_{12}O_2$	Ethyl 2-methylpropanoate	383.3	553	3.07	421
$C_6H_{12}O_2$	Methyl pentanoate	400.6	567	3.19	
$C_6H_{12}O_3$	Ethylene glycol monoethyl ether acetate	429.6	611	3.18	441
$C_6H_{12}O_3$	Paraldehyde	397.5	563		
$C_6H_{13}Cl$	1-Chlorohexane	408.3	599		
$C_6H_{13}Cl$	3-Chloro-3-methylpentane	389	528		
C_6H_{14}	Hexane	341.88	507.6	3.025	368
C_6H_{14}	2-Methylpentane	333.41	497.7	3.04	368
C_6H_{14}	3-Methylpentane	336.42	504.6	3.12	368
C_6H_{14}	2,2-Dimethylbutane	322.88	489.0	3.10	358
C_6H_{14}	2,3-Dimethylbutane	331.08	500.0	3.15	361
$C_6H_{14}O$	1-Hexanol	430.8	610.3	3.417	387
$C_6H_{14}O$	2-Hexanol	413	585.9	3.31	384
$C_6H_{14}O$	3-Hexanol	408	582.4	3.36	383
$C_6H_{14}O$	2-Methyl-1-pentanol	422	604.4	3.45	
$C_6H_{14}O$	4-Methyl-1-pentanol	425.1	603.5		
$C_6H_{14}O$	2-Methyl-2-pentanol	394.3	559.5		
$C_6H_{14}O$	4-Methyl-2-pentanol	404.8	574.4		
$C_6H_{14}O$	2-Methyl-3-pentanol	399.7	576.0	3.46	
$C_6H_{14}O$	3-Methyl-3-pentanol	395.6	575.6	3.52	
$C_6H_{14}O$	Dipropyl ether	363.23	530.6	3.028	
$C_6H_{14}O$	Diisopropyl ether	341.66	500.32	2.832	386
$C_6H_{14}O$	Methyl pentyl ether	372	546.53	3.042	391

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
$C_6H_{14}O_2$	1-Propoxy-2-propanol	423	605.1	3.051	
$C_6H_{14}O_2$	Ethylene glycol monobutyl ether	441.6	633.9		424
$C_6H_{14}O_2$	1,1-Diethoxyethane	375.40	527		
$C_6H_{14}O_3$	Diethylene glycol monoethyl ether	469	670	3.167	
$C_6H_{15}N$	Dipropylamine	382.5	555.8	3.63	
$C_6H_{15}N$	Diisopropylamine	357.1	523.1	3.02	
$C_6H_{15}N$	Triethylamine	362	535.6	3.032	389
C_7F_8	Perfluorotoluene	377.7	534.47	2.705	428
C_7F_{14}	Perfluoro-1-heptene	354.2	478.2		
C_7F_{14}	Perfluoromethylcyclohexane	349.5	485.91	2.019	570
C_7F_{16}	Perfluoroheptane	355.7	474.8	1.62	664
C_7HF_{15}	1*H*-Pentadecafluoroheptane	369.2	495.8		
$C_7H_3F_5$	2,3,4,5,6-Pentafluorotoluene	390.7	566.52	3.126	384
$C_7H_4BrF_3$	1-Bromo-2-(trifluoromethyl)benzene	440.7	656.5		
$C_7H_4BrF_3$	1-Bromo-3-(trifluoromethyl)benzene	424.7	627.1		
$C_7H_4BrF_3$	1-Bromo-4-(trifluoromethyl)benzene	433	629.8		
C_7H_5N	Benzonitrile	464.3	699.4	4.21	
$C_7H_6F_2$	2,4-Difluorotoluene	390	581.4		
$C_7H_6F_2$	2,5-Difluorotoluene	391	587.8		
$C_7H_6F_2$	2,6-Difluorotoluene	385	581.8		
$C_7H_6F_2$	3,4-Difluorotoluene	385	598.5		
C_7H_6O	Benzaldehyde	452.0	695	4.65	
C_7H_7F	2-Fluorotoluene	388	591.2		
C_7H_7F	3-Fluorotoluene	388	591.8		
C_7H_7F	4-Fluorotoluene	389.8	592.1		
C_7H_8	Toluene	383.78	591.80	4.110	316
C_7H_8O	*o*-Cresol	464.19	697.6	5.01	
C_7H_8O	*m*-Cresol	475.42	705.8	4.56	309
C_7H_8O	*p*-Cresol	475.13	704.6	5.15	
C_7H_8O	Benzyl alcohol	478.46	715	4.3	
C_7H_8O	Anisole	426.9	646.1	4.222	341
C_7H_9N	2-Methylaniline	473.5	707	4.37	
C_7H_9N	3-Methylaniline	476.5	707	4.28	
C_7H_9N	4-Methylaniline	473.6	706	4.58	
C_7H_9N	*N*-Methylaniline	469.4	701	5.20	
C_7H_9N	2,3-Dimethylpyridine	434.27	655.4	4.10	356
C_7H_9N	2,4-Dimethylpyridine	431.53	647	3.95	361
C_7H_9N	2,5-Dimethylpyridine	430.13	645	3.85	361
C_7H_9N	2,6-Dimethylpyridine	417.16	624	3.85	361
C_7H_9N	3,4-Dimethylpyridine	452.25	684	4.20	355
C_7H_9N	3,5-Dimethylpyridine	444.99	668	4.05	361
C_7H_{14}	1-Heptene	366.79	537.3	2.92	409
C_7H_{14}	Cycloheptane	391.6	604.2	3.82	353
C_7H_{14}	Methylcyclohexane	374.08	572.1	3.48	369
C_7H_{14}	Ethylcyclopentane	376.7	569.5	3.40	375
C_7H_{14}	1,1-Dimethylcyclopentane	360.7	547	3.45	
C_7H_{14}	*cis*-1,2-Dimethylcyclopentane	372.7	565	3.45	
C_7H_{14}	*trans*-1,2-Dimethylcyclopentane	365.1	553	3.45	
C_7H_{14}	*cis*-1,3-Dimethylcyclopentane	364.0	551	3.45	
C_7H_{14}	*trans*-1,3-Dimethylcyclopentane	364.9	553	3.45	
$C_7H_{14}O$	2-Heptanone	424.20	611.5	3.436	
$C_7H_{14}O_2$	Heptanoic acid	495.4	679	2.90	
$C_7H_{14}O_2$	Pentyl acetate	422.4	600	2.68	470
$C_7H_{14}O_2$	Isopentyl acetate	415.7	599		
$C_7H_{14}O_2$	Isobutyl propanoate	410	592		
$C_7H_{14}O_2$	Propyl butanoate	416.2	600		
$C_7H_{14}O_2$	Propyl isobutanoate	408.6	589		
$C_7H_{14}O_2$	Ethyl pentanoate	419.3	570		

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
$C_7H_{14}O_2$	Ethyl 3-methylbutanoate	408.2	588		
$C_7H_{15}Cl$	1-Chloroheptane	433.6	614		
C_7H_{16}	Heptane	371.6	540.2	2.74	428
C_7H_{16}	2-Methylhexane	363.19	530.4	2.74	421
C_7H_{16}	3-Methylhexane	365	535.2	2.81	404
C_7H_{16}	3-Ethylpentane	366.7	540.6	2.89	416
C_7H_{16}	2,2-Dimethylpentane	352.4	520.5	2.77	416
C_7H_{16}	2,3-Dimethylpentane	362.93	537.3	2.91	393
C_7H_{16}	2,4-Dimethylpentane	353.64	519.8	2.74	418
C_7H_{16}	3,3-Dimethylpentane	359.21	536.4	2.95	414
C_7H_{16}	2,2,3-Trimethylbutane	354.01	531.1	2.95	398
$C_7H_{16}O$	1-Heptanol	449.60	632.6	3.058	435
$C_7H_{16}O$	2-Heptanol	432	608.3	3.021	442
$C_7H_{16}O$	3-Heptanol	430	605.4		434
$C_7H_{16}O$	4-Heptanol	429	602.6		432
$C_7H_{16}O_2$	1-Butoxy-2-propanol	444.7	624.9	2.739	
$C_8F_{16}O$	Perfluoro-2-butyltetrahydrofuran	375.8	500.2	1.607	588
C_8F_{18}	Perfluorooctane	379.1	502	1.66	
C_8H_7N	4-Methylbenzonitrile	490.2	723		
C_8H_7N	Indole	526.8	794	4.8	356
C_8H_8	Styrene	418	635.2	3.87	
C_8H_8O	Acetophenone	475	713	4.40	380
$C_8H_8O_3$	Methyl salicylate	496.1	709		
C_8H_{10}	Ethylbenzene	409.34	617.15	3.609	374
C_8H_{10}	*o*-Xylene	417.7	630.3	3.732	370
C_8H_{10}	*m*-Xylene	412.27	617.0	3.541	375
C_8H_{10}	*p*-Xylene	411.52	616.2	3.511	378
$C_8H_{10}O$	2-Ethylphenol	477.7	703.0		
$C_8H_{10}O$	3-Ethylphenol	491.6	718.8		
$C_8H_{10}O$	4-Ethylphenol	491.1	716.4		
$C_8H_{10}O$	2,3-Xylenol	490.1	722.8		
$C_8H_{10}O$	2,4-Xylenol	484.13	707.6		
$C_8H_{10}O$	2,5-Xylenol	484.3	706.9		
$C_8H_{10}O$	2,6-Xylenol	474.22	701.0		
$C_8H_{10}O$	3,4-Xylenol	500	729.8		
$C_8H_{10}O$	3,5-Xylenol	494.89	715.6		
$C_8H_{10}O$	1-Phenylethanol	478	699	3.77	
$C_8H_{10}O$	Phenetole	442.96	647	3.42	
$C_8H_{11}N$	*N*-Ethylaniline	476.2	698		
$C_8H_{11}N$	*N,N*-Dimethylaniline	467.30	687	3.63	
$C_8H_{14}O_4$	Diethyl succinate	490.9	663		
$C_8H_{15}N$	Octanenitrile	478.40	674.4	2.85	
C_8H_{16}	1-Octene	394.44	567.0	2.68	468
C_8H_{16}	Cyclooctane	422	647.2	3.56	410
C_8H_{16}	Ethylcyclohexane	405.1	609	3.04	
C_8H_{16}	*cis*-1,2-Dimethylcyclohexane	403.0	606	2.95	
C_8H_{16}	*trans*-1,2-Dimethylcyclohexane	396.7	596	2.94	
C_8H_{16}	*cis*-1,3-Dimethylcyclohexane	393.3	591	2.94	
C_8H_{16}	*trans*-1,3-Dimethylcyclohexane	397.7	598	2.94	
C_8H_{16}	*trans*-1,4-Dimethylcyclohexane	392.6	587.7		
$C_8H_{16}O_2$	Octanoic acid	512	695	2.64	
$C_8H_{16}O_2$	2-Ethylhexanoic acid	501	674.6	2.778	528
$C_8H_{16}O_2$	Isopentyl propanoate	433.4	611		
$C_8H_{16}O_2$	Isobutyl butanoate	430.1	611		
$C_8H_{16}O_2$	Isobutyl isobutanoate	421.8	602		
$C_8H_{16}O_2$	Propyl 3-methylbutanoate	429.1	609		
$C_8H_{16}O_4$	Diethylene glycol monoethyl ether acetate	491.7	663	2.73	
$C_8H_{17}Cl$	1-Chlorooctane	456.7	643		

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
C_8H_{18}	Octane	398.82	568.7	2.49	492
C_8H_{18}	2-Methylheptane	390.81	559.7	2.50	488
C_8H_{18}	3-Methylheptane	392.1	563.6	2.55	464
C_8H_{18}	4-Methylheptane	390.87	561.7	2.54	476
C_8H_{18}	3-Ethylhexane	391.8	565.5	2.61	455
C_8H_{18}	2,2-Dimethylhexane	380.01	549.8	2.53	478
C_8H_{18}	2,3-Dimethylhexane	388.77	563.5	2.63	468
C_8H_{18}	2,4-Dimethylhexane	382.7	553.5	2.56	472
C_8H_{18}	2,5-Dimethylhexane	382.27	550.0	2.49	482
C_8H_{18}	3,3-Dimethylhexane	385.12	562.0	2.65	443
C_8H_{18}	3,4-Dimethylhexane	390.88	568.8	2.69	466
C_8H_{18}	3-Ethyl-2-methylpentane	388.81	567.1	2.70	442
C_8H_{18}	3-Ethyl-3-methylpentane	391.42	576.5	2.81	455
C_8H_{18}	2,2,3-Trimethylpentane	383	563.5	2.73	436
C_8H_{18}	2,2,4-Trimethylpentane	372.37	543.8	2.57	468
C_8H_{18}	2,3,3-Trimethylpentane	388.0	573.5	2.82	455
C_8H_{18}	2,3,4-Trimethylpentane	386.7	566.4	2.73	460
C_8H_{18}	2,2,3,3-Tetramethylbutane	379.60	567.8	2.87	461
$C_8H_{18}O$	1-Octanol	468.31	652.5	2.777	497
$C_8H_{18}O$	2-Octanol	452.5	629.6	2.754	519
$C_8H_{18}O$	3-Octanol	444	628.5		515
$C_8H_{18}O$	4-Octanol	449.5	625.1		515
$C_8H_{18}O$	4-Methyl-3-heptanol	443	623.5		
$C_8H_{18}O$	5-Methyl-3-heptanol	445	621.2		
$C_8H_{18}O$	2-Ethyl-1-hexanol	457.8	640.6	2.8	
$C_8H_{18}O$	Dibutyl ether	413.43	584.1	3.01	
$C_8H_{18}O$	Di-*tert*-butyl ether	380.38	550		
$C_8H_{19}N$	Dibutylamine	432.8	607.5	3.11	
$C_8H_{19}N$	Diisobutylamine	412.8	584.4	3.20	
$C_8H_{20}Si$	Tetraethylsilane	427.9	603.7	2.602	
C_9F_{20}	Perfluorononane	398.5	524	1.56	
C_9H_7N	Quinoline	510.31	782	4.86	371
C_9H_7N	Isoquinoline	516.37	803	5.10	374
C_9H_{10}	Indan	451.12	684.9	3.95	
C_9H_{12}	Propylbenzene	432.39	638.35	3.200	440
C_9H_{12}	Isopropylbenzene	425.56	631.0	3.209	
C_9H_{12}	2-Ethyltoluene	438.4	651	3.38	
C_9H_{12}	3-Ethyltoluene	434.5	637	3.25	
C_9H_{12}	4-Ethyltoluene	435	640.2	3.23	
C_9H_{12}	1,2,3-Trimethylbenzene	449.27	664.5	3.454	
C_9H_{12}	1,2,4-Trimethylbenzene	442.53	649.1	3.232	
C_9H_{12}	1,3,5-Trimethylbenzene	437.89	637.3	3.127	
$C_9H_{13}N$	2-Methyl-*N*,*N*-dimethylaniline	467.3	668	3.12	
C_9H_{18}	1-Nonene	420.1	594.0		526
C_9H_{18}	Cyclononane	451.6	682	3.34	
C_9H_{18}	1α,3α,5β-1,3,5-Trimethylcyclohexane	413.7	602.2		
$C_9H_{18}O$	2-Nonanone	468.5	651.9	2.482	
$C_9H_{18}O$	5-Nonanone	461.60	640		
$C_9H_{18}O_2$	Nonanoic acid	527.7	711	2.40	
$C_9H_{18}O_2$	Isopentyl butanoate	452	619		
$C_9H_{18}O_2$	Isobutyl 3-methylbutanoate	441.7	621		
C_9H_{20}	Nonane	423.97	594.6	2.29	555
C_9H_{20}	2-Methyloctane	416.4	582.8	2.31	
C_9H_{20}	2,2-Dimethylheptane	405.9	576.7	2.35	
C_9H_{20}	2,2,5-Trimethylhexane	397.24	569.8		
C_9H_{20}	2,2,3,3-Tetramethylpentane	413.4	607.5	2.74	
C_9H_{20}	2,2,3,4-Tetramethylpentane	406.2	592.6	2.60	
C_9H_{20}	2,2,4,4-Tetramethylpentane	395.44	574.6	2.49	

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm^3 mol^{-1}
C_9H_{20}	2,3,3,4-Tetramethylpentane	414.7	607.5	2.72	
$C_9H_{20}O$	1-Nonanol	486.52	670.7	2.528	572
$C_9H_{20}O$	2-Nonanol	466.7	649.6	2.53	575
$C_9H_{20}O$	3-Nonanol	468	648.0		577
$C_9H_{20}O$	4-Nonanol	465.7	645.1		575
$C_{10}F_8$	Perfluoronaphthalene	482	673.1		
$C_{10}F_{18}$	Perfluorodecalin	415	566	1.52	
$C_{10}F_{22}$	Perfluorodecane	417.4	542	1.45	
$C_{10}H_8$	Naphthalene	491.1	748.4	4.05	407
$C_{10}H_9N$	1-Naphthylamine	573.9	850	5.0	438
$C_{10}H_9N$	2-Naphthylamine	579.4	850	4.9	438
$C_{10}H_{12}$	1,2,3,4-Tetrahydronaphthalene	480.8	720	3.65	408
$C_{10}H_{14}$	Butylbenzene	456.46	660.5	2.89	497
$C_{10}H_{14}$	Isobutylbenzene	445.94	650	3.05	
$C_{10}H_{14}$	1-Isopropyl-4-methylbenzene	450.3	652	2.8	
$C_{10}H_{14}$	*p*-Diethylbenzene	456.9	657.9	2.803	
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene	470.0	676	2.9	
$C_{10}H_{14}O$	Thymol	505.7	698		
$C_{10}H_{16}$	*d*-Limonene	451	653		470
$C_{10}H_{16}$	α-Pinene	429.4	644		454
$C_{10}H_{16}$	3-Carene	444	658		487
$C_{10}H_{18}$	1,3-Decadiene	442	615		
$C_{10}H_{18}$	*cis*-Decahydronaphthalene	469.0	702.3	3.20	
$C_{10}H_{18}$	*trans*-Decahydronaphthalene	460.5	687.1		
$C_{10}H_{20}$	1-Decene	443.7	617	2.22	584
$C_{10}H_{20}O$	Decanal	481.7	674.2		
$C_{10}H_{20}O$	Menthol	489	694		
$C_{10}H_{20}O_2$	Decanoic acid	541.9	726	2.23	
$C_{10}H_{20}O_2$	Ethyl octanoate	481.7	659		
$C_{10}H_{20}O_4$	Diethylene glycol monobutyl ether acetate	518	681	3.15	
$C_{10}H_{22}$	Decane	447.30	617.7	2.11	624
$C_{10}H_{22}$	3,3,5-Trimethylheptane	428.9	609.5	2.32	
$C_{10}H_{22}$	2,2,3,3-Tetramethylhexane	433.5	623.0	2.51	
$C_{10}H_{22}$	2,2,5,5-Tetramethylhexane	410.6	581.4	2.19	
$C_{10}H_{22}O$	1-Decanol	504.3	687.3	2.315	649
$C_{10}H_{22}O$	2-Decanol	484	668.6		646
$C_{10}H_{22}O$	3-Decanol	486	666.1		643
$C_{10}H_{22}O$	4-Decanol	483.7	663.7		643
$C_{10}H_{22}O$	5-Decanol	474	663.2		646
$C_{10}H_{22}S$	Diisopentyl sulfide	484	664		
$C_{11}H_{10}$	1-Methylnaphthalene	517.9	772	3.60	
$C_{11}H_{10}$	2-Methylnaphthalene	514.3	761		
$C_{11}H_{22}O_2$	Ethyl nonanoate	500.2	674		
$C_{11}H_{24}$	Undecane	469.1	639	1.98	689
$C_{11}H_{24}O$	1-Undecanol	518	703.6	2.147	718
$C_{12}H_8$	Acenaphthylene	553	792	3.20	
$C_{12}H_9N$	Carbazole	627.84	901.8	3.13	454
$C_{12}H_{10}$	Biphenyl	529.3	773	3.38	497
$C_{12}H_{10}O$	Diphenyl ether	531.2	766.8		
$C_{12}H_{12}$	2,7-Dimethylnaphthalene	538	775	3.23	601
$C_{12}H_{18}$	Hexamethylbenzene	536.6	758		
$C_{12}H_{24}$	1-Dodecene	487.0	658	1.93	
$C_{12}H_{26}$	Dodecane	489.47	658	1.82	754
$C_{12}H_{26}O$	1-Dodecanol	533	719.4	1.994	
$C_{13}H_9N$	Acridine	618.01	891.1	3.21	548
$C_{13}H_9N$	Phenanthridine	622.1	895	3.6	548
$C_{13}H_{11}N$	9-Methylcarbazole	616.79	890	3.38	572
$C_{13}H_{12}$	Diphenylmethane	538.2	760	2.71	563

CRITICAL CONSTANTS (continued)

Molecular Formula	Name	T_b/K	T_c/K	P_c/MPa	V_c/cm³ mol⁻¹
$C_{13}H_{26}O_2$	Methyl dodecanoate	540	712		
$C_{13}H_{28}$	Tridecane	508.62	675	1.68	823
$C_{13}H_{28}O$	1-Tridecanol	547	734	1.935	
$C_{14}H_{10}$	Anthracene	613.1	869.3		554
$C_{14}H_{10}$	Phenanthrene	613	869		
$C_{14}H_{30}$	Tetradecane	526.73	693	1.57	894
$C_{14}H_{30}O$	1-Tetradecanol	560	747	1.81	
$C_{15}H_{32}$	Pentadecane	543.8	708	1.48	966
$C_{16}H_{34}$	Hexadecane	560.01	723	1.40	1034
$C_{16}H_{34}$	2,2,4,4,6,8,8-Heptamethylnonane	519.5	692		
$C_{16}H_{34}O$	1-Hexadecanol	585	770	1.61	
$C_{17}H_{36}$	Heptadecane	575.2	736	1.34	1103
$C_{17}H_{36}O$	1-Heptadecanol	597	780	1.50	
$C_{18}H_{14}$	*o*-Terphenyl	605	857	2.99	731
$C_{18}H_{14}$	*m*-Terphenyl	636	883	2.48	724
$C_{18}H_{14}$	*p*-Terphenyl	649	908	2.99	729
$C_{18}H_{38}$	Octadecane	589.5	747	1.29	1189
$C_{18}H_{38}O$	1-Octadecanol	608	790	1.44	
$C_{19}H_{40}$	Nonadecane	603.1	755	1.16	
$C_{20}H_{42}$	Eicosane	616	768	1.07	
$C_{20}H_{42}O$	1-Eicosanol	629	809	1.30	
$C_{21}H_{44}$	Heneicosane	629.7	778	1.03	
$C_{22}H_{46}$	Docosane	641.8	786	0.98	
$C_{23}H_{48}$	Tricosane	653	790	0.92	
$C_{24}H_{50}$	Tetracosane	664.5	800	0.87	
$C_{30}H_{50}$	Squalene	694.5	795.9	0.59	

SUBLIMATION PRESSURE OF SOLIDS

This table gives the sublimation (vapor) pressure of some representative solids as a function of temperature. Entries include simple inorganic and organic substances in their solid phase below room temperature, as well as polycyclic organic compounds which show measurable sublimation pressure only at elevated temperatures. Substances are listed by molecular formula in the Hill order. Values marked by * represent the solid-liquid-gas triple point. Note that some pressure values are in pascals (Pa) and others are in kilopascals (kPa). For conversion, 1 kPa = 7.506 mmHg = 0.0098692 atm.

REFERENCES

1. Lide, D.R. and Kehiaian, H.V., *CRC Handbook of Thermophysical and Thermochemical Data,* CRC Press, Boca Raton, FL, 1994.
2. *TRC Thermodynamic Tables,* Thermodynamic Research Center, Texas A&M University, College Station, TX.
3. Oja, V. and Suuberg, E.M., *J. Chem. Eng. Data*,43, 486, 1998.

Ar	*T*/K	55	60	65	70	75	80	83.81*	
Argon	*p*/kPa	0.2	0.8	2.8	7.7	18.7	40.7	68.8*	
BrH	*T*/K	135	140	150	160	170	180	185.1*	
Hydrogen bromide	*p*/kPa	0.1	0.3	1.1	3.3	8.7	20.1	27.4*	
Br_2	*T*/K	170	180	190	200	210	220	230	240*
Bromine	*p*/Pa	0.069	0.416	2.04	8.45	30.3	96.0	273	710*
ClH	*T*/K	120	130	140	150	155	159.0*		
Hydrogen chloride	*p*/kPa	0.1	0.5	1.9	5.8	9.5	13.5*		
Cl_2	*T*/K	120	130	140	150	160	170*		
Chlorine	*p*/Pa	0.144	1.52	11.2	63.1	283	1054*		
F_4Si	*T*/K	130	140	150	160	170	175	180	186.3*
Tetrafluorosilane	*p*/kPa	0.2	0.9	3.9	14.0	43.8	74.2	122.4	220.8*
F_6S	*T*/K	150	165	180	190	200	210	220	223.1*
Sulfur hexafluoride	*p*/kPa	0.4	2.6	11.3	25.9	54.5	106.1	195.1	232.7*
HI	*T*/K	160	170	180	190	200	210	220	222.4*
Hydrogen iodide	*p*/kPa	0.2	0.8	2.2	5.3	11.7	23.6	44.1	49.3*
H_2O	*T*/K	190	210	225	240	250	260	270	273.16*
Water	*p*/Pa	0.032	0.702	4.942	27.28	76.04	195.8	470.1	611.66*
H_2S	*T*/K	140	150	160	165	170	175	180	187.6*
Hydrogen sulfide	*p*/kPa	0.2	0.6	1.9	3.2	5.2	8.3	12.7	22.7*
H_3N	*T*/K	160	170	180	190	195	195.4*		
Ammonia	*p*/kPa	0.1	0.4	1.2	3.5	5.8	6.12*		
I_2	*T*/K	240	250	260	270	280	290	300	310*
Iodine	*p*/Pa	0.081	0.297	0.971	2.89	7.92	20.1	47.9	107*
Kr	*T*/K	80	90	95	100	105	110	115.8*	
Krypton	*p*/kPa	0.4	2.7	6.0	12.1	22.8	40.4	73.1*	
NO	*T*/K	85	90	95	100	105	109.5*		
Nitric oxide	*p*/kPa	0.1	0.4	1.3	3.8	10.0	21.9*		
Xe	*T*/K	110	120	130	140	150	155	160	161.4*
Xenon	*p*/kPa	0.3	1.5	4.9	14.0	34.2	51.1	74.2	81.7*
CHN	*T*/K	200	210	220	230	240	250	255	259.83*
Hydrogen cyanide	*p*/kPa	0.2	0.4	1.0	2.2	4.8	9.7	13.6	18.62*
CH_4	*T*/K	65	70	75	80	85	90.69*		
Methane	*p*/kPa	0.1	0.3	0.8	2.1	4.9	11.70*		

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CO	T/K	50	55	60	65	68.13*			
Carbon monoxide	p/kPa	0.1	0.6	2.6	8.2	15.4*			
CO_2	T/K	130	140	155	170	185	194.7	205	216.58*
Carbon dioxide	p/kPa	0.032	0.187	1.674	9.987	44.02	101.3	227.1	518.0*
C_2Cl_6	T/K	275	300	325	350	375	400	425	459.9*
Hexachloroethane	p/Pa	0.004	0.056	0.383	1.62	5.30	14.8	36.4	107.4*
C_2H_2	T/K	130	140	150	160	170	180	190	192.4*
Acetylene	p/kPa	0.2	0.7	2.6	7.8	20.6	49.0	106.3	126.0*
$C_2H_4O_2$	T/K	250	260	270	280	289.7*			
Acetic acid	p/kPa	0.092	0.199	0.406	0.79	1.29*			
C_5H_{12}	T/K	200	210	220	230	240	250	255	256.58*
Neopentane	p/kPa	0.7	1.6	3.6	7.3	13.9	24.8	32.4	35.8*
$C_6H_6Cl_6$	T/K	300	320	330	340	350	360	370	380
1,2,3,4,5,6-Hexa-chlorocyclohexane (Lindane)	p/Pa	0.01	0.13	0.39	1.04	2.66	6.42	14.8	32.7
$C_6H_6O_2$	T/K	330	340	350	360	370	380		
Resorcinol	p/Pa	1.03	2.78	7.09	17.2	39.6	87.6		
$C_6H_6O_2$	T/K	350	360	370	380	390	400		
p-Hydroquinone	p/Pa	1.20	3.18	7.96	19.0	43.4	95.1		
$C_{10}H_8$	T/K	250	270	280	290	300	310	330	353.43*
Naphthalene	p/Pa	0.036	0.514	1.662	4.918	13.43	34.15	182.9	999.6*
$C_{12}H_8N_2$	T/K	290	300	310	320				
Phenazine	p/Pa	0.0013	0.0046	0.0150	0.0448				
$C_{12}H_8O$	T/K	300	310	320	330	340	350		
Dibenzofuran	p/Pa	0.408	1.21	3.35	8.71	21.4	50.0		
$C_{12}H_9N$	T/K	350	355	360					
Carbazole	p/Pa	0.086	0.140	0.245					
$C_{13}H_7NO_2$	T/K	330	340	350	360	370	380		
Benz[g]isoquinoline-5,10-dione	p/Pa	0.006	0.018	0.053	0.148	0.394	0.994		
$C_{13}H_8O$	T/K	330	340	350					
1H-Phenalen-1-one	p/Pa	0.040	0.113	0.302					
$C_{13}H_8O_2$	T/K	400	410	420	430				
3-Hydroxy-1H-phenalen-1-one	p/Pa	0.006	0.018	0.053	0.144				
$C_{13}H_9N$	T/K	290	300	310	320				
Acridine	p/Pa	0.0024	0.0085	0.0278	0.0845				
$C_{13}H_9N$	T/K	310	320	330	340				
Phenanthridine	p/Pa	0.020	0.066	0.206	0.603				

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$C_{14}H_{10}$	*T*/K	320	330	340	350	360	370	380	390
Anthracene	*p*/Pa	0.014	0.043	0.125	0.342	1.01	2.38	5.35	11.5
$C_{14}H_{10}$	*T*/K	300	310	320	330	340	350	360	
Phenanthrene	*p*/Pa	0.025	0.085	0.270	0.796	2.02	4.89	11.2	
$C_{16}H_{10}$	*T*/K	320	330	340	350	360	370	380	390
Pyrene	*p*/Pa	0.008	0.024	0.073	0.208	0.556	1.32	2.86	6.30
$C_{16}H_{10}O$	*T*/K	360	370	380	390	400			
1-Pyrenol	*p*/Pa	0.005	0.016	0.047	0.135	0.364			
$C_{16}H_{12}S$	*T*/K	330	340	350	360	370	380	390	
Benzo[b]naphtho-(2,1-d)thiophene	*p*/Pa	0.001	0.004	0.012	0.036	0.098	0.255	0.631	
$C_{17}H_{12}$	*T*/K	340	350	360	370	380	390	400	
11*H*-Benzo[b]fluorene	*p*/Pa	0.003	0.009	0.029	0.085	0.235	0.619	1.55	
$C_{18}H_{10}O_4$	*T*/K	420	430	440	450				
6,11-Dihydroxy-5,12-naphthacenedione	*p*/Pa	0.008	0.022	0.055	0.131				
$C_{18}H_{12}$	*T*/K	390	400	410	420				
Chrysene	*p*/Pa	0.087	0.221	0.539	1.26				
$C_{18}H_{12}$	*T*/K	390	400	410	420	430	440	450	460
Naphthacene	*p*/Pa	0.005	0.014	0.035	0.084	0.194	0.432	0.928	1.929
$C_{20}H_{12}$	*T*/K	390	400	410	420	430			
Perylene	*p*/Pa	0.006	0.015	0.040	0.102	0.246			
$C_{22}H_{14}$	*T*/K	450	460	470	480	490			
Pentacene	*p*/Pa	0.002	0.006	0.013	0.031	0.069			
$C_{24}H_{12}$	*T*/K	430	440	450	460	470	480	490	500
Coronene	*p*/Pa	0.004	0.010	0.021	0.046	0.097	0.197	0.389	0.747

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VAPOR PRESSURE

This table gives vapor pressure data for about 1800 inorganic and organic substances. In order to accommodate elements and compounds ranging from refractory to highly volatile in a single table, the temperature at which the vapor pressure reaches specified pressure values is listed. The pressure values run in decade steps from 1 Pa (about 7.5 μm Hg) to 100 kPa (about 750 mm Hg). All temperatures are given in °C.

The data used in preparing the table came from a large number of sources; the main references used for each substance are indicated in the last column. Since the data were refit in most cases, values appearing in this table may not be identical with values in the source cited. The temperature entry in the 100 kPa column is close to, but not identical with, the normal boiling point (which is defined as the temperature at which the vapor pressure reaches 101.325 kPa). Although some temperatures are quoted to 0.1°C, uncertainties of several degrees should generally be assumed. Values followed by an "e" were obtained by extrapolating (usually with an Antoine equation) beyond the region for which experimental measurements were available and are thus subject to even greater uncertainty.

Compounds are listed by molecular formula following the Hill convention. Substances not containing carbon are listed first, followed by those that contain carbon. To locate an organic compound by name or CAS Registry Number when the molecular formula is not known, use the table *Physical Constants of Organic Compounds* in Section 3 and its indexes to determine the molecular formula. The indexes to *Physical Constants of Inorganic Compounds* in Section 4 can be used in a similar way.

More extensive and detailed vapor pressure data on selected important substances appear in other tables in this section of the *Handbook*. These substances are flagged by a symbol following the name as follows:

* See *Vapor Pressure of Fluids below 300 K*
** See *IUPAC Recommended Data for Vapor Pressure Calibration*
*** See *Vapor Pressure of Ice* and *Vapor Pressure of Water from 0 to 370°C*

The following notations appear after individual temperature entries:

s — Indicates the substance is a solid at this temperature.
e — Indicates an extrapolation beyond the region where experimental measurements exist.
i — Indicates the value was calculated from ideal gas thermodynamic functions, such as those in the *JANAF Thermochemical Tables* (see Reference 8).

REFERENCES

1. Lide, D.R., and Kehiaian, H.V., *CRC Handbook of Thermophysical and Thermochemical Data*, CRC Press, Boca Raton, FL, 1994.
2. Stull, D., in *American Institute of Physics Handbook, Third Edition,* Gray, D.E., Ed., McGraw Hill, New York, 1972.
3. Hultgren, R., Desai, P.D., Hawkins, D.T., Gleiser, M., Kelley, K.K., and Wagman, D.D., *Selected Values of Thermodynamic Properties of the Elements,* American Society for Metals, Metals Park, OH, 1973.
4. Stull, D., *Ind. Eng. Chem.*, 39, 517, 1947.
5. *TRCVP, Vapor Pressure Database, Version 2.2P*, Thermodynamic Research Center, Texas A&M University, College Station, TX.
6. *TRC Thermodynamic Tables,* Thermodynamic Research Center, Texas A&M University, College Station, TX.
7. Ohe, S., *Computer Aided Data Book of Vapor Pressure*, Data Book Publishing Co., Tokyo, 1976.
8. Chase, M.W., Davies, C.A., Downey, J.R., Frurip, D.J., McDonald, R.A., and Syverud, A.N., *JANAF Thermochemical Tables, Third Edition, J. Phys. Chem. Ref. Data,* Vol. 14, Suppl. 1, 1985.
9. Barin, I., *Thermochemical Data of Pure Substances*, VCH Publishers, New York, 1993.
10. Jacobsen, R.T., et. al, *International Thermodynamic Tables of the Fluid State, No. 10. Ethylene*, Blackwell Scientific Publications, Oxford, 1988.
11. Wakeham, W.A., *International Thermodynamic Tables of the Fluid State, No.* 12. *Methanol,* Blackwell Scientific Publications, Oxford, 1993.
12. Janz, G.J., *Molten Salts Handbook,* Academic Press, New York, 1967.
13. Ohse, R.W. *Handbook of Thermodynamic and Transport Properties of Alkali Metals*, Blackwell Scientific Publications, Oxford, 1994.
14. Gschneidner, K.A., in *CRC Handbook of Chemistry and Physics, 77th Edition*, p. 4-112, CRC Press, Boca Raton, FL, 1996.
15. Leider, H.R., Krikorian, O.H., and Young, D.A., *Carbon,* 11, 555, 1973.
16. Ruzicka, K., and Majer, V., *J. Phys. Chem. Ref. Data*, 23, 1, 1994.
17. Tillner-Roth, R., and Baehr, H.D., *J. Phys. Chem. Ref. Data,* 23, 657, 1994.
18. Younglove, B.A., and McLinden, M.O., *J. Phys. Chem. Ref. Data*, 23, 731, 1994.
19. Outcalt, S.L., and McLinden, M.O., *J. Phys. Chem. Ref. Data*, 25, 605, 1996.
20. Weber, L.A., and Defibaugh, D.R., *J. Chem. Eng. Data,* 41, 382, 1996.
21. Rodrigues, M.F., and Bernardo-Gil, M.G., *J. Chem. Eng. Data*, 41, 581, 1996.
22. Piacente, V., Gigli, G., Scardala, P., and Giustini, A., *J. Phys. Chem.*, 100, 9815, 1996.
23. Barton, J.L., and Bloom, H., *J. Phys. Chem.*, 60, 1413, 1956.
24. Sense, K.A., Alexander, C.A., Bowman, R.E., and Filbert, R.B., *J. Phys. Chem.*, 61, 337, 1957.
25. Ewing, C.T., and Stern, K.H., *J. Phys. Chem.* 78, 1998, 1974.
26. Cady, G.H., and Hargreaves, G.B., *J. Chem. Soc.*, 1961, 1563; 1961, 1568.
27. Skudlarski, K., Dudek, J., and Kapala, J., *J. Chem. Thermodynamics*, 19, 857, 1987.
28. Wagner, W., and de Reuck, K.M., *International Thermodynamic Tables of the Fluid State, No. 9. Oxygen*, Blackwell Scientific Publications, Oxford, 1987.

29. Marsh, K.N., Editor, *Recommended Reference Materials for the Realization of Physicochemical Properties*, Blackwell Scientific Publications, Oxford, 1987.
30. Alcock, C.B., Itkin, V.P., and Horrigan, M.K., *Canadian Metallurgical Quarterly*, 23, 309, 1984.
31. Stewart, R.B., and Jacobsen, R.T., *J. Phys. Chem. Ref. Data*, 18, 639, 1989.
32. Sifner, O., and Klomfar, J., *J. Phys. Chem. Ref. Data*, 23, 63, 1994.
33. Bah, A., and Dupont-Pavlovsky, N., *J. Chem. Eng. Data*, 40, 869, 1995.
34. Behrens, R.G., and Rosenblatt, G., *J. Chem. Thermodynamics*, 4, 175, 1972.
35. Behrens, R.G., and Rosenblatt, G., *J. Chem. Thermodynamics*, 5, 173, 1973.
36. Haar, L., Gallagher, J.S., and Kell, G.S., *NBS/NRC Steam Tables*, Hemisphere Publishing Corp., New York, 1984.
37. Wagner, W., Saul, A., and Pruss, A., *J. Phys. Chem. Ref. Data*, 23, 515. 1994.
38. Behrens, R.G., Lemons, R.S., and Rosenblatt, G., *J. Chem. Thermodynamics*, 6, 457, 1974.
39. Boublik, T., Fried, V., and Hala, E., *The Vapor Pressure of Pure Substances, Second Edition*, Elsevier, Amsterdam, 1984.
40. Goodwin, R.D., *J. Phys. Chem. Ref. Data*, 14, 849, 1985.
41. Younglove, B.A., and Ely, J.F., *J. Phys. Chem. Ref. Data*, 16, 577, 1987.

		Temperature in °C for the indicated pressure						
Mol. Form.	**Name**	**1 Pa**	**10 Pa**	**100 Pa**	**1 kPa**	**10 kPa**	**100 kPa**	**Ref.**
Substances not containing carbon:								
Ag	Silver	1010	1140	1302	1509	1782	2160	2
AgBr	Silver(I) bromide	569 i	656 i	765 i	905 i	1093 i	1359 i	9
AgCl	Silver(I) chloride	670	769	873	1052	1264	1561	4
AgI	Silver(I) iodide	594	686	803	959	1177	1503	4
Al	Aluminum	1209	1359	1544	1781	2091	2517	2
AlB_3H_{12}	Aluminum borohydride				-46.8	-9.4	45.5	4
$AlCl_3$	Aluminum trichloride	58.4 s	76.5 s	97.1 s	120.7 s	148.2 s	180.5 s	4
AlF_3	Aluminum trifluoride	744 s	819 s	906 s	1008 s	1130 s	1276 s	8
AlI_3	Aluminum triiodide				218	285	385	4
Al_2O_3	Aluminum oxide			2122	2351	2629	2975	4
Ar	Argon*		-226.4 s	-220.3 s	-212.4 s	-201.7 s	-186.0	1,5,31
As	Arsenic	280 s	323 s	373 s	433 s	508 s	601 s	3
$AsCl_3$	Arsenic(III) chloride			-8 e	21.3	63.1	129.4	1
AsF_3	Arsenic(III) fluoride					8.1	56.0	4
AsI_3	Arsenic(III) iodide				187	261	367 e	7
As_2O_3	Arsenic(III) oxide (arsenolite)	133.7 s	163.0 s	196.8 s	236.2 s	283.0		34
At	Astatine	88 s	119 s	156 s	202 s	258 s	334	2
Au	Gold	1373	1541	1748	2008	2347	2805	2
B	Boron	2075	2289	2549	2868	3272	3799	2
BBr_3	Boron tribromide			-45 e	-15 e	27.5	90.4	1
BCl_3	Boron trichloride*			-94.0	-70.5	-37.4	12.3	4
BF_3	Boron trifluoride*	-173.9 s	-166.0 s	-156.0 s	-143.0 s	-125.9	-101.1	4
B_2F_4	Tetrafluorodiborane						-34	1
B_2H_6	Diborane			-162 e	-147.0	-125.8	-92.6	1
B_5H_9	Pentaborane(9)				-34.8	3.8	57.6	4
Ba	Barium	638 s	765	912	1115	1413	1897	9
Be	Beryllium	1189 s	1335	1518	1750	2054	2469	2
$BeBr_2$	Beryllium bromide	203 s	240 s	283 s	335 s	397 s	473 s	4
$BeCl_2$	Beryllium chloride	196 s	237 s	284 s	339 s	402 s	487	4
BeF_2	Beryllium fluoride		686 e	767 e	869	999	1172 e	7
BeI_2	Beryllium iodide	188 s	229 s	276 s	333 s	402 s	487	4
Bi	Bismuth	668	768	892	1052	1265	1562	2
$BiBr_3$	Bismuth tribromide			217 s	273 i	348 i	455 i	4,9
$BiCl_3$	Bismuth trichloride				248.9	328.6	438.7	1,4
BrCs	Cesium bromide	531 s	601 s	701 i	834 i	1019 i	1293 e	9
BrH	Hydrogen bromide*		-153.3 s	-140.4 s	-123.8 s	-101.5 s	-67.0	5
BrH_3Si	Bromosilane				-81.0	-47.3	2.2	4
BrH_4N	Ammonium bromide	121 s	154 s	195 s	246 s	310.4 s	395.1 s	5
BrK	Potassium bromide	597 s	674 s	773				25
BrLi	Lithium bromide		630	733	868	1049	1308	4
BrNa	Sodium bromide			791	931	1120	1389	4
BrRb	Rubidium bromide			766	903	1087	1350	4
BrTl	Thallium(I) bromide				509	635	817	4
Br_2	Bromine*	-87.7 s	-71.8 s	-52.7 s	-29.3 s	2.5	58.4	1
Br_2Cd	Cadmium bromide	373 s	435 s	509 s				27
Br_2Hg	Mercury(II) bromide	71 s	98 s	132 s	174 s	227 s	318	4
Br_2OS	Thionyl bromide	-49 e	-29 e	-5 e	27.8	72.9	139.6	5

VAPOR PRESSURE (continued)

Mol. Form.	Name	Temperature in °C for the indicated pressure 1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
Br_2Pb	Lead(II) bromide	374	431	502	597	726	914	4
Br_2S_2	Sulfur bromide	-7 e	15 e	42 e	78.4	128.1	200.9	5
Br_3In	Indium(III) bromide			304.6 s	328.7 s	364.8 s		1
Br_3OP	Phosphorus(V) oxybromide				64 e	115.5	191.4	5
Br_3P	Phosphorus(III) bromide		-23 e	5 e	42.3	94.6	172.6	5
Br_3Sb	Antimony(III) bromide				136.5	196.9	286.5	1
Br_4Ge	Germanium(IV) bromide				51	105	188	4
Br_4Sn	Tin(IV) bromide				67	122	204	4
Br_4Zr	Zirconium(IV) bromide	136 s	167 s	203 s	245 s	295 s	356 s	4
Br_5P	Phosphorus(V) bromide		-19 s	4 s	31 s	65.5 s	110.1	5
Ca	Calcium	591 s	683 s	798 s	954	1170	1482	2
Cd	Cadmium	257 s	310 s	381	472	594	767	2
$CdCl_2$	Cadmium chloride	412 s	471 s	541 s	634	768	959	23, 27
CdF_2	Cadmium fluoride				1257	1461	1742	4
CdI_2	Cadmium iodide	296 s	344 s	406	498	622	795	4,27
CdO	Cadmium oxide	770 s	866 s	983 s	1128 s	1314 s	1558 s	4
Ce	Cerium	1719	1921	2169	2481	2886	3432	14
ClCs	Cesium chloride			730	864	1043	1297	4
ClCu	Copper(I) chloride		459	543	675	914	1477	4
ClF	Chlorine fluoride*				-144.4	-122.6	-90.2	5
ClF_2P	Phosphorus(III) chloride difluoride				-119.5	-91.1	-47.6	5
ClF_3	Chlorine trifluoride				-63.7	-33.0	11.4	5
ClF_5	Chlorine pentafluoride				-88 e	-59	-14	7
ClH	Hydrogen chloride*				-138.2 s	-118.0	-85.2	1,5
$ClHO_3S$	Chlorosulfonic acid	-40 e	-20 e	5 e	38.7	85.0	153.6	5
ClH_4N	Ammonium chloride	91 s	121 s	159 s	204.7 s	263.1 s	339.5 s	5
ClK	Potassium chloride	625 s	704 s	804	945	1137	1411	23,25
ClLi	Lithium chloride		649 i	761 i	905 i	1101 i	1381 i	8
ClNO	Nitrosyl chloride		-116 s	-100 s	-78.7 s	-50.2	-5.7	5
$ClNO_2$	Nitryl chloride	-121 e	-113 e	-102 e	-86.1	-60.9	-15.7	5
ClNa	Sodium chloride	653 s	733 s	835	987	1182	1461	23,25
ClO_2	Chlorine dioxide*					-34.3	10.5	5
ClRb	Rubidium chloride			777	916	1105	1379	4
ClTl	Thallium(I) chloride				504	626	806	4
Cl_2	Chlorine*	-145 s	-133.7 s	-120.2 s	-103.6 s	-76.1	-34.2	1
Cl_2Co	Cobalt(II) chloride					818	1048	4
Cl_2FP	Phosphorus(III) dichloride fluoride				-71.1	-37.4	13.5	5
Cl_2F_3P	Phosphorus(V) dichloride trifluoride		-120 e	-101 e	-77.1	-44.3	3 e	7
Cl_2Fe	Iron(II) chloride				685	821	1025	4
Cl_2Hg	Mercury(II) chloride	64.4 s	94.7 s	130.8 s	174.5 s	228.5 s	304.0	4
Cl_2Mg	Magnesium chloride			762	908	1111	1414	4
Cl_2Mn	Manganese(II) chloride				760	933	1189	4
Cl_2Ni	Nickel(II) chloride	534 s	592 s	662 s	747 s	852 s	985 s	4
Cl_2OS	Thionyl chloride	-99 e	-81 e	-58 e	-27.1	14.6	75.2	5
Cl_2O_2S	Sulfuryl chloride				-27 e	11.8	69.0	5
Cl_2Pb	Lead(II) chloride			541 e	637	765	949	23
Cl_2S	Sulfur dichloride	-76 e	-61 e	-41 e	-16.7	15.3	58.7	5
Cl_2S_2	Sulfur chloride	-55 e	-36 e	-12 e	21.0	67.2	137.1	5
Cl_2Sn	Tin(II) chloride		253	308	381	479	622	4
Cl_2Zn	Zinc chloride	305 i	356 i	419 i	497 i	596 i	726 i	4,9,12
Cl_3Fe	Iron(III) chloride	118 s	153 s	190 s	229 s	268 s	319	4
Cl_3HSi	Trichlorosilane			-81 e	-56 e	-21 e	31.6	7
Cl_3N	Nitrogen trichloride				-25 e	13.2	70.6	5
Cl_3OP	Phosphorus(V) oxychloride					39.9	105.0	5
Cl_3P	Phosphorus(III) chloride	-93 e	-77 e	-55 e	-26.0	14.5	75.7	5
Cl_4Po	Polonium(IV) chloride					300.6	389.4	5
Cl_4Se	Selenium tetrachloride	23 s	45 s	71 s	102 s	141.4 s	191.1 s	5
Cl_4Si	Tetrachlorosilane*				-39 e	0 e	57.3	1
Cl_4Te	Tellurium tetrachloride				237 e	299.4	387.8	5
Cl_4Zr	Zirconium(IV) chloride	117 s	146 s	181 s	222 s	272 s	336 s	9
Cl_5P	Phosphorus(V) chloride	-2 s	19 s	44 s	74 s	111.4 s	158.9 s	5
Co	Cobalt	1517	1687	1892	2150	2482	2925	2
Cr	Chromium	1383 s	1534 s	1718 s	1950	2257	2669	2
Cs	Cesium	144.5	195.6	260.9	350.0	477.1	667.0	13,30

VAPOR PRESSURE (continued)

Mol. Form.	Name	Temperature in °C for the indicated pressure 1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
CsF	Cesium fluoride				825	999	1249	4
CsI	Cesium iodide	523 s	595 s	692	854	1029	1278	4,25
Cu	Copper	1236	1388	1577	1816	2131	2563	2
CuI	Copper(I) iodide				636	864	1331	4
Dy	Dysprosium	1105 s	1250 s	1431 i	1681 i	2031 i	2558 i	3
Er	Erbium	1231 s	1390 s	1612 i	1890 i	2279 i	2859 i	3
Eu	Europium	590 s	684 s	799 s	961	1179	1523	14
FH	Hydrogen fluoride*				-71.1	-33.7	19.2	1,5
FHO_3S	Fluorosulfonic acid	-14 e	4 e	28 e	59.1	101.3	162.2	5
FK	Potassium fluoride			869	1017	1216	1499	4
FLi	Lithium fluoride	801 s	896	1024	1188	1395	1672	4,12,25
FNO	Nitrosyl fluoride			-131 e	-116.1	-94.3	-60.1	5
FNO_2	Nitryl fluoride		-156 e	-144 e	-128.1	-106.0	-72.6	5
FNO_3	Fluorine nitrate	-160 e	-149 e	-135 e	-115.1	-87.4	-45.0	5
FNa	Sodium fluoride		920 s	1058	1218	1426	1702	4,12,24
FRb	Rubidium fluoride			910	1001	1145	1409	4,12
F_2	Fluorine*	-235 s	-229.5 s	-222.9 s	-214.8	-204.3	-188.3	1,5
F_2O	Fluorine monoxide*	-211.7	-204.7	-195.9	-184.2	-168.2	-144.9	5
F_2OS	Thionyl fluoride			-124 e	-106.5	-81.5	-44.1	5
F_2O_2Re	Rhenium(VI) dioxydifluoride				89.2	131.9	185 e	26
F_2Pb	Lead(II) fluoride				865	1054	1292	4
F_2Xe	Xenon difluoride			2.9 s	31.8 s	67.9 s	114 s	1,5
F_2Zn	Zinc fluoride	731 s	813 s	911 i	1048 i	1237 i	1503 i	9
F_3N	Nitrogen trifluoride*	-201 e	-194 e	-185 e	-172.8	-155.5	-129.2	5
F_3OP	Phosphorus(V) oxyfluoride	-124 s	-113 s	-100 s	-83.7 s	-64.1 s	-39.7 s	5
F_3P	Phosphorus(III) fluoride*				-152 e	-132.6	-101.4	5
F_4MoO	Molybdenum(VI) oxytetrafluoride	-21 s	3 s	33 s	69.3 s	117.3	184.1	26
F_4ORe	Rhenium(VI) oxytetrafluoride	5 s	26 s	50.7 s	80.1 s	117.1	171.2	26
F_4OW	Tungsten(VI) oxytetrafluoride	2 s	25 s	52.1 s	84.3 s	126.7	185.4	26
F_4S	Sulfur tetrafluoride				-110.0	-82.1	-40.3	5
F_4Se	Selenium tetrafluoride				13.6	51.6	104.7	5
F_4Si	Tetrafluorosilane*	-166 s	-157 s	-145.6 s	-132.3 s	-115.7 s	-94.9 s	4,7
F_5Mo	Molybdenum(V) fluoride				86.6	140.3	213 e	26
F_5Nb	Niobium(V) fluoride				80	140	224	4
F_5ORe	Rhenium(VII) oxypentafluoride	-103 s	-84 s	-59 s	-28 s	13.7 s	72.8	26
F_5Os	Osmium(V) fluoride			74.1	113.2	162.3	226 e	26
F_5P	Phosphorus(V) fluoride	-157 s	-148 s	-137 s	-124.5 s	-108.6 s	-84.8	5
F_5Re	Rhenium(V) fluoride			58.8	99.5	152 e	221 e	26
F_5Ta	Tantalum(V) fluoride					119	229	4
F_6Ir	Iridium(VI) fluoride	-88 s	-71 s	-51 s	-27 s	3.8 s	53.1	26
F_6Mo	Molybdenum(VI) fluoride	-98 s	-82 s	-64 s	-41.2 s	-13.4 s	33.5	26
F_6Os	Osmium(VI) fluoride	-89 s	-73 s	-54 s	-30.6 s	-1.7 s	47.4	26
F_6Re	Rhenium(VI) fluoride	-97 s	-82 s	-63 s	-40.2 s	-11.9 s	33.4	26
F_6S	Sulfur hexafluoride*	-158 s	-147 s	-133.6 s	-116.6 s	-94.4 s	-64.1 s	5
F_6Se	Selenium hexafluoride	-143 s	-132 s	-118 s	-100.7 s	-77.8 s	-46.5 s	5
F_6Te	Tellurium hexafluoride	-142 s	-130 s	-115 s	-96 s	-71.8 s	-39.1 s	5
F_6W	Tungsten(VI) fluoride	-107 s	-92 s	-74 s	-52.1 s	-24.8 s	16.9	26
$F_{10}S_2$	Sulfur decafluoride					-22.0	28.5	5
Fe	Iron	1455 s	1617	1818	2073	2406	2859	2
Fr	Francium	131 e	181 e	246 e	335 e	465 e	673 e	2
Ga	Gallium	1037	1175	1347	1565	1852	2245	2
Gd	Gadolinium	1563 i	1755 i	1994 i	2300 i	2703 i	3262 i	3
Ge	Germanium	1371	1541	1750	2014	2360	2831	2
HI	Hydrogen iodide*	-146 s	-135.2 s	-120.8 s	-101.9 s	-75.9 s	-35.9	5
HKO	Potassium hydroxide	520 e	601 e	704	842	1035	1325	4
HNO_3	Nitric acid			-37 e	-9 e	28.4	82.2	5
HN_3	Hydrazoic acid			-79 e	-54 e	-18.0	35.7	5
HNaO	Sodium hydroxide	513	605	722	874	1080	1377	4
H_2	Hydrogen*					-258.6	-252.8	1
H_2I_2Si	Diiodosilane				11.8	70.5	149.4	4
H_2O	Water***	-60.7 s	-42.2 s	-20.3 s	7.0	45.8	99.6	36,37
H_2O_2	Hydrogen peroxide			13 e	45 e	89.0	149.8	5
H_2O_4S	Sulfuric acid	72	103	140	187	248	330	4
H_2S	Hydrogen sulfide*		-149 s	-136 s	-118.9 s	-95.9 s	-60.5	1,5
H_2S_2	Hydrogen disulfide				-27 e	12.2	70.7	5
H_2Se	Hydrogen selenide	-145 s	-134 s	-120 s	-102.8 s	-78.9 s	-41.5	5

VAPOR PRESSURE (continued)

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
H_2Te	Hydrogen telluride					-46.6	-2.3	5
H_3ISi	Iodosilane				-47.7	-10.1	45.2	4
H_3N	Ammonia*	-139 s	-127 s	-112 s	-94.5 s	-71.3	-33.6	1,5,6
H_3NO	Hydroxylamine				43.7	73.3	109.8	4
H_3P	Phosphine*	-182 s	-173 s	-161 s	-145 s	-122.7	-88.0	5
H_4IN	Ammonium iodide	125 s	159 s	201 s	253 s	318.4 s	405.2 s	5
H_4N_2	Hydrazine				14.7	55.6	113 e	5
H_4Si	Silane*			-181	-165.4	-143.7	-111.8	4
He	Helium*					-270.6	-268.9	2
Hf	Hafnium	2416	2681	3004	3406	3921	4603	9
Hg	Mercury**	42.0	76.6	120.0	175.6	250.3	355.9	29,30
HgI_2	Mercury(II) iodide	85.1 s	115.6 s	152.4 s	197.8 s	255.1 s	353.6	4
Ho	Holmium	1159 s	1311 s	1502 i	1767 i	2137 i	2691 i	3
IK	Potassium iodide			731	866	1052	1322	4
ILi	Lithium iodide	545	619	710	824	972	1170	4
INa	Sodium iodide			753	883	1058	1301	4
IRb	Rubidium iodide			733	866	1045	1302	4
ITl	Thallium(I) iodide				520	644	821	4
I_2	Iodine (rhombic)	-12.8 s	9.3 s	35.9 s	68.7 s	108 s	184.0	1,2
I_2Pb	Lead(II) iodide			470	558	682	869	4
I_2Zn	Zinc iodide	301 s	351 s	409 s	488 i	598 i	750 i	9
I_3Sb	Antimony(III) iodide				214.9	292.0	401.2	4
I_4Sn	Tin(IV) iodide				167.1	242.7	347.7	4
I_4Zr	Zirconium(IV) iodide	187 s	220 s	259 s	305 s	361 s	430 s	4
In	Indium	923	1052	1212	1417	1689	2067	2
Ir	Iridium	2440 s	2684	2979	3341	3796	4386	2
K	Potassium	200.2	256.5	328	424	559	756.2	13,30
Kr	Krypton*	-214.0 s	-208.0 s	-199.4 s	-188.9 s	-174.6 s	-153.6	5
La	Lanthanum	1732 i	1935 i	2185 i	2499 i	2905 i	3453 i	3
Li	Lithium	524.3	612.3	722.1	871.2	1064.3	1337.1	13,30
Lu	Lutetium	1633 s	1829.8	2072.8	2380 i	2799 i	3390 i	3
Mg	Magnesium	428 s	500 s	588 s	698	859	1088	2
Mn	Manganese	955 s	1074 s	1220 s	1418	1682	2060	2
Mo	Molybdenum	2469 s	2721	3039	3434	3939	4606	2
MoO_3	Molybdenum(VI) oxide				801	935	1151	4
NO	Nitric oxide*	-201 s	-195 s	-188 s	-179.3 s	-168.1 s	-151.9	5
N_2	Nitrogen*	-236 s	-232 s	-226.8 s	-220.2 s	-211.1 s	-195.9	1,5
N_2O	Nitrous oxide*	-167 s	-157 s	-145.4 s	-131.1 s	-112.9 s	-88.7	5
N_2O_4	Nitrogen tetroxide	-92 s	-78 s	-61 s	-41.1 s	-16.6 s	28.7	5
N_2O_5	Nitrogen pentoxide	-71 s	-56 s	-40 s	-19.9 s	3.9 s	33.2	5
Na	Sodium	280.6	344.2	424.3	529	673	880.2	13,30
Nb	Niobium	2669	2934	3251	3637	4120	4740	2
Nd	Neodymium	1322.3	1501.2	1725.3	2023 i	2442 i	3063 i	3
Ne	Neon*	-261 s	-260 s	-258 s	-255 s	-252 s	-246.1	2
Ni	Nickel	1510	1677	1881	2137	2468	2911	2
OPb	Lead(II) oxide	724	816	928	1065	1241	1471	4
OSr	Strontium oxide	1789 s	1903 s	2047 s	2235 s	2488 s		4
O_2	Oxygen*				-211.9	-200.5	-183.1	1,28
O_2S	Sulfur dioxide*			-98 s	-80 s	-52.2	-10.3	1,5
O_2Se	Selenium dioxide	124.5 s	153.9 s	188 s	228 s	275 s	315 s	38
O_2Si	Silicon dioxide	1966 i	2149 i	2368 i				8
O_3	Ozone*	-189 e	-182 e	-172 e	-158 e	-139.7	-111.5	5
O_3P_2	Phosphorus(III) oxide				47.3	100.3	172.8	4
O_3S	Sulfur trioxide				-20 s	6.6 s	44.5	5
O_3Sb_2	Antimony(III) oxide (valentinite)	426.1 s	478 s	539 s	610 s	907	1420	4,35
O_5P_2	Phosphorus(V) oxide	285 s	328 s	377.5 s	434.4 s	500.5 s	591	4
O_7Re_2	Rhenium(VII) oxide	147 s	176 s	208 s	244 s	284 s	362	4
Os	Osmium	2887 s	3150	3478	3875	4365	4983	2
P	Phosphorus (white)	6 s	34 s	69	115	180	276	3,9
P	Phosphorus (red)	182 s	216 s	256 s	303 s	362 s	431 s	2,3
Pb	Lead	705	815	956	1139	1387	1754	2
PbS	Lead(II) sulfide	656 s	741 s	838 s	953 s	1088 s	1280	4
Pd	Palladium	1448 s	1624	1844	2122	2480	2961	2
Po	Polonium				573 e	730.2	963.3	5
Pr	Praseodymium	1497.7	1699.4	1954 i	2298 i	2781 i	3506 i	3
Pt	Platinum	2057	2277 e	2542	2870	3283	3821	2

VAPOR PRESSURE (continued)

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
Pu	Plutonium	1483	1680	1925	2238	2653	3226	2
Ra	Radium	546 s	633 s	764	936	1173	1526	2
Rb	Rubidium	160.4	212.5	278.9	368	496.1	685.3	13,30
Re	Rhenium	3030 s	3341	3736	4227	4854	5681	2
Rh	Rhodium	2015	2223	2476	2790	3132	3724	2
Rn	Radon*	-163 s	-152 s	-139 s	-121.4 s	-97.6 s	-62.3	5
Ru	Ruthenium	2315 s	2538	2814	3151	3572	4115	2
S	Sulfur	102 s	135	176	235	318	444	3
Sb	Antimony	534 s	603 s	738	946	1218	1585	2,3
Sc	Scandium	1372 s	1531 s	1733 i	1993 i	2340 i	2828 i	3
Se	Selenium	227	279	344	431	540	685	3
Si	Silicon	1635	1829	2066	2363	2748	3264	2
Sm	Samarium	728 s	833 s	967 s	1148 i	1402 i	1788 i	3
Sn	Tin	1224	1384	1582	1834	2165	2620	2
Sr	Strontium	523 s	609 s	717 s	866	1072	1373	2
Ta	Tantalum	3024	3324	3684	4122	4666	5361	2
Tb	Terbium	1516.1	1706.1	1928 i	2232 i	2640 i	3218 i	3
Tc	Technetium	2454 e	2725 e	3051 e	3453 e	3961 e	4621 e	2
Te	Tellurium			502 e	615 e	768.8	992.4	5
Th	Thorium	2360	2634	2975	3410	3986	4782	2
Ti	Titanium	1709	1898	2130 e	2419	2791	3285	2
Tl	Thallium	609	704	824	979	1188	1485	2
Tm	Thulium	844 s	962 s	1108 s	1297 s	1548 i	1944 i	3
U	Uranium	2052	2291	2586	2961	3454	4129	2
V	Vanadium	1828 s	2016	2250	2541	2914	3406	2
W	Tungsten	3204 s	3500	3864	4306	4854	5550	2
Xe	Xenon*	-190 s	-181 s	-170 s	-155.8 s	-136.6 s	-108.4	5,32
Y	Yttrium	1610.1	1802.3	2047 i	2354 i	2763 i	3334 i	3
Yb	Ytterbium	463 s	540 s	637 s	774 s	993 i	1192 i	3
Zn	Zinc	337 s	397 s	477	579	717	912 e	2
Zr	Zirconium	2366	2618	2924	3302	3780	4405	2
Substances containing carbon:								
C	Carbon (graphite)		2566 s	2775 s	3016 s	3299 s	3635 s	15
$CBrClF_2$	Bromochloro-difluoromethane	-136 e	-123 e	-106 e	-83.4	-51.8	-4.3	1
$CBrCl_3$	Bromotrichloromethane				-6 e	38.9	104.4	5
$CBrF_3$	Bromotrifluoromethane*	-168 e	-156 e	-142 e	-122.8	-96.6	-58.1	5
CBrN	Cyanogen bromide				-13 s	17.7 s	61.0	1
CBr_2F_2	Dibromodifluoromethane		-110 e	-91 e	-66 e	-30 e	22.5	1
CBr_4	Tetrabromomethane			25.6 s	65.8 s	111.6	188.9	5
$CClF_3$	Chlorotrifluoromethane	-176 e	-167 e	-155 e	-139 e	-116 e	-81.7	5
CClN	Cyanogen chloride		-94.6 s	-78.1 s	-57 s	-29 s	13.0	5
CCl_2F_2	Dichlorodifluoromethane*	-150 e	-138 e	-122 e	-101.8	-73.1	-30.0	5
CCl_2O	Carbonyl chloride	-127 e	-113 e	-96 e	-73 e	-40.6	7.2	5
CCl_3F	Trichlorofluoromethane*		-107 e	-89 e	-63 e	-28.5	23.3	1,5
CCl_3NO_2	Trichloronitromethane		-59 e	-30 e	4.4	47.8	112.0	5
CCl_4	Tetrachloromethane*	-79.4 s	-70.8 s	-53.5 s	-24.4 s	15.8	76.2	1,5
CFN	Cyanogen fluoride		-135 s	-121.2 s	-104.1 s	-82.8 s	-46.2	1,5
CF_4	Tetrafluoromethane*	-199.9 s	-193 s	-183.9 s	-171.6	-153.9	-128.3	1,5
$CHBrF_2$	Bromodifluoromethane		-128 s	-111.4 s	-89.7 s	-59.7 s	-16 s	5
$CHBr_3$	Tribromomethane				30.5	78.3	148.8	1
$CHClF_2$	Chlorodifluoromethane*	-152 e	-141 e	-126 e	-107.1	-80.5	-41.1	5
$CHCl_2F$	Dichlorofluoromethane	-76 e	-70 e	-61 e	-49 e	-28.7	8.6	1
$CHCl_3$	Trichloromethane*			-61 e	-34 e	4.3	60.8	1
CHF_3	Trifluoromethane*			-152 e	-136 e	-114.4	-82.3	1
CHI_3	Triiodomethane	51.1 s	82.7 s	121 e			218.0	5
CHN	Hydrogen cyanide*			-77 s	-52.6 s	-22.7 s	25.4	1,5
CHNO	Cyanic acid			-81.1	-56.8	-23.9	23 e	5
CH_2BrCl	Bromochloromethane	-83 e	-69 e	-50 e	-25 e	11.4	67.7	1
CH_2Br_2	Dibromomethane			-37 e	-7 e	35.2	96.5	5
CH_2ClF	Chlorofluoromethane		-124 e	-108 e	-86.2	-55.7	-9.4	5
CH_2Cl_2	Dichloromethane*		-92 e	-73 e	-48 e	-12.5	39.3	1
CH_2F_2	Difluoromethane*	-156.7	-145.8	-131.9	-113.6	-88.6	-51.9	1
CH_2I_2	Diiodomethane			17 e	55 e	106.1	181.6	5
CH_2O	Formaldehyde*				-91 e	-61.7	-19.3	1

VAPOR PRESSURE (continued)

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
CH_2O_2	Formic acid	-56 s	-40.4 s	-22.3 s	-0.8 s	37.0	100.2	1,5
CH_3AsF_2	Methyldifluoroarsine				-15 e	22.1	76.1	5
CH_3BO	Borane carbonyl				-124	-99	-64	4
CH_3Br	Bromomethane				-77 e	-44.3	3.3	1
CH_3Cl	Chloromethane*	-140.2 s	-128.6 s	-114.7 s	-96 e	-67.1	-24.4	1,33
CH_3Cl_3Si	Methyltrichlorosilane		-83 e	-61 e	-33 e	7 e	65.7	1
CH_3F	Fluoromethane*				-130 e	-111 e	-78.6	1
CH_3I	Iodomethane				-49 e	-12.4	42.1	1
CH_3NO	Formamide		22 e	53 e	93 e	145.0	218 e	5
CH_3NO_2	Nitromethane				-2 e	40 e	100.8	1
CH_3NO_3	Methyl nitrate		-75 e	-55 e	-27 e	9.8	63 e	5
CH_4	Methane*	-220 s	-214.2 s	-206.8 s	-197 s	-183.6 s	-161.7	5,41
CH_4Cl_2Si	Dichloromethylsilane			-77 e	-51 e	-14 e	40.5	1
CH_4O	Methanol*	-87 e	-69 e	-47.5	-20.4	15.2	64.2	11
CH_4S	Methanethiol		-115 e	-97 e	-74 e	-41.7	5.7	1
CH_5ClSi	Chloromethylsilane	-129 e	-115 e	-97.9	-74.4	-41.5	8.3	5
CH_5N	Methylamine				-76.7	-48.1	-6.6	1
CH_6N_2	Methylhydrazine			-31 e	-4.7	32.9	91 e	1
CH_6OSi	Methyl silyl ether				-90.2	-61.8	-18 e	1
CH_6Si	Methylsilane			-144 e	-124.6	-97.5	-57.5	5
CIN	Cyanogen iodide						153.8	5
CNNa	Sodium cyanide		672 e	798	961	1182	1497	4
CN_4O_8	Tetranitromethane				18.0	61.8	124 e	5
CO	Carbon monoxide*			-223 s	-216.5 s	-207.2 s	-191.7	40
COS	Carbon oxysulfide*			-136 e	-117 e	-90.0	-50.4	1
COSe	Carbon oxyselenide			-120	-98	-67	-22	4
CO_2	Carbon dioxide*	-159.1 s	-148.9 s	-136.7 s	-121.6 s	-103.1 s	-78.6 s	5
CS_2	Carbon disulfide		-96 e	-76 e	-49 e	-10.9	45.9	1
CSe_2	Carbon diselenide			-24 e	9.4	56.2	127 e	1
$C_2Br_2ClF_3$	1,2-Dibromo-1-chloro-1,2,2-trifluoroethane						92.3	5
$C_2Br_2F_4$	1,2-Dibromotetrafluoroethane		-97 e	-75 e	-46 e	-7.2	47.1	5
C_2Br_4	Tetrabromoethylene		-54.5 s	-31.7 s	-3.5 s	32.2 s	226.0	5
C_2ClF_3	Chlorotrifluoroethylene	-146 e	-134 e	-119 e	-99 e	-71 e	-28.4	1
C_2ClF_5	Chloropentafluoroethane					-80.3	-39.4	1
$C_2Cl_2F_4$	1,1-Dichlorotetrafluoroethane					-45.4	2.7	5
$C_2Cl_2F_4$	1,2-Dichlorotetrafluoroethane				-76.8	-44.9	3.2	5
$C_2Cl_3F_3$	1,1,1-Trichlorotrifluoroethane						45.6	1,5
$C_2Cl_3F_3$	1,1,2-Trichlorotrifluoroethane					-8.2	47.3	1,5
C_2Cl_3N	Trichloroacetonitrile				-16 e	25.3	85.1	1
C_2Cl_4	Tetrachloroethylene			-22 e	10 e	54.4	120.7	1
$C_2Cl_4F_2$	1,1,1,2-Tetrachloro-2,2-difluoroethane				-7 e	31.0	91.1	5
$C_2Cl_4F_2$	1,1,2,2-Tetrachloro-1,2-difluoroethane					32.3	92.5	1
C_2Cl_4O	Trichloroacetyl chloride			-25 e	7 e	51.7	117.8	1,5
C_2Cl_6	Hexachloroethane	-7.6 s	9.9 s	33.6 s	67.7 s	116.9 s	184.2 s	5
C_2F_3N	Trifluoroacetonitrile				-126.1	-102.5	-67.8	1
C_2F_4	Tetrafluoroethylene				-132.3	-109.7	-75.8	1
$C_2F_4N_2O_4$	1,1,2,2-Tetrafluoro-1,2-dinitroethane				-30 e	6.4	59.5	5
C_2F_6	Hexafluoroethane**			-155.2 s	-137.5 s	-113.4 s	-78.4 s	1,5
$C_2HBrClF_3$	2-Bromo-2-chloro-1,1,1-trifluoroethane				-41.4	-4.8	49.8	1
C_2HBr_3O	Tribromoacetaldehyde			15.0	52.7	103.0	173.5	5
C_2HClF_4	1-Chloro-1,1,2,2-tetrafluoroethane			-110 e	-87.6	-57.0	-12.1	5
$C_2HCl_2F_3$	2,2-Dichloro-1,1,1-trifluoroethane		-101.0	-82.2	-57.4	-23.3	26.7	18
C_2HCl_3	Trichloroethylene	-74 e	-59 e	-39 e	-12 e	26.7	86.8	1
C_2HCl_3O	Trichloroacetaldehyde			-41.6	-9.8	33.8	97.4	5
$C_2HCl_3O_2$	Trichloroacetic acid				83.8	130.0	197.2	1,5
C_2HCl_5	Pentachloroethane		-23 e	3 e	37.4	86.0	159.4	1
$C_2HF_3O_2$	Trifluoroacetic acid					16.8	71.4	1,5
C_2HF_5O	Trifluoromethyl difluoromethyl ether	-147 e	-136 e	-121 e	-102 e	-75.0	-35.4	20
C_2H_2	Acetylene*			-146.6 s	-130.7 s	-110.6 s	-84.8 s	5

Mol. Form.	Name	Temperature in °C for the indicated pressure 1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
$C_2H_2Br_2$	*cis*-1,2-Dibromoethylene		-45 e	-21 e	10 e	52.2	114.8	1
$C_2H_2Br_2$	*trans*-1,2-Dibromoethylene				-4 e	42.2	107.4	5
$C_2H_2Br_2Cl_2$	1,2-Dibromo-1,1-dichloroethane					103.6	177.8	5
$C_2H_2Br_2Cl_2$	1,2-Dibromo-1,2-dichloroethane		-11 e	22 e	64.1	119 e	193 e	5
$C_2H_2Br_4$	1,1,2,2-Tetrabromoethane	14 e	38 e	69 e	109 e	163.7	242.9	5
$C_2H_2Cl_2$	1,1-Dichloroethylene	-116 e	-101 e	-82 e	-57 e	-21.4	31.2	1
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethylene			-62 e	-34 e	3.8	60.3	1
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethylene				-44 e	-7.5	47.3	1
$C_2H_2Cl_2F_2$	1,2-Dichloro-1,1-difluoroethane	-101 e	-87 e	-68 e	-42.2	-6.8	46.3	5
$C_2H_2Cl_2O$	Chloroacetyl chloride			-23.7	5.6	46.1	105.6	5
$C_2H_2Cl_4$	1,1,1,2-Tetrachloroethane	-58 e	-40 e	-15 e	17 e	62.2	129.7	1
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane		-22 e	1 e	32.4	76.9	144.7	1
$C_2H_2F_4$	1,1,1,2-Tetrafluoroethane				-94.3	-66.8	-26.4	17
$C_2H_2F_4$	1,1,2,2-Tetrafluoroethane				-96.0	-66.9	-23.3	5
C_2H_2O	Ketene		-151 e	-135 e	-115 e	-88.2	-50.0	1
C_2H_3Br	Bromoethylene	-124 e	-110 e	-92 e	-68 e	-34.5	15.4	5
C_2H_3BrO	Acetyl bromide	-78 e	-65 e	-49 e	-25 e	13.9	84 e	5
$C_2H_3Br_3$	1,1,2-Tribromoethane	-18 e	4 e	32 e	68 e	117.1	188.4	5
C_2H_3Cl	Chloroethylene	-139 e	-127 e	-110 e	-89 e	-59.0	-14.1	1
$C_2H_3ClF_2$	1-Chloro-1,1-difluoroethane		-123 e	-107 e	-85.3	-55.4	-10.5	5
C_2H_3ClO	Acetyl chloride	-100 e	-85 e	-66 e	-40 e	-3.6	50.4	1
$C_2H_3ClO_2$	Chloroacetic acid				78.4	123.9	188.9	1
$C_2H_3Cl_2F$	1,1-Dichloro-1-fluoroethane		-101 e	-83 e	-57.9	-22.7	31.4	5
$C_2H_3Cl_2F$	1,2-Dichloro-1-fluoroethane			-50 e	-23.8	14.1	73.4	5
$C_2H_3Cl_3$	1,1,1-Trichloroethane				-25.3	14.2	73.7	5
$C_2H_3Cl_3$	1,1,2-Trichloroethane			-23 e	7 e	49.9	113.4	1
C_2H_3F	Fluoroethylene			-153.3	-135.2	-109.9	-72.2	5
C_2H_3FO	Acetyl fluoride					-64.1	17.0	5
$C_2H_3F_3$	1,1,1-Trifluoroethane				-113 e	-86.6	-47.8	1
$C_2H_3F_3O$	2,2,2-Trifluoroethanol			-33 e	-8 e	26.0	74 e	5
C_2H_3I	Iodoethylene				-41 e	-3 e	55.6	5
C_2H_3IO	Acetyl iodide				-0.6	47 e	107.0	5
C_2H_3N	Acetonitrile				-20 e	21.4	81.2	1
C_2H_3NO	Methylisocyanate				-43.5	-10.2	38.8	1
C_2H_3NS	Methyl thiocyanate			-18.4	16.2	63.5	132.5	5
C_2H_4	Ethylene*				-155.6	-135.1	-104.0	1,10
C_2H_4BrCl	1-Bromo-2-chloroethane				-0.4	41.7	105.7	6
$C_2H_4Br_2$	1,1-Dibromoethane		-49 e	-26 e	5 e	46.4	107.6	5
$C_2H_4Br_2$	1,2-Dibromoethane				18 e	62.2	130.9	1
C_2H_4ClF	1-Chloro-1-fluoroethane				-69.9	-36.1	15.8	5
$C_2H_4Cl_2$	1,1-Dichloroethane		-84 e	-64 e	-36.7	1.0	56.9	1
$C_2H_4Cl_2$	1,2-Dichloroethane				-16.4	23.7	83.1	1
$C_2H_4F_2$	1,1-Difluoroethane			-115.2	-94.6	-66.1	-24.3	19
$C_2H_4N_2O_6$	Ethylene glycol dinitrate	4 e	25.6	51.0	81 e	117 e	162 e	5
C_2H_4O	Acetaldehyde		-105 e	-87 e	-62.8	-29.4	20.0	5
C_2H_4O	Ethylene oxide		-111 e	-93 e	-70 e	-37.0	10.2	1
$C_2H_4O_2$	Acetic acid	-42.8 s	-26.7 s	-8 s	14.2 s	55.9	117.5	1,5
$C_2H_4O_2$	Methyl formate		-95 e	-76 e	-51.8	-18.1	31.4	5
$C_2H_4O_3$	Peroxyacetic acid				14.4	55.3	109.7	5
$C_2H_4O_3$	Glycolic acid						99.9	5
$C_2H_5AsF_2$	Ethyldifluoroarsine			-36 e	-6.0	35.0	93.1	5
C_2H_5Br	Bromoethane	-111 e	-96 e	-77 e	-51.3	-15.5	38.0	5
C_2H_5Cl	Chloroethane	-126 e	-112 e	-94 e	-70 e	-37.0	12.0	1
C_2H_5ClO	2-Chloroethanol	-61 e	-39 e	-12 e	23 e	67.1	127.3	5
C_2H_5ClO	Chloromethyl methyl ether	-96 e	-80 e	-59 e	-32 e	6 e	61 e	5
$C_2H_5Cl_3OSi$	Trichloroethoxysilane	-78 e	-60 e	-36.0	-4.6	38.7	102.0	5
$C_2H_5Cl_3Si$	Trichloroethylsilane	-79 e	-61 e	-38 e	-8 e	34.9	98.7	5
C_2H_5F	Fluoroethane		-142 e	-127 e	-106.3	-78.7	-37.9	1
C_2H_5FO	2-Fluoroethanol			-22 e	8.3	47.5	99 e	5
C_2H_5I	Iodoethane	-94 e	-78 e	-56 e	-27.9	11.9	71.9	5
C_2H_5N	Ethyleneimine		-74 e	-55 e	-30 e	4.1	55 e	5
C_2H_5NO	Acetamide	16.7 s	39.1 s	65.2 s	102.8	150.8	218.2	5
C_2H_5NO	*N*-Methylformamide		13 e	41 e	78 e	127.9	199.1	1
$C_2H_5NO_2$	Nitroethane	-61 e	-44 e	-21 e	8.3	50.1	113.5	5
$C_2H_5NO_3$	Ethyl nitrate	-81 e	-63 e	-41 e	-12 e	28.2	87 e	1
C_2H_6	Ethane*	-183.3 s	-173.2	-161.3	-145.3	-122.8	-88.8	41
$C_2H_6Cl_2Si$	Dichlorodimethylsilane					11.1	70.1	5

VAPOR PRESSURE (continued)

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
C_2H_6Hg	Dimethyl mercury				-13.5	29.0	92.1	5
$C_2H_6N_2O$	*N*-Nitrosodimethylamine				30.7	80.5	149.8	5
C_2H_6O	Ethanol	-73 e	-56 e	-34 e	-7 e	29.2	78.0	1,5
C_2H_6O	Dimethyl ether*		-135 e	-118 e	-96.8	-67.6	-25.1	1,5
C_2H_6OS	Dimethyl sulfoxide			27.4	65.0	115.9	188.6	1
$C_2H_6O_2$	Ethylene glycol	2 e	24 e	51.1	86.1	132.5	196.9	1
$C_2H_6O_2$	Ethyl hydroperoxide	-70 e	-49 e	-25 e	6.8	47.0	101 e	5
$C_2H_6O_2S$	Dimethyl sulfone				109 e	166.8	248.9	5
C_2H_6S	Ethanethiol	-112 e	-97 e	-78 e	-53 e	-18 e	34.7	1
C_2H_6S	Dimethyl sulfide		-96 e	-77 e	-51.2	-16.0	37.0	1,5
$C_2H_6S_2$	Dimethyl disulfide	-71 e	-53 e	-29 e	1.7	45.0	109.3	5
$C_2H_7BO_2$	Dimethoxyborane	-116 e	-101.9	-83.5	-59.2	-25.4	25 e	5
C_2H_7N	Ethylamine			-71 e	-53 e	-27 e	16.4	1
C_2H_7N	Dimethylamine			-88 e	-66.9	-37.2	6.6	1
C_2H_7NO	Ethanolamine		11 e	35 e	66.2	109.0	170.6	1
$C_2H_8N_2$	1,2-Ethanediamine				17.0	57.5	116.6	1,5
$C_2H_8N_2$	1,1-Dimethylhydrazine			-52 e	-25.6	10.5	63 e	5
$C_2H_8N_2$	1,2-Dimethylhydrazine		-49 e	-33 e	-9 e	26.4	88 e	1
C_2N_2	Cyanogen	-127 s	-114.1 s	-98.5 s	-79.2 s	-54.9 s	-21.4	5
C_3ClF_5O	Chloropentafluoroacetone	-122 e	-109 e	-93 e	-71 e	-39.4	7.4	5
C_3Cl_6	Hexachloropropene	-12 e	11 e	40 e	79 e	132.8	213.6	5
C_3F_6	Perfluoropropene	-150 e	-138 e	-122 e	-101 e	-72 e	-30.6	5
C_3F_6O	Perfluoroacetone			-113 e	-94 e	-67.8	-27.6	5
C_3F_8	Perfluoropropane		-139 e	-124 e	-105 e	-77.5	-37.0	1
C_3HN	Cyanoacetylene			-58.7 s	-35.6 s	-7 s	42.0	5
$C_3H_2F_6O$	1,1,1,3,3,3-Hexafluoro-2-propanol					12.7	57.1	5
$C_3H_3F_5$	1,1,1,2,2-Pentafluoropropane					-60 e	-17.9	5
C_3H_3N	2-Propenenitrile		-72 e	-50 e	-22 e	17.7	77.0	1
C_3H_3NS	Thiazole					54.4	117.8	5
C_3H_4	Allene*		-129 e	-118 e	-101.4	-76.7	-34.7	5
C_3H_4	Propyne				-94 e	-65.3	-23.2	1
$C_3H_4ClF_3$	3-Chloro-1,1,1-trifluoropropane	-102 e	-87 e	-68 e	-43 e	-8 e	45.3	5
$C_3H_4Cl_2O$	1,1-Dichloroacetone				1 e	47.8	118.0	5
$C_3H_4Cl_2O_2$	Methyl dichloroacetate	-44 e	-25 e	0 e	33 e	77.7	142.3	5
$C_3H_4Cl_4$	1,1,1,2-Tetrachloropropane	-48 e	-28 e	-2 e	32 e	79.1	149.5	5
$C_3H_4F_4O$	2,2,3,3-Tetrafluoro-1-propanol			-10 e	17 e	53.9	107.2	5
C_3H_4O	Acrolein		-87 e	-67 e	-40 e	-3.0	52.8	1
$C_3H_4O_2$	Propenoic acid				35 e	78.0	140.7	1
$C_3H_4O_2$	Vinyl formate			-58 e	-34 e	-1.6	46.2	1
$C_3H_4O_2$	2-Oxetanone		-21 e	8 e	45.5	93.8	159.3	5
$C_3H_4O_3$	Ethylene carbonate	12.7 s	37 e				247	5
C_3H_5Br	*cis*-1-Bromopropene	-100 e	-84 e	-64 e	-37 e	1.0	57.4	5
C_3H_5Br	2-Bromopropene	-112 e	-95 e	-75 e	-47 e	-9 e	48.0	5
C_3H_5Br	3-Bromopropene	-98 e	-80 e	-58 e	-28 e	12 e	69.6	5
C_3H_5Cl	*cis*-1-Chloropropene	-114 e	-100 e	-81 e	-55 e	-20.1	32.4	5
C_3H_5Cl	*trans*-1-Chloropropene		-97 e	-77 e	-52 e	-16.2	37.0	5
C_3H_5Cl	2-Chloropropene	-120 e	-106 e	-87 e	-63 e	-28.7	22.3	5
C_3H_5Cl	3-Chloropropene	-107 e	-92 e	-72.4	-46.3	-9.8	44.6	5
C_3H_5ClO	Epichlorohydrin			-21 e	11 e	53.8	115.5	5
$C_3H_5ClO_2$	Methyl chloroacetate		-28 e	-5 e	25 e	66.9	129.1	5
$C_3H_5Cl_3$	1,1,3-Trichloropropane	-51 e	-31 e	-5 e	28 e	75.3	145.1	5
$C_3H_5Cl_3$	1,2,3-Trichloropropane			2 e	37 e	84.9	156.3	5
$C_3H_5Cl_3Si$	Trichloro-2-propenylsilane					53.0	116.5	5
C_3H_5I	3-Iodopropene	-80 e	-62 e	-39 e	-8 e	36 e	101.5	5
C_3H_5N	Propanenitrile	-69.4	-55.3	-36.0	-7.9	35.2	97.4	1,5
C_3H_5NO	Acrylamide			109.6	161 e			5
C_3H_5NO	3-Hydroxypropanenitrile	-11 e	18 e	53 e	96.1	150.3	220.8	5
C_3H_5NS	Ethyl thiocyanate	-39 e	-20 e	4 e	35 e	79.1	143.4	5
C_3H_5NS	Ethyl isothiocyanate				17.4	66 e	136 e	5
$C_3H_5N_3O_9$	Trinitroglycerol	48.6	75.7	118 e	191 e	353 e	1007 e	5
C_3H_6	Propene*	-160.6	-149.0	-134.3	-114.9	-88.2	-47.9	1,5
C_3H_6	Cyclopropane			-124 e	-104 e	-75.7	-33.1	1
C_3H_6BrCl	1-Bromo-3-chloropropane	-51 e	-31 e	-6 e	28 e	74.1	142.9	5
$C_3H_6Br_2$	1,2-Dibromopropane	-46 e	-26 e	-2 e	31 e	75.3	139.5	5

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
$C_3H_6Br_2$	1,3-Dibromopropane	-30 e	-9 e	17 e	52 e	98.7	166.8	5
$C_3H_6Cl_2$	1,1-Dichloropropane				-14 e	27.0	87.7	5
$C_3H_6Cl_2$	1,2-Dichloropropane	-78 e	-61 e	-38.1	-8.1	33.7	95.9	5
$C_3H_6Cl_2$	1,3-Dichloropropane	-65 e	-46 e	-22 e	10 e	54.0	119.9	5
$C_3H_6Cl_2$	2,2-Dichloropropane				-28 e	10.8	68.9	5
$C_3H_6Cl_2O$	1,3-Dichloro-2-propanol			21.8	59.0	107.6	173.9	5
$C_3H_6N_2O_4$	1,1-Dinitropropane	-9 e	12 e	39 e	73.2	120 e	187 e	5
C_3H_6O	Allyl alcohol	-63 e	-48 e	-21.9	6.8	44.5	96.2	5
C_3H_6O	Methyl vinyl ether			-114 e	-89 e	-52.7	4.6	1
C_3H_6O	Propanal			-69 e	-42 e	-6 e	47.7	1
C_3H_6O	Acetone	-95	-81.8	-62.8	-35.6	1.3	55.7	1,5
C_3H_6O	Methyloxirane	-109 e	-95 e	-76 e	-51.5	-17.2	33.9	5
$C_3H_6O_2$	Propanoic acid			0 e	35.1	79.9	140.8	1,5
$C_3H_6O_2$	Ethyl formate		-80 e	-61 e	-35 e	1 e	54.0	1
$C_3H_6O_2$	Methyl acetate	-95 e	-79 e	-59 e	-33 e	3.3	56.6	1
$C_3H_6O_2$	1,3-Dioxolane		-72 e	-50 e	-22 e	17.0	75.3	1
$C_3H_6O_3$	1,3,5-Trioxane					53 e	113.7	1
C_3H_6S	Thiacyclobutane		-62 e	-40 e	-9 e	32.5	94.5	5
C_3H_7Br	1-Bromopropane	-95 e	-78 e	-57 e	-28 e	11.6	70.6	1
C_3H_7Br	2-Bromopropane		-84 e	-65 e	-39.6	-1.7	59.1	1,5
C_3H_7Cl	1-Chloropropane	-106 e	-90 e	-71 e	-44.5	-8.1	46.2	1
C_3H_7Cl	2-Chloropropane		-91 e	-74 e	-51.1	-17.8	35.4	1,5
C_3H_7ClO	2-Chloro-1-propanol				23 e	63.8	125.7	5
C_3H_7F	1-Fluoropropane	-133 e	-120 e	-103 e	-80.7	-49.4	-2.8	5
C_3H_7I	1-Iodopropane	-78 e	-60 e	-37 e	-6 e	36.9	102.0	5
C_3H_7I	2-Iodopropane	-89 e	-71 e	-47 e	-16.3	26.5	89.2	5
C_3H_7N	Allylamine		-88 e	-65 e	-37 e	0.4	52 e	5
C_3H_7NO	*N*,*N*-Dimethylformamide	-39 e	-20 e	5 e	38.0	83.9	152.6	1
C_3H_7NO	*N*-Methylacetamide	-13.3 s	13 s	43 e	83.8	136.1	206.3	5
$C_3H_7NO_2$	1-Nitropropane	-56 e	-37 e	-13 e	20 e	64.8	130.8	1
$C_3H_7NO_2$	2-Nitropropane		-48 e	-22 e	10.7	55.6	119.8	1
$C_3H_7NO_3$	Propyl nitrate			-23.9	6.1	48.1	111 e	5
C_3H_8	Propane*	-156.9	-145.6	-130.9	-111.4	-83.8	-42.3	1,41
C_3H_8O	1-Propanol	-54 e	-38 e	-16 e	10 e	47 e	96.9	1,5
C_3H_8O	2-Propanol	-65 e	-49 e	-28 e	-1.3	33.6	82.0	1,5
C_3H_8O	Ethyl methyl ether	-98 e	-89 e	-77 e	-60 e	-34.8	7.0	5
$C_3H_8O_2$	1,2-Propylene glycol	-11 e	13 e	42 e	78 e	125.0	187.2	5
$C_3H_8O_2$	1,3-Propylene glycol	4 e	30 e	62 e	101 e	149.9	214.0	5
$C_3H_8O_2$	Ethylene glycol monomethyl ether	-57 e	-37 e	-12 e	21 e	63.8	124.3	1
$C_3H_8O_2$	Dimethoxymethane	-93 e	-81 e	-64 e	-42 e	-9.3	41.7	5
$C_3H_8O_3$	Glycerol	96 e	113 e	136 e	168 e	213.4	287 e	1
C_3H_8S	1-Propanethiol	-94 e	-78 e	-57 e	-29.1	9.6	67.4	1,5
C_3H_8S	2-Propanethiol	-102 e	-87 e	-67 e	-41 e	-3 e	52.2	1
C_3H_8S	Ethyl methyl sulfide	-94 e	-78 e	-57 e	-29.7	8.8	66.3	1
$C_3H_8S_2$	1,3-Propanedithiol	-53 e	-28 e	3 e	43 e	97 e	172.4	5
C_3H_9As	Trimethylarsine			-74 e	-45 e	-5.4	52.0	5
$C_3H_9BO_3$	Trimethyl borate				-14 e	15.6	67.9	5
C_3H_9BS	Methyl dimethylthioborane			-62 e	-30.4	11.4	70.7	5
C_3H_9ClSi	Trimethylchlorosilane				-37.8	0.4	57.3	5
C_3H_9N	Propylamine		-81 e	-63 e	-38.3	-4.1	46.9	1,5
C_3H_9N	Isopropylamine		-91 e	-74 e	-50.4	-17.6	31.5	1,5
C_3H_9N	Trimethylamine		-114 e	-97 e	-75.0	-43.8	2.6	1,5
C_3H_9NO	1-Amino-2-propanol			18 e	53.2	98.2	157.9	5
$C_3H_9O_4P$	Trimethyl phosphate	-31 e	-7 e	23.6	62.8	116.0	192.0	5
C_3H_9P	Trimethylphosphine			-81 e	-53 e	-15.0	37.1	5
C_3H_9Sb	Trimethylstibine			-56 e	-23.8	19 e	80 e	5
$C_3H_{10}N_2$	1,2-Propanediamine		-35.4	-12.0	18.8	61 e	119 e	5
C_3N_2O	Carbonyl dicyanide				-21.7	15.3	65.2	5
C_4Cl_6	Hexachloro-1,3-butadiene	-1 e	22 e	50 e	86.7	137.0	209.7	5
$C_4F_6O_3$	Trifluoroacetic acid anhydride			-63 e	-39 e	-7.1	38.8	5
C_4F_8	Perfluorocyclobutane						-6.2	1
C_4F_{10}	Perfluorobutane		-122 e	-105 e	-82 e	-49.8	-2.5	1,5
$C_4H_2Cl_2O_2$	*trans*-2-Butenedioyl dichloride			8.0	45.6	94.3	159.8	5
$C_4H_2Cl_2S$	2,5-Dichlorothiophene			-20 e	22 e	81.4	171 e	5

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
$C_4H_2O_3$	Maleic anhydride				73.7	127.9	201.7	5
C_4H_3ClS	2-Chlorothiophene		-62 e	-35 e	2 e	51.8	123 e	5
C_4H_3IS	2-Iodothiophene			-25 e	23 e	94.9	181.0	5
C_4H_4	1-Buten-3-yne			-96.1	-73.4	-41.8	4.9	5
$C_4H_4N_2$	Succinonitrile	24.8 s					266.0	5
C_4H_4O	Furan			-78 e	-54 e	-20 e	31.0	1
$C_4H_4O_2$	Diketene				19.3	63.3	126 e	5
$C_4H_4O_3$	Succinic anhydride				121 e	180.8	260.8	5
$C_4H_4O_4$	Fumaric acid	123.9 s	150 s	180 s				5
C_4H_4S	Thiophene				-17 e	23.7	83.7	5
C_4H_5Cl	2-Chloro-1,3-butadiene	-113 e	-95 e	-71 e	-41 e	0.3	59.0	5
C_4H_5ClO	2-Methyl-2-propenoyl chloride		-57 e	-35 e	-5 e	36.4	98.2	5
$C_4H_5Cl_3O_2$	Ethyl trichloroacetate			15.3	51.9	100.1	166.6	5
C_4H_5N	3-Butenenitrile	-67 e	-48 e	-23.1	9.3	53.7	118.4	5
C_4H_5N	Methylacrylonitrile				-12 e	29.0	89.8	5
C_4H_5N	Pyrrole			-8 e	24 e	66.7	129.4	1
$C_4H_5NO_2$	Methyl cyanoacetate	-3 e	19 e	48 e	84 e	134.0	204.6	5
C_4H_5NS	Allyl isothiocyanate	-45 e	-27 e	-3 e	32.1	89 e	198 e	5
C_4H_5NS	4-Methylthiazole						67.0	5
C_4H_6	1,2-Butadiene	-132 e	-117 e	-98 e	-72.8	-38.9	10.5	5
C_4H_6	1,3-Butadiene*			-106 e	-83 e	-51.9	-4.7	1
C_4H_6	1-Butyne	-125 e	-111 e	-94 e	-71.2	-39.4	7.8	1
C_4H_6	2-Butyne		-89.2 s	-73.8 s	-53.5 s	-23.9	26.6	5
$C_4H_6Cl_2O_2$	Ethyl dichloroacetate			2.6	40.1	89.1	156.3	5
C_4H_6O	Divinyl ether		-99 e	-80 e	-56 e	-22.1	28.0	5
C_4H_6O	*trans*-2-Butenal	-74 e	-56 e	-33 e	-3 e	39.7	102.4	5
C_4H_6O	3-Buten-2-one					21 e	81.0	5
C_4H_6O	Cyclobutanone			-34 e	-4 e	37.1	97 e	5
$C_4H_6O_2$	*cis*-Crotonic acid			30 e	63 e	106.7	168.9	5
$C_4H_6O_2$	*trans*-Crotonic acid				74 e	120.8	184.9	5
$C_4H_6O_2$	3-Butenoic acid	-19 e	2 e	27 e	61 e	105.6	168.6	5
$C_4H_6O_2$	Methacrylic acid			22 e	56 e	99.9	161.5	5
$C_4H_6O_2$	Vinyl acetate	-88 e	-71 e	-50 e	-22 e	16.2	72.2	1
$C_4H_6O_2$	Methyl acrylate		-71 e	-48 e	-18 e	22 e	79.9	5
$C_4H_6O_2$	2,3-Butanedione					30.7	84.8	5
$C_4H_6O_2$	gamma-Butyrolactone		-17 e	24 e	72 e	130.2	203 e	5
$C_4H_6O_3$	Acetic anhydride	-44 e	-25 e	-1 e	31 e	75.1	139.7	1
$C_4H_6O_3$	Propylene carbonate	-40 e	-5 e	43 e	112 e	220 e	410 e	5
$C_4H_6O_4$	Dimethyl oxalate				50.5	98.1	163.0	5
C_4H_7Br	*trans*-1-Bromo-1-butene	-87 e	-68 e	-43.3	-11.4	31.9	94.4	5
C_4H_7Br	2-Bromo-1-butene	-87 e	-70 e	-48 e	-20 e	20.7	80.6	5
C_4H_7Br	*cis*-2-Bromo-2-butene	-90 e	-72 e	-49.0	-18.5	23.5	85.2	5
C_4H_7Br	*trans*-2-Bromo-2-butene	-86 e	-67 e	-43.4	-12.0	31.0	93.5	5
$C_4H_7Br_3$	1,2,3-Tribromobutane	0 e	23 e	53 e	91 e	143.7	219.5	5
$C_4H_7Br_3$	1,2,4-Tribromobutane	-3 e	20 e	49 e	87 e	139.4	214.5	5
C_4H_7Cl	3-Chloro-1-butene			-64 e	-36 e	4 e	63.6	5
C_4H_7Cl	*cis*-2-Chloro-2-butene	-100 e	-83 e	-62 e	-34 e	6 e	66.4	5
C_4H_7Cl	*trans*-2-Chloro-2-butene	-102 e	-86 e	-65 e	-37 e	3 e	62.2	5
C_4H_7Cl	3-Chloro-2-methylpropene		-75 e	-54 e	-25 e	13.8	71.5	5
$C_4H_7ClO_2$	Ethyl chloroacetate			-2.6	32.6	79.1	143.8	5
C_4H_7N	Butanenitrile	-67 e	-48 e	-24 e	8 e	52.3	117.2	1
C_4H_8	1-Butene	-139.0	-125.2	-107.8	-85.3	-53.7	-6.6	1,5
C_4H_8	*cis*-2-Butene	-131.2	-117.4	-99.8	-76.7	-44.8	3.4	1,5
C_4H_8	*trans*-2-Butene			-102 e	-80 e	-47.6	0.6	1
C_4H_8	Isobutene	-139.1	-125.5	-108.2	-85.5	-54.5	-7.3	1,5
C_4H_8	Cyclobutane				-71.8	-38.1	12.1	5
C_4H_8	Methylcyclopropane	-130 e	-116 e	-99.3	-76.3	-44.2	4.2	5
$C_4H_8Br_2$	1,2-Dibromobutane	-54 e	-30 e	0.4	39.6	92.1	166.1	5
$C_4H_8Br_2$	1,4-Dibromobutane	-13 e	9 e	37 e	74 e	124.0	196.5	5
$C_4H_8Cl_2$	1,1-Dichlorobutane			-25 e	6 e	49.3	113.4	5
$C_4H_8Cl_2$	1,2-Dichlorobutane			-28.4	5.8	53.1	123.1	5
$C_4H_8Cl_2$	1,4-Dichlorobutane		-26 e	0 e	35 e	82.4	153.4	5
$C_4H_8Cl_2$	2,2-Dichlorobutane		-58 e	-35 e	-5 e	37.8	102.1	5
$C_4H_8Cl_2O$	Bis(2-chloroethyl) ether	-32 e	-9 e	19.8	56.9	106.9	177.9	5
C_4H_8O	Ethyl vinyl ether		-102 e	-81 e	-53.1	-16.5	34.7	5
C_4H_8O	1,2-Epoxybutane	-135 e	-114 e	-87 e	-53 e	-5.5	62.1	5

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
C_4H_8O	Butanal	-88 e	-72 e	-50 e	-22 e	16.6	74.5	1,5
C_4H_8O	Isobutanal			-56 e	-29 e	8 e	63.8	1
C_4H_8O	2-Butanone	-85 e	-68 e	-46 e	-18.1	21.2	79.2	1
C_4H_8O	Tetrahydrofuran	-94 e	-78 e	-57.3	-29.8	9 e	65.6	1
$C_4H_8O_2$	Butanoic acid			12.9	52.2	101.4	163.3	1,5
$C_4H_8O_2$	2-Methylpropanoic acid	-30.1	-8.2	18.1	50.5	92.9	154.0	5
$C_4H_8O_2$	Propyl formate	-78 e	-62 e	-42 e	-15.1	23.0	80.4	1,5
$C_4H_8O_2$	Isopropyl formate	-80 e	-65 e	-47 e	-22.2	13.2	67.7	5
$C_4H_8O_2$	Ethyl acetate	-83 e	-66 e	-45 e	-18 e	20.4	76.8	1
$C_4H_8O_2$	Methyl propanoate	-80 e	-64 e	-43 e	-15.8	22.2	79.0	1
$C_4H_8O_2$	*cis*-2-Butene-1,4-diol	17 e	44 e	77 e	117.4	168.5	234.9	5
$C_4H_8O_2$	1,3-Dioxane			-37 e	-3 e	43.4	106.0	5
$C_4H_8O_2$	1,4-Dioxane					39.6	101.0	1
$C_4H_8O_2S$	Sulfolane		49 e	87 e	135 e	198.0	283.5	5
C_4H_8S	Tetrahydrothiophene	-66 e	-47 e	-23 e	9.4	54.1	120.5	1
C_4H_9Br	1-Bromobutane	-68.4	-53.9	-34.1	-5.4	37.6	101.1	1,5
C_4H_9Br	2-Bromobutane	-86 e	-68 e	-46 e	-16 e	26.6	90.7	5
C_4H_9Br	1-Bromo-2-methylpropane	-85 e	-68 e	-46 e	-16 e	26.8	91.1	5
C_4H_9Br	2-Bromo-2-methylpropane					11.7	72.4	1,5
C_4H_9Cl	1-Chlorobutane	-87 e	-71 e	-49 e	-21 e	18.4	78.1	1
C_4H_9Cl	2-Chlorobutane	-96 e	-80 e	-59 e	-31.0	8.5	67.9	1
C_4H_9Cl	1-Chloro-2-methylpropane	-94 e	-78 e	-56.6	-28.7	10.2	68.5	5
C_4H_9Cl	2-Chloro-2-methylpropane					-4.2	50.3	5
$C_4H_9Cl_3Si$	Butyltrichlorosilane					77.2	148.4	5
C_4H_9F	1-Fluorobutane	-114 e	-99 e	-80 e	-55 e	-20.0	32.1	5
C_4H_9F	2-Fluorobutane	-117 e	-103 e	-85 e	-60.7	-26.7	24.7	5
C_4H_9I	1-Iodobutane	-62 e	-43 e	-19 e	14 e	60.5	130.0	5
C_4H_9I	2-Iodobutane	-70 e	-51 e	-27 e	5 e	50 e	119.5	5
C_4H_9I	1-Iodo-2-methylpropane		-47 e	-21.4	12.0	56.8	120.0	5
C_4H_9I	2-Iodo-2-methylpropane	-75.1 s	-58.8 s	-39.5 s	-5.2	41 e	100.0	5
C_4H_9N	Pyrrolidine		-59 e	-38 e	-10 e	28.5	86.2	1
C_4H_9NO	*N*-Methylpropanamide				81.1	105 e		5
C_4H_9NO	*N*,*N*-Dimethylacetamide	-8 e	8 e	28.0	56.4	98.2	165.7	1
C_4H_9NO	2-Butanone oxime		-18 e	7 e	38.9	81.9	142.9	5
C_4H_9NO	Morpholine				21 e	64.5	128.5	1
$C_4H_9NO_3$	Isobutyl nitrate			-18 e	15.1	59.2	123.0	5
C_4H_{10}	Butane*	-134.3	-121.0	-103.9	-81.1	-49.1	-0.8	1,41
C_4H_{10}	Isobutane*		-129.0	-113.0	-90.9	-59.4	-12.0	1,41
$C_4H_{10}O$	1-Butanol	-37 e	-20 e	0 e	28 e	64 e	117.4	1
$C_4H_{10}O$	2-Butanol	-50 e	-34 e	-14 e	12.6	48.2	99.2	1,5
$C_4H_{10}O$	2-Methyl-1-propanol	-39 e	-24 e	-5 e	20.9	56.0	107.6	1,5
$C_4H_{10}O$	2-Methyl-2-propanol					34.4	82.1	1,5
$C_4H_{10}O$	Diethyl ether	-111 e	-96 e	-77 e	-52.6	-17.8	34.1	1
$C_4H_{10}O$	Methyl propyl ether				-40 e	-11.3	38.7	5
$C_4H_{10}O$	Isopropyl methyl ether				-56 e	-21.2	30.4	5
$C_4H_{10}O_2$	1,3-Butanediol	-4 e	23 e	55 e	94 e	142.9	206.1	5
$C_4H_{10}O_2$	1,4-Butanediol		45 e	77 e	116 e	164.7	227.6	5
$C_4H_{10}O_2$	2,3-Butanediol		15 e	43 e	77 e	121.2	180.3	5
$C_4H_{10}O_2$	Ethylene glycol monoethyl ether	-49 e	-29 e	-3 e	30 e	73.6	135.3	1
$C_4H_{10}O_2$	Ethylene glycol dimethyl ether			-44 e	-15 e	25.2	85.2	1
$C_4H_{10}O_2$	Dimethylacetal	-89 e	-74 e	-55 e	-29 e	7.7	64.1	5
$C_4H_{10}O_2$	Diethylperoxide				-39 e	3.6	65.0	5
$C_4H_{10}O_2S$	Bis(2-hydroxyethyl) sulfide			31 e	114.2		282.0	5
$C_4H_{10}O_3$	Diethylene glycol	35 e	58 e	86 e	123 e	173.6	245.2	1
$C_4H_{10}O_4S$	Diethyl sulfate		3 e	36 e	79 e	134 e	208.3	5
$C_4H_{10}S$	1-Butanethiol	-77 e	-59 e	-37 e	-6 e	35.4	98.0	5
$C_4H_{10}S$	2-Butanethiol	-86 e	-69 e	-47 e	-17 e	23.4	84.5	5
$C_4H_{10}S$	2-Methyl-1-propanethiol		-66 e	-44 e	-15 e	26.5	88.1	5
$C_4H_{10}S$	2-Methyl-2-propanethiol					5.8	63.8	5
$C_4H_{10}S$	Diethyl sulfide	-80 e	-62 e	-40 e	-10.8	30.3	91.7	1
$C_4H_{10}S$	Methyl propyl sulfide	-78 e	-61 e	-38 e	-8 e	33.1	95.1	5
$C_4H_{10}S$	Isopropyl methyl sulfide	-85 e	-68 e	-46 e	-17 e	23.4	84.3	5
$C_4H_{10}S_2$	1,4-Butanedithiol	-17 e	5 e	32 e	69.1	119.9	195.1	5
$C_4H_{10}S_2$	Diethyl disulfide	-46 e	-26 e	0 e	35 e	82.4	153.5	5

VAPOR PRESSURE (continued)

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
$C_4H_{11}N$	Butylamine			-46 e	-18.1	20.0	75.9	5
$C_4H_{11}N$	*sec*-Butylamine			-55 e	-29.1	7.5	62.3	5
$C_4H_{11}N$	*tert*-Butylamine			-67 e	-42.4	-8.1	43.7	5
$C_4H_{11}N$	Isobutylamine	-85 e	-70 e	-50 e	-24.5	12.0	67.3	5
$C_4H_{11}N$	Diethylamine			-46 e	-26 e	5 e	55.2	1
$C_4H_{11}NO$	*N*,*N*-Dimethylethanolamine	-52 e	-31 e	-6 e	27 e	70.9	133 e	5
$C_4H_{11}NO_2$	Diethanolamine	53 e	77 e	107 e	146 e	197.3	268 e	5
$C_4H_{12}BN$	(Dimethylamino)dimethyl-borane		-81 e	-60.1	-31.9	7.0	64.2	5
$C_4H_{12}Cl_2OSi_2$	1,3-Dichloro-1,1,3,3-tetramethyldisiloxane		-33 e	-9 e	23.8	69.1	136.5	5
$C_4H_{12}O_4Si$	Tetramethyl silicate				14.4	59.3	119.7	5
$C_4H_{12}Si$	Tetramethylsilane			-83 e	-59 e	-25 e	26.7	5
$C_4H_{12}Sn$	Tetramethylstannane			-55.0	-25.6	16.6	77.7	5
$C_4H_{13}N_3$	Diethylenetriamine	-10 e	13 e	43 e	80 e	129.6	198 e	5
C_4NiO_4	Nickel carbonyl					-12	42	4
C_5F_{12}	Perfluoropentane				-54.7	-20.9	28.6	5
C_5FeO_5	Iron pentacarbonyl				0	44	105	4
C_5H_4ClN	2-Chloropyridine			7.4	45.8	97.3	169.9	5
$C_5H_4O_2$	Furfural	-26 e	-8 e	16 e	47 e	92.4	161.4	1
C_5H_5N	Pyridine			-23 e	8 e	51.0	114.9	1
C_5H_6	1,3-Cyclopentadiene			-77 e	-51 e	-14 e	39.8	5
$C_5H_6N_2$	Pentanedinitrile	24.1	52 e	85 e	126 e	178 e	245 e	5
C_5H_6O	2-Methylfuran			-66 e	-35 e	6 e	64.5	1
$C_5H_6O_2$	Furfuryl alcohol	-30 e	-5 e	25 e	62.6	109.3	169.7	5
C_5H_6S	2-Methylthiophene		-58 e	-32 e	2 e	47.9	112.2	1
C_5H_6S	3-Methylthiophene		-53 e	-28 e	6 e	50.6	115.1	1
C_5H_7N	1-Methylpyrrole				8 e	49.9	112.3	5
$C_5H_7NO_2$	Ethyl cyanoacetate	16 e	39 e	67.0	102.1	146.7	205.6	5
C_5H_8	1,2-Pentadiene	-109 e	-93 e	-73 e	-46.1	-9.7	44.5	5
C_5H_8	*cis*-1,3-Pentadiene	-109 e	-93 e	-73 e	-47.0	-10.5	43.7	1,5
C_5H_8	*trans*-1,3-Pentadiene			-75 e	-49.0	-13 e	42 e	1
C_5H_8	1,4-Pentadiene	-120 e	-105 e	-86 e	-60.9	-26.2	25.6	5
C_5H_8	2,3-Pentadiene	-106 e	-90 e	-70 e	-42.9	-6.3	47.9	5
C_5H_8	3-Methyl-1,2-butadiene	-111 e	-95 e	-75 e	-49.2	-13.1	40.4	5
C_5H_8	2-Methyl-1,3-butadiene	-115 e	-100 e	-81 e	-55.4	-19.7	33.7	1,5
C_5H_8	1-Pentyne			-75 e	-49.1	-13.5	39.9	5
C_5H_8	2-Pentyne	-100 e	-85 e	-65 e	-37.9	-0.5	55.7	5
C_5H_8	3-Methyl-1-butyne			-82 e	-57.5	-23.1	28.6	5
C_5H_8	Cyclopentene	-109 e	-94 e	-74 e	-48 e	-11.1	43.8	5
C_5H_8	Spiropentane	-110 e	-95 e	-76 e	-51 e	-15 e	38.6	5
C_5H_8O	3-Methyl-3-buten-2-one			-35 e	-5 e	36.0	97.3	5
C_5H_8O	Cyclopropyl methyl ketone		-57 e	-31 e	3 e	49 e	112 e	5
C_5H_8O	Cyclopentanone		-39 e	-14 e	19 e	64 e	130.3	1
C_5H_8O	3,4-Dihydro-2H-pyran				-22 e	22.0	84.9	5
$C_5H_8O_2$	4-Pentenoic acid	0 e	19 e	44 e	77 e	122.0	187.5	5
$C_5H_8O_2$	Vinyl propanoate					31.2	94 e	5
$C_5H_8O_2$	Ethyl acrylate		-55 e	-32.7	-2.8	38.5	99.2	5
$C_5H_8O_2$	Methyl methacrylate			-31 e	-1 e	39.7	100.0	1
$C_5H_8O_2$	2,4-Pentanedione			-5 e	24.7	67.8	137.4	1
$C_5H_8O_2$	Tetrahydro-2*H*-pyran-2-one		5 e	35.1	74.4	128.3	207.0	5
$C_5H_8O_3$	Methyl acetoacetate				50.1	101.1	171.3	5
$C_5H_8O_4$	Glutaric acid		121 e	153.2	191.9	240.3	302.5	5
$C_5H_8O_4$	Dimethyl malonate	-22 e	1 e	30.0	66.7	114.7	180.2	5
$C_5H_9ClO_2$	Ethyl 2-chloropropanoate			1.4	36.4	82.5	146.0	5
$C_5H_9ClO_2$	Isopropyl chloroacetate			-2 e	35.0	83.3	148.1	5
C_5H_9N	Pentanenitrile	-54 e	-34 e	-8 e	26 e	72.2	140.9	1
C_5H_9N	2,2-Dimethylpropanenitrile					41.1	104.8	5
C_5H_9NO	*N*-Methyl-2-pyrrolidone	1 e	24 e	53.1	92.3	147.2	229 e	5
C_5H_{10}	1-Pentene	-118.9	-103.4	-84.0	-58.8	-23.3	29.6	1,5
C_5H_{10}	*cis*-2-Pentene	-113.8	-98.1	-78.4	-52.7	-16.8	36.6	1,5
C_5H_{10}	*trans*-2-Pentene	-114.5	-98.9	-79.1	-53.3	-17.5	36.0	1,5
C_5H_{10}	2-Methyl-1-butene	-117.7	-102.2	-82.7	-57.2	-21.9	30.8	1,5
C_5H_{10}	3-Methyl-1-butene	-125.0	-110.1	-91.2	-66.7	-32.1	19.7	1,5
C_5H_{10}	2-Methyl-2-butene	-113.4	-97.6	-77.7	-51.6	-15.8	38.2	1,5

VAPOR PRESSURE (continued)

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
C_5H_{10}	Cyclopentane			-77.0	-45.4	-7.1	48.8	5
C_5H_{10}	Ethylcyclopropane	-118 e	-102 e	-83 e	-57 e	-20 e	35.5	5
C_5H_{10}	*cis*-1,2-Dimethylcyclopropane	-118 e	-103 e	-83 e	-57 e	-20 e	36.6	5
C_5H_{10}	*trans*-1,2-Dimethylcyclopropane	-122 e	-108 e	-89 e	-63 e	-27 e	27.8	5
$C_5H_{10}Br_2$	1,5-Dibromopentane	1 e	25 e	54 e	93 e	145.6	221.8	5
$C_5H_{10}Cl_2$	1,2-Dichloropentane				30 e	77.4	147.8	5
$C_5H_{10}Cl_2$	1,5-Dichloropentane	-31 e	-10 e	17 e	54 e	104.1	178.9	5
$C_5H_{10}N_2$	3-(Dimethylamino)-propanenitrile				51.1	101.8	171.4	5
$C_5H_{10}O$	Cyclopentanol		-13 e	11.5	42.2	82.5	140.0	5
$C_5H_{10}O$	Allyl ethyl ether			-56 e	-28.7	9.8	67.2	5
$C_5H_{10}O$	Pentanal	-71 e	-53 e	-31 e	-1 e	40.8	102.6	5
$C_5H_{10}O$	2-Pentanone				-1 e	40.3	101.9	1,5
$C_5H_{10}O$	3-Pentanone			-31 e	-1 e	40 e	101.6	1
$C_5H_{10}O$	3-Methyl-2-butanone	-69 e	-54 e	-34 e	-6.9	32.2	94.0	1,5
$C_5H_{10}O$	Tetrahydropyran				-15 e	26.0	88 e	5
$C_5H_{10}O$	2-Methyltetrahydrofuran				-20 e	19.7	79.8	5
$C_5H_{10}O_2$	Pentanoic acid	-7.4	15.3	42.7	76.3	122.1	185.7	5
$C_5H_{10}O_2$	2-Methylbutanoic acid	-10 e	10 e	36 e	69 e	112.8	175.2	5
$C_5H_{10}O_2$	3-Methylbutanoic acid	-15.8	4 e	30.0	64.7	110.6	176.1	5
$C_5H_{10}O_2$	Butyl formate			-29 e	2 e	44.4	105.7	5
$C_5H_{10}O_2$	Isobutyl formate	-69 e	-53 e	-31 e	-3 e	37.4	97.6	5
$C_5H_{10}O_2$	Propyl acetate	-69 e	-51 e	-29 e	0 e	40.9	101.2	1
$C_5H_{10}O_2$	Isopropyl acetate		-61 e	-40 e	-11 e	29.8	88.2	5
$C_5H_{10}O_2$	Ethyl propanoate	-69 e	-52 e	-30 e	-1 e	38.9	98.7	1
$C_5H_{10}O_2$	Methyl butanoate	-68 e	-50 e	-28 e	0.9	41.7	102.3	5
$C_5H_{10}O_2$	Methyl isobutanoate	-83 e	-65 e	-41 e	-11 e	31 e	92.1	5
$C_5H_{10}O_2$	Tetrahydrofurfuryl alcohol	-40 e	-16 e	15 e	55 e	106 e	176.8	5
$C_5H_{10}O_3$	Diethyl carbonate		-42 e	-17 e	17 e	61.6	125.9	5
$C_5H_{10}O_3$	Ethylene glycol monomethyl ether acetate	-47 e	-26 e	0 e	34 e	79.4	144.1	5
$C_5H_{10}S$	Thiacyclohexane				24 e	71.1	141.2	5
$C_5H_{10}S$	Cyclopentanethiol				18 e	64 e	131.7	5
$C_5H_{11}Br$	1-Bromopentane	-60 e	-41 e	-16 e	16 e	61.5	129.1	5
$C_5H_{11}Br$	2-Bromopentane	-69 e	-51 e	-27 e	5 e	49.7	116.9	5
$C_5H_{11}Br$	3-Bromopentane	-68 e	-50 e	-26 e	6 e	50.8	118.1	5
$C_5H_{11}Br$	1-Bromo-3-methylbutane	-67 e	-49 e	-25 e	8 e	52.4	119.9	5
$C_5H_{11}Cl$	1-Chloropentane	-73 e	-55 e	-32 e	-1 e	42.5	107.9	5
$C_5H_{11}Cl$	2-Chloropentane	-80 e	-62 e	-39 e	-9 e	33.2	96.1	5
$C_5H_{11}Cl$	3-Chloropentane	-77 e	-60 e	-37 e	-7 e	34.9	97.3	5
$C_5H_{11}Cl$	2-Chloro-2-methylbutane			-52 e	-21 e	21.8	85.2	5
$C_5H_{11}Cl$	1-Chloro-2,2-dimethyl-propane				-17 e	23.5	83.9	5
$C_5H_{11}F$	1-Fluoropentane	-97 e	-80 e	-60 e	-32 e	5.7	62.4	5
$C_5H_{11}I$	1-Iodopentane	-47 e	-27 e	-1 e	34 e	83.0	156.5	5
$C_5H_{11}I$	1-Iodo-3-methylbutane		-34 e	-6.6	28.8	77.3	147.8	5
$C_5H_{11}N$	Cyclopentylamine	-66 e	-48 e	-26 e	4 e	45.8	108 e	5
$C_5H_{11}N$	Piperidine				2 e	43.3	105.8	5
$C_5H_{11}N$	*N*-Methylpyrrolidine				-23 e	18.5	78 e	5
$C_5H_{11}NO_3$	3-Methylbutyl nitrate		-26 e	1.0	35.5	81.7	147.0	5
C_5H_{12}	Pentane**	-115.5	-99.8	-80.0	-54.0	-18.1	35.7	16
C_5H_{12}	Isopentane	-119 e	-105 e	-86 e	-61 e	-26 e	27.5	1
C_5H_{12}	Neopentane*		-107.5 s	-90.8 s	-68.8 s	-38.5 s	9.2	1,5
$C_5H_{12}N_2O$	Tetramethylurea			20.7	58.0	106.7	179.5	5
$C_5H_{12}O$	1-Pentanol	-27 e	-10 e	12 e	41 e	79.8	137.4	5
$C_5H_{12}O$	2-Pentanol	-35 e	-19 e	1 e	28.0	64.9	118.7	1
$C_5H_{12}O$	3-Pentanol	-41 e	-25 e	-4 e	24 e	61.1	114.9	5
$C_5H_{12}O$	2-Methyl-1-butanol	-27 e	-11 e	9 e	36.2	73.4	128.3	1
$C_5H_{12}O$	3-Methyl-1-butanol	-22 e	-7 e	13 e	39.1	75.7	130.1	5
$C_5H_{12}O$	2-Methyl-2-butanol			-5 e	17.7	50.6	101.7	1,5
$C_5H_{12}O$	3-Methyl-2-butanol			-3 e	22.7	58.2	111.1	5
$C_5H_{12}O$	2,2-Dimethyl-1-propanol					59.2	112.7	5
$C_5H_{12}O$	Butyl methyl ether			-54 e	-27 e	12 e	69.8	1
$C_5H_{12}O$	Methyl *tert*-butyl ether			-66 e	-39 e	-2 e	54.8	1
$C_5H_{12}O$	Ethyl propyl ether	-92 e	-77 e	-57 e	-30.5	6.7	63.4	1,5

Mol. Form.	Name	1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
		Temperature in °C for the indicated pressure						
$C_5H_{12}O_2$	1,5-Pentanediol	25 e	52 e	85 e	125 e	175.1	238.9	5
$C_5H_{12}O_2$	Ethylene glycol monopropyl ether				40 e	85.6	149.3	5
$C_5H_{12}O_2$	Diethoxymethane		-65 e	-43 e	-14 e	27.3	87.7	5
$C_5H_{12}O_3$	Diethylene glycol monomethyl ether		12 e	40 e	76 e	124.2	193.7	1
$C_5H_{12}S$	1-Pentanethiol	-60 e	-41 e	-17 e	15 e	60 e	126.2	1
$C_5H_{12}S$	2-Pentanethiol	-70 e	-52 e	-28 e	3 e	46.6	111.9	5
$C_5H_{12}S$	3-Pentanethiol	-70 e	-51 e	-28 e	4 e	47.7	113.4	5
$C_5H_{12}S$	2-Methyl-1-butanethiol				8.0	52.3	118.5	5
$C_5H_{12}S$	3-Methyl-1-butanethiol				7.8	51.9	117.9	5
$C_5H_{12}S$	2-Methyl-2-butanethiol				-8.0	34.6	98.7	5
$C_5H_{12}S$	Butyl methyl sulfide		-43 e	-19 e	13 e	57 e	123.0	1
$C_5H_{12}S$	*tert*-Butyl methyl sulfide				-7.8	34.7	98.4	5
$C_5H_{12}S$	Ethyl propyl sulfide	-64 e	-46 e	-23 e	9 e	52.7	118.0	5
$C_5H_{12}S$	Ethyl isopropyl sulfide	-72 e	-54 e	-31 e	0 e	42.7	106.9	5
$C_5H_{13}N$	Pentylamine		-52 e	-29 e	1 e	42.8	104.0	5
C_6BrF_5	Bromopentafluorobenzene			-10 e	23 e	68 e	136.0	5
C_6ClF_5	Chloropentafluorobenzene		-44 e	-21 e	11 e	53.8	117.6	1
$C_6Cl_3F_3$	1,3,5-Trichloro-2,4,6-trifluorobenzene	-19 e	4 e	32 e	70 e	121.7	197.9	1
C_6F_6	Hexafluorobenzene		-56.9 s	-36 s	-11.5 s	22.6	79.9	1,5
C_6F_{12}	Perfluorocyclohexane				-46.2 s	-7.6 s	48.9 s	5
C_6F_{14}	Perfluorohexane		-75 e	-57 e	-32 e	2.8	56.8	5
C_6F_{14}	Perfluoro-2-methylpentane				-33 e	2.9	57.1	5
C_6F_{14}	Perfluoro-3-methylpentane	-95 e	-80 e	-60 e	-34 e	2.8	57.9	5
C_6F_{14}	Perfluoro-2,3-dimethylbutane					4.3	59.3	5
C_6HF_5	Pentafluorobenzene			-41 e	-13 e	27 e	85.3	5
C_6HF_5O	Pentafluorophenol				39 e	82 e	145.2	5
$C_6H_2F_4$	1,2,3,4-Tetrafluorobenzene			-36 e	-7 e	33.8	94.0	1
$C_6H_2F_4$	1,2,3,5-Tetrafluorobenzene			-43 e	-14 e	25.5	84.1	1
$C_6H_2F_4$	1,2,4,5-Tetrafluorobenzene					30.7	89.9	1
$C_6H_3Cl_3O$	2,4,6-Trichlorophenol			71.8	114.0	169.5	245.7	5
$C_6H_3F_3$	1,3,5-Trifluorobenzene					18.2	75.0	5
$C_6H_4Br_2$	*m*-Dibromobenzene	-7 e	16 e	44 e	83 e	137.0	218.2	5
$C_6H_4ClNO_2$	1-Chloro-4-nitrobenzene	15.4 s	35.8 s		97 e	156.0	238 e	5
$C_6H_4Cl_2$	*o*-Dichlorobenzene		-13 e	16.3	53.9	104.6	180.0	1,5
$C_6H_4Cl_2$	*m*-Dichlorobenzene		-22 e	8.0	46.7	97.8	172.5	1,5
$C_6H_4Cl_2$	*p*-Dichlorobenzene	-45.5 s	-21.8 s	8 s	46.7 s	99.0	173.6	1,5
$C_6H_4O_2$	*p*-Benzoquinone	-4.1 s	17.8 s	43.5 s	74.3 s	111.6 s		5
$C_6H_5AsCl_2$	Dichlorophenylarsine	6.9	35.2	70 e	113 e	170 e	245 e	5
C_6H_5Br	Bromobenzene		-25 e	1 e	34.9	83.1	155.4	1
C_6H_5Cl	Chlorobenzene		-43 e	-17 e	16.8	62.9	131.3	1,5
C_6H_5ClO	*o*-Chlorophenol				45.8	97.9	173.9	5
C_6H_5ClO	*m*-Chlorophenol			39.7	80.2	135.1	213.4	5
C_6H_5ClO	*p*-Chlorophenol			45.0	86.5	142.0	219.9	5
$C_6H_5Cl_3Si$	Trichlorophenylsilane			33 e	70.2	122.6	201 e	5
C_6H_5F	Fluorobenzene				-16.9	24.2	84.4	1
C_6H_5I	Iodobenzene	-30 e	-7 e	20.9	58.5	110.6	187.8	1
$C_6H_5NO_2$	Nitrobenzene		10 e	40 e	78 e	132 e	210.3	1
$C_6H_5NO_3$	*p*-Nitrophenol	72.6 s	97.4 s					5
C_6H_6	1,5-Hexadien-3-yne	-82 e	-66 e	-44.3	-16.0	23.7	83.6	5
C_6H_6	Benzene**			-40 s	-15.1 s	20.0	79.7	1,5
C_6H_6ClN	*o*-Chloroaniline		10 e	39.0	75.2	131.4	208.3	5
C_6H_6ClN	*m*-Chloroaniline	-5 e	19.7	49.4	94.2	162 e	1069 e	5
$C_6H_6N_2O_2$	*p*-Nitroaniline	87.8 s			192.0	252.6	331.2	5
C_6H_6O	Phenol	-9.7 s	9.6 s	34.1 s	68.9	113.7	181.4	1,5
$C_6H_6O_3$	1,2,3-Benzenetriol				162.0	222.8	308.3	5
C_6H_6S	Benzenethiol		-15 e	12 e	47 e	96.0	168.6	5
C_6H_7N	Aniline		-2.5	26.7	63.5	112.5	183.5	1,5
C_6H_7N	2-Methylpyridine	-56.5	-37.8	-13.9	18.3	62.9	129.0	1,5
C_6H_7N	3-Methylpyridine			-5 e	28.8	75.2	143.7	1
C_6H_7N	4-Methylpyridine	-58.2 s	-43.1 s	-3.9 s	29.6	76.1	144.9	1,5
C_6H_8	*cis*-1,3,5-Hexatriene					21 e	78 e	5
C_6H_8	1,3-Cyclohexadiene	-88 e	-71 e	-50 e	-21 e	19 e	79.9	5
C_6H_8	1,4-Cyclohexadiene				-15 e	27.3	85.0	5
$C_6H_8N_2$	Adiponitrile	30 e	61 e	100 e	148.6	211.8	297 e	5

Mol. Form.	Name	Temperature in °C for the indicated pressure 1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
$C_6H_8N_2$	*m*-Phenylenediamine			94.5	140.2	200.8	285.0	5
$C_6H_8N_2$	Phenylhydrazine		38 e	69 e	109 e	163.9	242.5	5
$C_6H_8O_4$	Dimethyl maleate		5 e	36 e	76 e	127.3	197 e	5
C_6H_8S	2,5-Dimethylthiophene		-43 e	-16 e	20 e	67.5	134.8	5
C_6H_{10}	*trans*-1,3-Hexadiene	-86 e	-70 e	-51 e	-24 e	14 e	72 e	5
C_6H_{10}	*trans*-1,4-Hexadiene	-98 e	-81 e	-60 e	-33 e	7 e	65 e	5
C_6H_{10}	1,5-Hexadiene	-99 e	-84 e	-64 e	-37 e	0.9	59.2	5
C_6H_{10}	*cis,cis*-2,4-Hexadiene					18 e	79.6	5
C_6H_{10}	*trans,cis*-2,4-Hexadiene	-89 e	-73 e	-52 e	-23 e	18 e	79.6	5
C_6H_{10}	*trans,trans*-2,4-Hexadiene				-23 e	18 e	79.6	5
C_6H_{10}	*trans*-2-Methyl-1,3-pentadiene	-92 e	-75 e	-54 e	-26 e	14 e	75.6	5
C_6H_{10}	2,3-Dimethyl-1,3-butadiene			-59 e	-30 e	9.7	68.1	5
C_6H_{10}	1-Hexyne	-91 e	-75 e	-54 e	-26 e	12.8	71.0	5
C_6H_{10}	2-Hexyne	-84 e	-67 e	-46 e	-17 e	23.6	84.1	5
C_6H_{10}	3-Hexyne	-86 e	-69 e	-48 e	-19.1	21.0	81.0	1,5
C_6H_{10}	4-Methyl-1-pentyne	-97 e	-81 e	-61 e	-34 e	4.1	60.7	5
C_6H_{10}	4-Methyl-2-pentyne	-91 e	-74 e	-54 e	-26 e	13.8	72.7	5
C_6H_{10}	Cyclohexene	-87 e	-70 e	-49 e	-19 e	21 e	82.6	1
$C_6H_{10}Cl_2$	1,1-Dichlorocyclohexane	-39 e	-19 e	8 e	43 e	93.5	170.5	5
$C_6H_{10}Cl_2$	*cis*-1,2-Dichlorocyclohexane			27 e	69 e	125.7	206.2	5
$C_6H_{10}O$	4-Methyl-4-penten-2-one	-59 e	-41 e	-17 e	14 e	57.0	121.0	5
$C_6H_{10}O$	Cyclohexanone		-25 e	1 e	36 e	84 e	155.2	1
$C_6H_{10}O$	Mesityl oxide	-56 e	-37 e	-13 e	19 e	63.5	129.3	5
$C_6H_{10}O_2$	Vinyl butanoate					53 e	114.5	5
$C_6H_{10}O_2$	Ethyl methacrylate				8 e	53.2	116.8	5
$C_6H_{10}O_2$	Allyl glycidyl ether				40.1	85.7	152.8	5
$C_6H_{10}O_3$	Ethyl acetoacetate	-25 e	-3 e	25.7	62.3	111.3	180.2	5
$C_6H_{10}O_3$	Propanoic anhydride	-32 e	-15 e	6 e	36 e	77.6	142.9	5
$C_6H_{10}O_4$	Diethyl oxalate	-5 e	18 e	44.9	79.4	124.3	185.2	5
$C_6H_{10}O_4$	Dimethyl succinate			30 e	70.4	123.3	195.4	5
$C_6H_{10}O_4$	Ethylene glycol diacetate	-17 e	6 e	35.0	71.9	121.1	190.0	5
$C_6H_{10}S$	Diallylsulfide	-58 e	-38 e	-12.4	21.7	68.8	138.1	5
$C_6H_{11}Cl$	Chlorocyclohexane		-35 e	-9 e	25 e	71.6	142.1	5
$C_6H_{11}N$	Hexanenitrile	-40 e	-19 e	8 e	43 e	91.5	163.2	1,5
$C_6H_{11}N$	4-Methylpentanenitrile		-50 e	-20 e	20 e	75.2	155.2	5
$C_6H_{11}NO$	Caprolactam	36.8 s	58.9 s	86.6 s			270	5
C_6H_{12}	1-Hexene	-99.8	-82.8	-61.4	-33.7	5.2	63.1	1,5
C_6H_{12}	*cis*-2-Hexene	-97 e	-80 e	-58 e	-30 e	9.9	68.5	5
C_6H_{12}	*trans*-2-Hexene	-94 e	-78 e	-57 e	-30 e	9.3	67.5	5
C_6H_{12}	*cis*-3-Hexene	-96 e	-79 e	-59 e	-30.8	7.9	66.0	5
C_6H_{12}	*trans*-3-Hexene	-95 e	-79 e	-58 e	-30.0	8.8	66.7	5
C_6H_{12}	2-Methyl-1-pentene	-98 e	-82 e	-62 e	-34.2	4.1	61.7	5
C_6H_{12}	3-Methyl-1-pentene	-104 e	-88 e	-68 e	-41.5	-3.6	53.8	5
C_6H_{12}	4-Methyl-1-pentene	-105 e	-89 e	-69 e	-41.6	-3.6	53.5	5
C_6H_{12}	2-Methyl-2-pentene	-95 e	-78 e	-58 e	-30 e	9.0	66.9	5
C_6H_{12}	3-Methyl-*cis*-2-pentene	-95 e	-79 e	-58 e	-30 e	8.9	67.3	5
C_6H_{12}	3-Methyl-*trans*-2-pentene	-93 e	-77 e	-55 e	-27.4	11.7	70.0	5
C_6H_{12}	4-Methyl-*cis*-2-pentene	-102 e	-86 e	-66 e	-38.7	-0.9	56.0	5
C_6H_{12}	4-Methyl-*trans*-2-pentene	-100 e	-84 e	-64 e	-36.8	1.2	58.2	5
C_6H_{12}	2-Ethyl-1-butene	-98 e	-81 e	-60 e	-32 e	6.6	64.3	5
C_6H_{12}	2,3-Dimethyl-1-butene	-103 e	-87 e	-67 e	-39.9	-1.9	55.2	5
C_6H_{12}	3,3-Dimethyl-1-butene	-110 e	-95 e	-76 e	-50.8	-14.5	40.8	5
C_6H_{12}	2,3-Dimethyl-2-butene		-75 e	-54 e	-25 e	14 e	72.9	1
C_6H_{12}	Cyclohexane	-85.6 s	-68.9 s	-47.6 s	-19.8 s	19.3	80.4	1,5
C_6H_{12}	Methylcyclopentane	-97 e	-80 e	-58 e	-28.8	11.6	71.4	1,5
C_6H_{12}	Ethylcyclobutane	-99 e	-82 e	-61 e	-32 e	9 e	70.2	5
C_6H_{12}	Isopropylcyclopropane	-104 e	-88 e	-68 e	-40 e	-1 e	57.9	5
C_6H_{12}	1-Ethyl-1-methylcyclopropane	-105 e	-89 e	-69 e	-41 e	-3 e	56.3	5
C_6H_{12}	1,1,2-Trimethylcyclopropane	-109 e	-94 e	-73 e	-46 e	-7 e	52.0	5
$C_6H_{12}Cl_2$	1,2-Dichlorohexane				49 e	98.1	171.7	5
$C_6H_{12}Cl_2O$	2,2′-Dichlorodiisopropyl ether		-1 e	27.3	63.4	112.3	182.1	5
$C_6H_{12}O$	Butyl vinyl ether	-87 e	-67 e	-42 e	-9.3	33.6	93.2	5
$C_6H_{12}O$	Isobutyl vinyl ether	-87 e	-68 e	-44 e	-13 e	26.5	80.7	5
$C_6H_{12}O$	Hexanal	-56 e	-37 e	-13 e	19 e	62.6	127.8	5
$C_6H_{12}O$	2-Hexanone	-43 e	-21 e	4.2	34.5	61.9	127.2	1,5
$C_6H_{12}O$	3-Hexanone		-40 e	-16 e	15 e	58.5	123.1	1
$C_6H_{12}O$	3-Methyl-2-pentanone				8.5	52.7	117.0	5

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
$C_6H_{12}O$	4-Methyl-2-pentanone	-61 e	-43 e	-21 e	9 e	51.5	116.1	5
$C_6H_{12}O$	2-Methyl-3-pentanone					50.2	113.0	5
$C_6H_{12}O$	3,3-Dimethyl-2-butanone			-30 e	0 e	42.5	105.7	1
$C_6H_{12}O$	Cyclohexanol			34 e	61 e	99.2	160.7	1
$C_6H_{12}O_2$	Hexanoic acid		33 e	59 e	93 e	139.3	204.5	1
$C_6H_{12}O_2$	4-Methylpentanoic acid	36 e	49 e	67.1	92.9	133.6	206.8	5
$C_6H_{12}O_2$	Diethylacetic acid	-9 e	16 e	46 e	83 e	130.7	192.5	5
$C_6H_{12}O_2$	Isopentyl formate	-60 e	-41 e	-17 e	15 e	59.1	124 e	5
$C_6H_{12}O_2$	Butyl acetate	-63 e	-43 e	-19 e	14 e	61.0	125.6	1,5
$C_6H_{12}O_2$	Isobutyl acetate	-63 e	-45 e	-21 e	10 e	53.4	116 e	5
$C_6H_{12}O_2$	Propyl propanoate	-62 e	-42 e	-18 e	14 e	58.3	122.0	5
$C_6H_{12}O_2$	Ethyl butanoate	-49 e	-34 e	-14 e	14.3	55.2	121.1	5
$C_6H_{12}O_2$	Ethyl 2-methylpropanoate	-65 e	-47 e	-24.6	5.4	47.3	109.8	5
$C_6H_{12}O_2$	Methyl pentanoate				19.2	63.7	127.4	5
$C_6H_{12}O_2$	Methyl isopentanoate					53.3	116.3	5
$C_6H_{12}O_2$	Diacetone alcohol	-41 e	-17 e	13 e	50.1	98.5	164 e	5
$C_6H_{12}O_3$	Ethylene glycol monoethyl ether acetate	-25 e	-8 e	14 e	44.6	88.0	155.6	5
$C_6H_{12}O_3$	Paraldehyde				17 e	62.2	124 e	5
$C_6H_{12}S$	Cyclohexanethiol					84.8	158.3	5
$C_6H_{12}S$	*cis*-Tetrahydro-2,5-dimethylthiophene	-53 e	-34 e	-8 e	25 e	72.0	142.1	5
$C_6H_{12}S$	Tetrahydro-3-methyl-2H-thiopyran	-48 e	-27 e	0 e	35 e	84.1	157.5	5
$C_6H_{13}Br$	1-Bromohexane	-45 e	-25 e	2 e	36 e	83.7	154.8	5
$C_6H_{13}Cl$	1-Chlorohexane	-55 e	-36 e	-11 e	21 e	66.7	134.6	5
$C_6H_{13}F$	1-Fluorohexane	-80 e	-62 e	-40 e	-11 e	30.4	91.1	5
$C_6H_{13}I$	1-Iodohexane	-33 e	-11 e	16 e	53 e	104.0	180.8	5
$C_6H_{13}N$	Cyclohexylamine			-9 e	22 e	66.6	133.5	1
C_6H_{14}	Hexane	-96.4 s	-79.2	-57.6	-29.3	9.8	68.3	16
C_6H_{14}	2-Methylpentane	-100 e	-84 e	-64 e	-36 e	2 e	59.9	1
C_6H_{14}	3-Methylpentane	-99 e	-83 e	-62 e	-34.3	4.6	62.9	1
C_6H_{14}	2,2-Dimethylbutane		-90 e	-71.5	-45.5	-7.7	49.4	1
C_6H_{14}	2,3-Dimethylbutane	-103 e	-87 e	-66 e	-39.0	-0.4	57.6	1
$C_6H_{14}O$	1-Hexanol		5 e	28 e	56.8	97.3	157.1	1
$C_6H_{14}O$	2-Hexanol	-28 e	-10 e	12 e	41.4	81.5	139.6	1
$C_6H_{14}O$	3-Hexanol	-43 e	-23 e	1 e	33 e	75.4	135.1	1
$C_6H_{14}O$	2-Methyl-1-pentanol			14 e	45.9	88.3	147.6	5
$C_6H_{14}O$	4-Methyl-1-pentanol			24 e	53 e	92.4	151.4	5
$C_6H_{14}O$	2-Methyl-2-pentanol	-29 e	-15 e	3 e	27.1	63.0	120.9	5
$C_6H_{14}O$	3-Methyl-2-pentanol				36.5	76.1	133.8	5
$C_6H_{14}O$	4-Methyl-2-pentanol	-43 e	-24 e	0 e	30 e	71.9	131.3	5
$C_6H_{14}O$	2-Methyl-3-pentanol				29.8	68.8	126.0	5
$C_6H_{14}O$	3-Methyl-3-pentanol		-23 e	-4 e	22.9	61.1	121.1	5
$C_6H_{14}O$	2-Ethyl-1-butanol		-5 e	17 e	46 e	85.7	146.1	5
$C_6H_{14}O$	3,3-Dimethyl-1-butanol	-37 e	-16 e	9 e	42 e	84.3	142.5	5
$C_6H_{14}O$	2,3-Dimethyl-2-butanol			-5 e	23 e	61.3	118.2	5
$C_6H_{14}O$	Dipropyl ether	-80 e	-63 e	-41 e	-12 e	28.8	89.7	1
$C_6H_{14}O$	Diisopropyl ether		-76 e	-55 e	-28 e	11 e	68.1	1
$C_6H_{14}O$	Butyl ethyl ether	-78 e	-61 e	-39 e	-10 e	31.0	91.9	1
$C_6H_{14}O$	*tert*-Butyl ethyl ether	-90 e	-74 e	-53 e	-24.6	14.4	72.6	5
$C_6H_{14}O_2$	2-Methyl-2,4-pentanediol	-8 e	17 e	48 e	86 e	134.4	197.5	5
$C_6H_{14}O_2$	Ethylene glycol monobutyl ether	-31 e	-8 e	20 e	55 e	103.2	170.2	5
$C_6H_{14}O_2$	1,1-Diethoxyethane	-68 e	-49 e	-26 e	3.7	44.2	101.9	5
$C_6H_{14}O_2$	Ethylene glycol diethyl ether		-59 e	-35.3	-2.8	44.4	118.8	5
$C_6H_{14}O_3$	1,2,6-Hexanetriol	92 e	114.8	146.0	191 e			5
$C_6H_{14}O_3$	Dipropylene glycol				110 e	162.6	231.4	5
$C_6H_{14}O_3$	Diethylene glycol monoethyl ether			40 e	80.3	132.4	201.4	5
$C_6H_{14}O_3$	Diethylene glycol dimethyl ether	-42 e	-20 e	8.3	44.3	92.3	159.4	5
$C_6H_{14}O_3$	Trimethylolpropane	73 e	98 e	128 e	167.8	220.5	295 e	5
$C_6H_{14}O_4$	Triethylene glycol	44 e	74 e	109.0	152.6	207.2	277.9	5
$C_6H_{14}S$	1-Hexanethiol	-45 e	-25 e	1 e	35 e	81.7	152.2	5
$C_6H_{14}S$	2-Hexanethiol	-50 e	-32 e	-8 e	25 e	69.9	138.4	5
$C_6H_{14}S$	Dipropyl sulfide	-50 e	-30 e	-6 e	28 e	73.6	142.4	5

Mol. Form.	Name	1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
		Temperature in °C for the indicated pressure						
$C_6H_{14}S$	Diisopropyl sulfide	-65 e	-47 e	-23 e	9 e	53.1	119.6	5
$C_6H_{14}S$	Isopropyl propyl sulfide				18.5	63.8	131.6	5
$C_6H_{14}S$	Butyl ethyl sulfide	-49 e	-30 e	-5 e	29 e	74.8	143.8	5
$C_6H_{15}N$	Hexylamine			-10 e	22 e	66.0	130.6	5
$C_6H_{15}N$	Butylethylamine				6.1	47.7	107.0	5
$C_6H_{15}N$	Dipropylamine		-48 e	-25 e	6 e	47.5	108.8	5
$C_6H_{15}N$	Diisopropylamine			-47 e	-17.5	23.5	84.0	5
$C_6H_{15}N$	Triethylamine	-58 e	-45 e	-29 e	-5 e	29.9	88.5	1
$C_6H_{15}NO$	2-Diethylaminoethanol					97 e	160.6	5
$C_6H_{15}NO_3$	Triethanolamine	75 e	108 e	148 e	196 e	256.7	334 e	5
$C_6H_{15}O_4P$	Triethyl phosphate			34	76	132	211	4
$C_6H_{16}N_2$	Hexamethylenediamine				76.0	128.2	199.0	5
$C_6H_{16}O_2Si$	Diethoxydimethylsilane	-62 e	-44 e	-21.2	9.1	51.0	113.0	5
$C_6H_{18}Cl_2O_2Si_3$	1,5-Dichloro-1,1,3,3,5,5-hexamethyltrisiloxane	-29 e	-7 e	22.2	59.7	110.5	183.4	5
$C_6H_{18}OSi_2$	Hexamethyldisiloxane		-56 e	-34 e	-5 e	37.1	100.1	5
C_6MoO_6	Molybdenum hexacarbonyl		17.4 s	42.8 s	73.1 s	109.9 s	155.4 s	5
C_7F_{14}	Perfluoromethylcyclohexane				-21 e	18 e	75.9	1
C_7F_{16}	Perfluoroheptane		-62 e	-41 e	-14 e	24.7	82.1	1
C_7HF_{15}	1H-Pentadecafluoroheptane				-7 e	35.9	96.0	5
$C_7H_3ClF_3NO_2$	1-Chloro-2-nitro-4-(trifluoromethyl)benzene	3 e	26 e	55 e	92.8	145.2	222.0	5
$C_7H_3F_5$	2,3,4,5,6-Pentafluorotoluene			-20 e	11 e	53.6	117.0	5
$C_7H_4ClF_3$	1-Chloro-2-(trifluoromethyl)benzene			1 e	34.5	81.8	151.8	5
$C_7H_4ClF_3$	1-Chloro-3-(trifluoromethyl)benzene	-53 e	-34 e	-9 e	24.2	69.8	137.2	5
$C_7H_4ClF_3$	1-Chloro-4-(trifluoromethyl)benzene			-9 e	24.2	70.4	138.1	5
$C_7H_4Cl_2O$	*o*-Chlorobenzoyl chloride				93 e	149 e	237.0	5
$C_7H_4Cl_2O$	*m*-Chlorobenzoyl chloride				87.8	147 e	225.0	5
$C_7H_4F_3NO_2$	1-Nitro-3-(trifluoromethyl)benzene		11 e	39 e	76.2	127.3	202.2	5
$C_7H_4F_4$	1-Fluoro-4-(trifluoromethyl)benzene			-38 e	-6 e	38.6	102.3	5
C_7H_5BrO	Benzoyl bromide	-15 e	11 e	42.6	83.9	139.5	218.0	5
C_7H_5ClO	Benzoyl chloride			27.5	67.0	120.4	196.7	5
$C_7H_5Cl_3$	(Trichloromethyl)benzene		9 e	40.6	81.5	136.2	213.0	5
$C_7H_5F_3$	(Trifluoromethyl)benzene				-3 e	39 e	101.6	5
C_7H_5N	Benzonitrile		-6 e	23.9	63.1	115.7	190.0	5
C_7H_5NS	Phenyl isothiocyanate				79.4	105 e	117 e	5
$C_7H_6Cl_2$	2,4-Dichlorotoluene		6 e	33 e	68.3	119.5	199.1	5
$C_7H_6Cl_2$	3,4-Dichlorotoluene	-13 e	9 e	38 e	76 e	129.3	208.4	5
$C_7H_6Cl_2$	(Dichloromethyl)benzene			31	72	130	213	4
C_7H_6O	Benzaldehyde		-9 e	19 e	54.6	104.6	178.3	1
$C_7H_6O_2$	Salicylaldehyde		-1 e	29 e	68 e	120.7	196.2	5
C_7H_7Br	*o*-Bromotoluene		-10 e	17 e	54 e	104.8	181.1	5
C_7H_7Br	*m*-Bromotoluene	-34 e	-11 e	19.4	58.1	109.9	183.1	5
C_7H_7Br	*p*-Bromotoluene				57 e	107.8	183.8	5
C_7H_7Br	(Bromomethyl)benzene			25.4	66.8	121.7	198.3	5
C_7H_7Cl	*o*-Chlorotoluene		-24 e	3 e	38 e	86.3	158.7	1,5
C_7H_7Cl	*m*-Chlorotoluene	-41 e	-21 e	6 e	41 e	89 e	161.8	5
C_7H_7Cl	*p*-Chlorotoluene				40 e	88.9	161.5	1,5
C_7H_7Cl	(Chloromethyl)benzene	-34 e	-11 e	17.7	55.4	106.3	178.9	5
C_7H_7ClO	1-Chloro-2-methoxybenzene	-22 e	2 e	33 e	72 e	125.2	201 e	5
C_7H_7F	*o*-Fluorotoluene		-50 e	-26 e	5 e	49.0	113.9	5
C_7H_7F	*m*-Fluorotoluene	-67 e	-48 e	-25 e	7 e	51.0	116.1	5
C_7H_7F	*p*-Fluorotoluene		-48 e	-24 e	7 e	51 e	116.2	5
$C_7H_7NO_2$	*o*-Nitrotoluene	23 e	40 e	62 e	94 e	141.9	221.9	5
$C_7H_7NO_2$	*m*-Nitrotoluene			45 e	89.7	148.7	231.3	5
$C_7H_7NO_3$	2-Nitroanisole	15 e	45 e	82 e	129 e	189.4	271.8	5
C_7H_8	Toluene	-78.1	-57.1	-31.3	1.5	45.2	110.1	5
C_7H_8	Bicyclo[2.2.1]hepta-2,5-diene				-15 e	27.4	91 e	5
$C_7H_8Cl_2Si$	Dichloromethylphenylsilane			32.4	71.8	126.0	205.0	5
C_7H_8O	*o*-Cresol	-6.4 s	12.8 s	40.2	72.3	120.3	190.5	1,5
C_7H_8O	*m*-Cresol	20.8	33.6	52.4	82.6	130.6	201.8	1,5

VAPOR PRESSURE (continued)

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
C_7H_8O	*p*-Cresol	-0.2 s	20.7 s	52.7	83.1	130.7	201.5	1,5
C_7H_8O	Benzyl alcohol	8 e	28 e	54 e	88 e	134.7	204.9	1
C_7H_8O	Anisole		-21 e	4 e	38 e	84 e	153.2	1,5
C_7H_8S	3-Methylbenzenethiol		0 e	29 e	66 e	117.9	194.6	5
C_7H_9N	Benzylamine			25.6	62.6	112.7	183.9	5
C_7H_9N	*o*-Methylaniline	1.0	18.8	42.6	76.1	125.6	199.9	1,5
C_7H_9N	*m*-Methylaniline	3.8	22.0	46.2	80.1	128.8	202.9	1,5
C_7H_9N	*p*-Methylaniline				77.1	126.2	199.9	5
C_7H_9N	*N*-Methylaniline	-16 e	6 e	34 e	70.3	121.1	195.8	1
C_7H_9N	2-Ethylpyridine	-46 e	-26 e	-1 e	33 e	79.3	149.0	5
C_7H_9N	3-Ethylpyridine	-38 e	-17 e	9 e	44 e	92.7	166.5	5
C_7H_9N	4-Ethylpyridine	-35 e	-15 e	11 e	46 e	94.4	168.6	5
C_7H_9N	2,3-Dimethylpyridine				42 e	89.9	160.6	5
C_7H_9N	2,4-Dimethylpyridine		-25 e	3.7	40.0	87.5	157.9	1,5
C_7H_9N	2,5-Dimethylpyridine			4 e	39 e	86.2	156.6	1
C_7H_9N	2,6-Dimethylpyridine			-3 e	29.9	75.8	143.6	1
C_7H_9N	3,4-Dimethylpyridine		-9 e	19 e	55 e	104.8	178.6	5
C_7H_9N	3,5-Dimethylpyridine			11 e	48 e	98 e	171.5	1
$C_7H_{10}N_2$	Toluene-2,4-diamine			100.4	145.3	202.9	279.5	5
C_7H_{12}	1-Heptyne	-75 e	-57 e	-35 e	-5 e	37.1	99.5	5
C_7H_{12}	2-Heptyne		-51 e	-27 e	4 e	46.9	111.5	5
C_7H_{12}	3-Heptyne	-71 e	-53 e	-31 e	0 e	42.7	106.4	5
C_7H_{12}	5-Methyl-1-hexyne	-80 e	-62 e	-40 e	-11 e	30.1	91.4	5
C_7H_{12}	5-Methyl-2-hexyne	-75 e	-57 e	-34 e	-4 e	38.6	102.0	5
C_7H_{12}	2-Methyl-3-hexyne	-78 e	-61 e	-39 e	-9 e	32.6	94.8	5
C_7H_{12}	4,4-Dimethyl-1-pentyne		-73 e	-52 e	-24 e	15.9	75.6	5
C_7H_{12}	4,4-Dimethyl-2-pentyne		-70 e	-48 e	-19 e	21.4	82.6	5
C_7H_{12}	Bicyclo[4.1.0]heptane					49.9	116.3	5
C_7H_{12}	Cycloheptene			-30.0	3.4	47.5	108 e	5
C_7H_{12}	1-Methylbicyclo(3,1,0)hexane					29.8	92.6	5
C_7H_{12}	Methylenecyclohexane	-76 e	-58 e	-35 e	-5 e	38 e	103.0	5
C_7H_{12}	1-Methylcyclohexene	-72 e	-53 e	-30 e	1 e	45 e	109.8	5
C_7H_{12}	4-Methylcyclohexene	-76 e	-59 e	-36 e	-5 e	37.9	102.3	5
C_7H_{12}	1-Ethylcyclopentene	-75 e	-57 e	-34 e	-3 e	40.7	105.8	5
C_7H_{12}	1,2-Dimethylcyclopentene	-75 e	-57 e	-34 e	-3 e	40.2	105.3	5
C_7H_{12}	1,5-Dimethylcyclopentene	-77 e	-59 e	-36 e	-5.5	37.3	101.5	5
$C_7H_{12}O$	Cycloheptanone			18 e	53.7	104.0	178.7	5
$C_7H_{12}O_2$	Butyl acrylate	-52 e	-31 e	-4.5	30.4	78.0	146.9	5
$C_7H_{12}O_2$	Propyl methacrylate				26 e	73.8	139.7	5
$C_7H_{12}O_3$	Ethyl levulinate		17 e	45.3	82.6	133.2	205.7	5
$C_7H_{12}O_4$	Diethyl malonate	-23 e	4 e	36.0	76.4	128.5	198.3	5
$C_7H_{12}O_4$	Dimethyl glutarate	-11 e	15 e	47 e	87.7	139.8	209.5	5
$C_7H_{13}ClO$	Heptanoyl chloride	-17 e	4 e	29.4	59.7	96.9	144.0	5
C_7H_{14}	1-Heptene	-82.1	-63.8	-40.6	-10.7	31.1	93.2	1,5
C_7H_{14}	*cis*-2-Heptene	-79 e	-61 e	-38 e	-8 e	34.3	98.0	5
C_7H_{14}	*trans*-2-Heptene	-79 e	-61 e	-39 e	-8 e	34.0	97.5	5
C_7H_{14}	*cis*-3-Heptene	-80 e	-62 e	-40 e	-10 e	32.3	95.3	5
C_7H_{14}	*trans*-3-Heptene	-80 e	-62 e	-40 e	-10 e	32.2	95.2	5
C_7H_{14}	2-Methyl-1-hexene	-81 e	-64 e	-42 e	-12 e	29.3	91.6	5
C_7H_{14}	4-Methyl-1-hexene	-84 e	-67 e	-45 e	-16 e	25.3	86.3	5
C_7H_{14}	2-Methyl-2-hexene	-80 e	-63 e	-40 e	-10 e	32.0	95.0	5
C_7H_{14}	*cis*-3-Methyl-2-hexene	-79 e	-62 e	-39 e	-9 e	33.4	96.8	5
C_7H_{14}	*trans*-4-Methyl-2-hexene	-83 e	-66 e	-44 e	-15 e	25.9	87.1	5
C_7H_{14}	*trans*-5-Methyl-2-hexene	-83 e	-66 e	-44 e	-15 e	26.3	87.7	5
C_7H_{14}	*trans*-2-Methyl-3-hexene	-84 e	-67 e	-45 e	-16 e	24.6	85.5	5
C_7H_{14}	3-Ethyl-1-pentene	-85 e	-68 e	-46 e	-17 e	23.2	83.7	5
C_7H_{14}	2,3-Dimethyl-1-pentene	-85 e	-68 e	-46 e	-17 e	23.4	83.8	5
C_7H_{14}	2,4-Dimethyl-1-pentene	-88 e	-71 e	-50 e	-21 e	20.0	81.2	5
C_7H_{14}	3,3-Dimethyl-1-pentene	-87 e	-71 e	-50 e	-21 e	18.1	77.1	5
C_7H_{14}	4,4-Dimethyl-1-pentene	-94 e	-78 e	-57 e	-28 e	11.5	72.1	5
C_7H_{14}	2,3-Dimethyl-2-pentene	-79 e	-62 e	-39 e	-9 e	33.5	96.9	5
C_7H_{14}	2,4-Dimethyl-2-pentene	-84 e	-68 e	-46 e	-18 e	22.6	82.9	5
C_7H_{14}	*cis*-3,4-Dimethyl-2-pentene	-83 e	-65 e	-43 e	-14 e	27.2	88.8	5
C_7H_{14}	*trans*-3,4-Dimethyl-2-pentene	-82 e	-64 e	-42 e	-13 e	29.0	91.1	5
C_7H_{14}	*cis*-4,4-Dimethyl-2-pentene	-90 e	-73 e	-51 e	-22 e	18.6	80.0	5
C_7H_{14}	*trans*-4,4-Dimethyl-2-pentene	-90 e	-73 e	-52 e	-23 e	16.6	76.3	5
C_7H_{14}	2,3,3-Trimethyl-1-butene	-91 e	-75 e	-53 e	-24.2	16.3	77.5	5
C_7H_{14}	Cycloheptane				6 e	51.1	118.4	1

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
C_7H_{14}	Methylcyclohexane	-79 e	-62 e	-39 e	-7.9	35.5	100.5	1
C_7H_{14}	Ethylcyclopentane	-76 e	-59 e	-35 e	-5 e	38.4	103.0	5
C_7H_{14}	1,1-Dimethylcyclopentane		-69 e	-47 e	-17 e	24.8	87.4	5
C_7H_{14}	*cis*-1,2-Dimethylcyclopentane			-38 e	-8 e	34.9	99.0	5
C_7H_{14}	*trans*-1,2-Dimethylcyclopentane	-83 e	-66 e	-43 e	-13 e	28.4	91.4	5
C_7H_{14}	*cis*-1,3-Dimethylcyclopentane	-84 e	-66 e	-44 e	-14 e	28.2	91.1	5
C_7H_{14}	*trans*-1,3-Dimethylcyclopentane	-84 e	-67 e	-44 e	-14 e	27.4	90.3	5
$C_7H_{14}O$	1-Heptanal	-41 e	-21 e	4 e	37 e	83.7	152.3	5
$C_7H_{14}O$	2-Heptanone		-22 e	3 e	36 e	82.2	150.6	1
$C_7H_{14}O$	3-Heptanone		-28 e	0 e	36 e	83.2	147.0	5
$C_7H_{14}O$	4-Heptanone	-27 e	-6 e	18.8	50.2	90.3	143.4	5
$C_7H_{14}O$	5-Methyl-2-hexanone		-27 e	-2 e	31.0	76.6	144.4	5
$C_7H_{14}O$	2,4-Dimethyl-3-pentanone	-61 e	-42 e	-18 e	14 e	58.5	124.8	1
$C_7H_{14}O_2$	Heptanoic acid	24 e	46 e	72 e	107 e	154.6	222.6	5
$C_7H_{14}O_2$	Pentyl acetate	-58 e	-39 e	-14 e	20 e	70.1	149 e	5
$C_7H_{14}O_2$	Isopentyl acetate	-51 e	-30 e	-4 e	30.3	76.2	141.4	5
$C_7H_{14}O_2$	Isobutyl propanoate	-35 e	-19 e	2 e	31 e	72.0	136.1	5
$C_7H_{14}O_2$	Propyl butanoate	-35 e	-19 e	3 e	32.0	74.9	142.8	5
$C_7H_{14}O_2$	Propyl isobutanoate		-28 e	-5.7	24.5	67.5	133.3	5
$C_7H_{14}O_2$	Isopropyl isobutanoate		-44 e	-19.7	12.2	56.0	120.1	5
$C_7H_{14}O_2$	Ethyl 3-methylbutanoate	-57 e	-36 e	-10 e	23.9	69.5	134.4	5
$C_7H_{14}O_2$	Methyl hexanoate	-47 e	-26 e	2 e	36.6	83.3	149 e	5
$C_7H_{14}O_2$	4-Methoxy-4-methyl-2-pentanone				43 e	89.8	160 e	5
$C_7H_{15}Br$	1-Bromoheptane	-30 e	-9 e	18 e	54 e	104.4	178.4	5
$C_7H_{15}Cl$	1-Chloroheptane	-39 e	-19 e	7 e	41 e	88.6	159.9	5
$C_7H_{15}F$	1-Fluoroheptane	-64 e	-45 e	-22 e	10 e	53.3	117.4	5
$C_7H_{15}I$	1-Iodoheptane	-19 e	3 e	32 e	71 e	123.8	203.4	5
C_7H_{16}	Heptane	-78.6	-60.2	-37.0	-6.6	35.4	98.0	16
C_7H_{16}	2-Methylhexane	-82 e	-65 e	-43 e	-13 e	27.8	89.7	1
C_7H_{16}	3-Methylhexane	-81 e	-64 e	-42 e	-12 e	29.2	91.5	1
C_7H_{16}	3-Ethylpentane	-81 e	-63 e	-41 e	-11 e	30.5	93.1	1
C_7H_{16}	2,2-Dimethylpentane	-90 e	-73 e	-52 e	-22.9	17.6	78.8	1
C_7H_{16}	2,3-Dimethylpentane	-87 e	-68.4	-45.3	-14.9	26.8	89.3	5
C_7H_{16}	2,4-Dimethylpentane	-89 e	-72 e	-50 e	-21.3	19.2	80.1	1
C_7H_{16}	3,3-Dimethylpentane	-88 e	-71 e	-49 e	-18.8	22.9	85.6	1
C_7H_{16}	2,2,3-Trimethylbutane				-23.2	18.1	80.4	5
$C_7H_{16}O$	1-Heptanol		17 e	40 e	70.1	112.5	176 e	1
$C_7H_{16}O$	2-Heptanol	-9 e	7 e	27 e	55.0	95.2	158.7	5
$C_7H_{16}O$	3-Heptanol	-8 e	7 e	27 e	54.5	93.9	156.3	5
$C_7H_{16}O$	4-Heptanol	-16 e	1 e	22 e	51 e	91.9	154.6	5
$C_7H_{16}O$	2,2-Dimethyl-3-pentanol			9 e	35 e	73.1	135.5	5
$C_7H_{16}S$	1-Heptanethiol	-30 e	-9 e	18 e	53 e	102.7	176.4	5
$C_7H_{17}N$	Heptylamine			5 e	39 e	86.7	156.4	5
$C_7H_{18}N_2$	*N,N*-Diethyl-1,3-propanediamine				50.1	99.9	167.7	5
C_8F_{18}	Perfluorooctane				5 e	45.0	105.6	5
$C_8H_4O_3$	Phthalic anhydride	48.2 s	72.4 s			192.7	284.2	5
C_8H_6O	Benzofuran		-16 e	12 e	47.9	97.7	170.7	5
C_8H_7Cl	*o*-Chlorostyrene	-33 e	-10 e	20 e	58 e	110.8	188 e	5
C_8H_7N	2-Methylbenzonitrile		1 e	32.1	72.2	126.6	204.7	5
C_8H_7N	4-Methylbenzonitrile			40.1	78.7	134.3	221.3	5
C_8H_7N	Benzeneacetonitrile	-3 e	23 e	55.3	97.4	153.7	233.1	5
C_8H_7N	Indole	20.6 s	44.5 s				254.0	5
$C_8H_7NO_4$	Methyl 2-nitrobenzoate	17 e	49 e	89 e	140 e	208 e	302 e	5
C_8H_8	Styrene		-31 e	-5 e	28.6	75.4	144.7	1
C_8H_8	1,3,5,7-Cyclooctatetraene				24.3	71.0	140.1	5
C_8H_8O	Acetophenone			36 e	73 e	125.3	201.5	5
$C_8H_8O_2$	Phenyl acetate		3 e	33.1	72.2	123.9	195.5	5
$C_8H_8O_2$	Methyl benzoate		-1 e	29 e	68 e	121.2	198.9	5
$C_8H_8O_2$	4-Methoxybenzaldehyde	9 e	35 e	68.1	110.8	167.9	248.5	5
$C_8H_8O_3$	Methyl salicylate	-1 e	22 e	51 e	88.8	141.8	219.9	5
C_8H_9Cl	1-Chloro-2-ethylbenzene	-30 e	-9 e	18 e	54 e	103.7	177.9	5
C_8H_9Cl	1-Chloro-4-ethylbenzene	-27 e	-6 e	22 e	58 e	108.7	183.9	5
$C_8H_9NO_2$	1-Ethyl-4-nitrobenzene	10 e	36 e	69 e	111.6	168 e	245 e	5
C_8H_{10}	Ethylbenzene	-56.2	-36.8	-12.0	21.1	67.1	135.7	1
C_8H_{10}	*o*-Xylene			-7 e	27 e	74.2	143.9	1
C_8H_{10}	*m*-Xylene		-35 e	-10 e	23.4	69.8	138.7	1
C_8H_{10}	*p*-Xylene				22.4	68.9	137.9	1

Mol. Form.	Name	Temperature in °C for the indicated pressure 1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
$C_8H_{10}O$	*o*-Ethylphenol		16.9	44.5	81.1	130.9	204.0	5
$C_8H_{10}O$	*m*-Ethylphenol	5.6	29.2	57.5	91.9	144.8	217.9	5
$C_8H_{10}O$	*p*-Ethylphenol			60 e	95.5	144.6	217.5	5
$C_8H_{10}O$	2,3-Xylenol	14.3 s	34.3 s	57.2 s	91.4	141.7	216.4	1,5
$C_8H_{10}O$	2,4-Xylenol			50.2	85.5	137.2	210.5	1,5
$C_8H_{10}O$	2,5-Xylenol	13.4 s	33.2 s	55.9 s	87.4	137.0	210.6	5
$C_8H_{10}O$	2,6-Xylenol	-3.1 s	16.7 s	39.6 s	75.3	125.9	200.6	1,5
$C_8H_{10}O$	3,4-Xylenol	19.7 s	40.2 s	63.7 s	102.1	152.3	226.4	1,5
$C_8H_{10}O$	3,5-Xylenol	16.5 s	37.2 s	61.1 s	98.0	147.9	221.3	1,5
$C_8H_{10}O$	Benzeneethanol	2 e	25 e	54 e	92 e	143.6	217.7	5
$C_8H_{10}O$	Phenetole		-9 e	17 e	51 e	99 e	169.3	5
$C_8H_{10}O_2$	2-Phenoxyethanol	21 e	46 e	75.9	115.4	168.7	244.8	5
$C_8H_{10}O_2$	1,3-Dimethoxybenzene	18 e	34 e	56 e	86.7	135.5	223 e	5
$C_8H_{11}N$	*p*-Ethylaniline	-2 e	21 e	49 e	87 e	139.4	216.7	5
$C_8H_{11}N$	*N*-Ethylaniline	-15 e	8 e	38 e	76.4	128.8	204.2	5
$C_8H_{11}N$	*N*,*N*-Dimethylaniline			28 e	66 e	118.1	193.6	1
$C_8H_{11}N$	2,4-Xylidine	-2 e	21 e	51 e	88 e	139.1	210.9	5
$C_8H_{11}N$	2,6-Xylidine			37 e	80 e	137.7	217.7	5
$C_8H_{11}N$	5-Ethyl-2-picoline	-33 e	-9.3	20 e			178.0	5
$C_8H_{11}NO$	*o*-Phenetidine	0 e	27 e	60 e	102.2	156.0	228.1	5
C_8H_{12}	1,5-Cyclooctadiene		-37 e	-8 e	30 e	80.2	150 e	5
C_8H_{12}	4-Vinylcyclohexene	-62 e	-43 e	-19 e	14.1	59.9	129 e	5
$C_8H_{12}O_4$	Diethyl maleate	-6 e	20 e	52.2	93.5	148.4	224.8	5
C_8H_{14}	2,5-Dimethyl-1,5-hexadiene	-38 e	-26 e	-10 e	14 e	50.8	115.1	5
C_8H_{14}	1-Octyne	-59 e	-40 e	-16 e	16 e	60.3	125.8	1
C_8H_{14}	2-Octyne	-52 e	-33 e	-8 e	25 e	70.6	137.8	1
C_8H_{14}	3-Octyne	-55 e	-35 e	-11 e	22 e	66.8	132.8	1
C_8H_{14}	4-Octyne	-56 e	-36 e	-12 e	21 e	65.6	131.4	1
C_8H_{14}	1-Ethylcyclohexene	-55 e	-35 e	-11 e	22 e	68 e	136.5	5
$C_8H_{14}O_2$	Cyclohexyl acetate					103.1	172.9	5
$C_8H_{14}O_2$	Butyl methacrylate				47 e	93.3	159.0	5
$C_8H_{14}O_3$	Butanoic anhydride	-28 e	-2 e	30 e	71 e	123.8	196.5	5
$C_8H_{14}O_4$	Ethyl succinate	-6 e	20 e	51.0	91.1	143.7	216.1	5
$C_8H_{14}O_4$	Dipropyl oxalate	-4 e	20 e	49.9	88.6	140.4	213.0	5
$C_8H_{14}O_4$	Dimethyl adipate		28 e	61 e	103 e	156.1	227.3	5
$C_8H_{15}Br$	(2-Bromoethyl)cyclohexane	-14 e	8 e	36.9	75.3	129.7	212.5	5
$C_8H_{15}ClO$	Octanoyl chloride	1 e	22 e	46 e	74.7	109 e	150 e	5
$C_8H_{15}N$	Octanenitrile	-15 e	8 e	37 e	75 e	127.7	204.4	5
C_8H_{16}	1-Octene	-65.7	-46.1	-21.4	10.5	54.9	120.9	1,5
C_8H_{16}	*cis*-2-Octene	-59 e	-41 e	-17 e	15 e	59 e	125.2	5
C_8H_{16}	*trans*-2-Octene	-59 e	-41 e	-17 e	14 e	59 e	124.5	5
C_8H_{16}	*cis*-3-Octene	-65 e	-46 e	-22 e	10 e	55.1	122.4	5
C_8H_{16}	*trans*-3-Octene	-61 e	-43 e	-19 e	13 e	57 e	122.8	5
C_8H_{16}	*cis*-4-Octene	-63 e	-44 e	-20 e	11 e	56 e	122.1	5
C_8H_{16}	*trans*-4-Octene	-65 e	-46 e	-22 e	10 e	54.6	121.8	5
C_8H_{16}	2-Methyl-1-heptene	-66 e	-48 e	-24 e	8 e	52.3	118.7	5
C_8H_{16}	2,2-Dimethyl-*cis*-3-hexene	-74 e	-56 e	-33 e	-3 e	40.1	105.0	5
C_8H_{16}	2,3-Dimethyl-2-hexene	-65 e	-47 e	-23 e	10 e	54.3	121.3	5
C_8H_{16}	2,3,3-Trimethyl-1-pentene		-53 e	-30 e	1 e	43.8	107.9	5
C_8H_{16}	2,4,4-Trimethyl-1-pentene	-79 e	-61 e	-38 e	-7 e	36.2	101.0	5
C_8H_{16}	2,3,4-Trimethyl-2-pentene	-68 e	-49 e	-26 e	6 e	50.0	115.8	5
C_8H_{16}	2,4,4-Trimethyl-2-pentene	-73 e	-56 e	-33 e	-2 e	40.4	104.5	5
C_8H_{16}	Cyclooctane				30 e	78 e	150.7	1
C_8H_{16}	Ethylcyclohexane	-61 e	-42 e	-17 e	15.8	61.9	131.3	5
C_8H_{16}	1,1-Dimethylcyclohexane			-27 e	5 e	50.6	119.1	5
C_8H_{16}	*cis*-1,2-Dimethylcyclohexane		-44 e	-20 e	14 e	59.7	129.2	5
C_8H_{16}	*trans*-1,2-Dimethylcyclohexane	-68 e	-49 e	-25 e	8 e	53.9	122.9	5
C_8H_{16}	*cis*-1,3-Dimethylcyclohexane	-68 e	-48 e	-23 e	10 e	55.6	123.1	5
C_8H_{16}	*trans*-1,3-Dimethylcyclohexane	-62 e	-45 e	-23 e	8 e	51.5	120.9	5
C_8H_{16}	*cis*-1,4-Dimethylcyclohexane	-66 e	-47 e	-23 e	10 e	55.3	123.8	5
C_8H_{16}	*trans*-1,4-Dimethylcyclohexane			-27 e	5 e	50.6	118.9	5
C_8H_{16}	Propylcyclopentane	-60 e	-41 e	-16 e	16.5	62.1	130.5	5
C_8H_{16}	Isopropylcyclopentane	-65 e	-46 e	-21 e	12 e	57.3	125.9	5
C_8H_{16}	1-Ethyl-1-methylcyclopentane	-67 e	-49 e	-24 e	8 e	53.2	121.0	5
C_8H_{16}	*cis*-1-Ethyl-2-methylcyclopentane	-63 e	-44 e	-19 e	13.3	59.1	127.6	5
C_8H_{16}	1,1,2-Trimethylcyclopentane				2 e	46.2	113.2	5
C_8H_{16}	1,1,3-Trimethylcyclopentane	-77 e	-59 e	-36 e	-5 e	38.7	104.4	5

Mol. Form.	Name	Temperature in °C for the indicated pressure 1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
C_8H_{16}	1′,2′,4a-1,2,4-Trimethylcyclo-pentane	-70 e	-52 e	-28 e	4 e	48.9	116.2	5
C_8H_{16}	1′,2a,4′-1,2,4-Trimethylcyclo-pentane	-74 e	-56 e	-33 e	-1 e	42.8	108.8	5
$C_8H_{16}O$	1-Propylcyclopentanol	9 e	24 e	43 e	69.0	108.4	173.5	5
$C_8H_{16}O$	Octanal			6 e	45.7	97.8	170.2	5
$C_8H_{16}O$	2-Octanone		-3 e	23 e	57 e	103.8	172.1	5
$C_8H_{16}O$	3-Octanone			8 e	47.7	97 e	161 e	5
$C_8H_{16}O$	2,2,4-Trimethyl-3-pentanone			11.3	42.1	81.7	134.6	5
$C_8H_{16}O_2$	Octanoic acid	37 e	58 e	85 e	120 e	165.5	238.4	1,5
$C_8H_{16}O_2$	2-Ethylhexanoic acid				108 e	159.6	226.6	5
$C_8H_{16}O_2$	Hexyl acetate	-37 e	-13 e	16 e	52.8	100.4	164 e	5
$C_8H_{16}O_2$	Isopentyl propanoate			3.1	40.7	90.6	159.8	5
$C_8H_{16}O_2$	Isobutyl isobutanoate	-47 e	-26 e	0.4	34.8	81.1	147.0	5
$C_8H_{16}O_2$	Propyl 3-methylbutanoate			1.8	38.9	87.9	155.6	5
$C_8H_{16}O_2$	Ethyl hexanoate	-31 e	-9 e	18.7	53.9	100.7	166.2	5
$C_8H_{16}O_2$	Methyl heptanoate	-30 e	-9 e	19 e	54.2	102.4	172 e	5
$C_8H_{16}O_4$	Diethylene glycol monoethyl ether acetate	-16 e	10.6	43.9	86.2	141.3	216.6	5
$C_8H_{17}Br$	1-Bromooctane	-17 e	6 e	34 e	72 e	123.8	200.3	5
$C_8H_{17}Cl$	1-Chlorooctane	-25 e	-4 e	23 e	59 e	108.8	182.9	5
$C_8H_{17}Cl$	3-(Chloromethyl)heptane					100.3	172.4	5
$C_8H_{17}F$	1-Fluorooctane				29 e	74.6	141.8	5
$C_8H_{17}I$	1-Iodooctane	-6 e	18 e	48 e	87 e	142.5	224.5	5
C_8H_{18}	Octane		-42.6	-17.9	14.4	58.9	125.3	16
C_8H_{18}	2-Methylheptane	-69 e	-49.1	-24.5	7.6	51.6	117.2	1,5
C_8H_{18}	3-Methylheptane	-67 e	-48.1	-23.6	8.5	52.7	118.5	1,5
C_8H_{18}	4-Methylheptane	-65 e	-47 e	-24 e	7.8	51.6	117.2	5
C_8H_{18}	3-Ethylhexane				8 e	52.1	118.1	5
C_8H_{18}	2,2-Dimethylhexane	-73 e	-55 e	-32 e	-1.5	41.6	106.4	5
C_8H_{18}	2,3-Dimethylhexane				5 e	49.2	115.1	5
C_8H_{18}	2,4-Dimethylhexane				0.6	43.9	109.0	5
C_8H_{18}	2,5-Dimethylhexane	-71 e	-53 e	-30 e	0.7	43.8	108.6	5
C_8H_{18}	3,3-Dimethylhexane	-72 e	-54 e	-30 e	1.4	45.4	111.5	5
C_8H_{18}	3,4-Dimethylhexane				7 e	50.9	117.3	5
C_8H_{18}	3-Ethyl-2-methylpentane	-69 e	-50 e	-27 e	5 e	48.9	115.2	5
C_8H_{18}	3-Ethyl-3-methylpentane	-70 e	-51 e	-27 e	5 e	50.2	117.8	5
C_8H_{18}	2,2,3-Trimethylpentane	-74 e	-56 e	-32 e	-0.8	43.1	109.4	5
C_8H_{18}	2,2,4-Trimethylpentane	-81.9	-63.4	-39.8	-8.9	34.0	98.8	5
C_8H_{18}	2,3,3-Trimethylpentane	-72 e	-54 e	-30 e	2.1	46.9	114.3	5
C_8H_{18}	2,3,4-Trimethylpentane	-74 e	-54.5	-30.0	2.2	46.7	113.1	1,5
C_8H_{18}	2,2,3,3-Tetramethylbutane	-62.5 s	-44 s	-20.9 s	8.9 s	48.8 s	105.8	5
$C_8H_{18}O$	1-Octanol	12 e	30 e	53 e	84 e	128.2	194.8	1,39
$C_8H_{18}O$	2-Octanol			40 e	69.9	112.5	179.4	1,39
$C_8H_{18}O$	3-Octanol	12 e	24 e	40 e	64 e	102.8	174.1	1
$C_8H_{18}O$	4-Octanol			40 e	66.9	107.3	176.0	1,39
$C_8H_{18}O$	4-Methyl-3-heptanol	-52 e	-28 e	1 e	39 e	87.6	155.0	5
$C_8H_{18}O$	5-Methyl-3-heptanol	-35 e	-16 e	8 e	40 e	84.8	153.0	5
$C_8H_{18}O$	4-Methyl-4-heptanol	-17 e	1 e	24 e	55 e	97.2	160.7	5
$C_8H_{18}O$	2-Ethyl-1-hexanol			45 e	75 e	118.3	184.2	1
$C_8H_{18}O$	2-Ethyl-2-hexanol	-13 e	4 e	26 e	55 e	96.3	160.3	5
$C_8H_{18}O$	2,4,4-Trimethyl-2-pentanol		-7 e	13 e	40 e	79.8	146.1	5
$C_8H_{18}O$	2,2,4-Trimethyl-3-pentanol	-2 e	9 e	24 e	47 e	82.6	150.4	5
$C_8H_{18}O$	Dibutyl ether	-55 e	-35 e	-8 e	26 e	73.0	141.2	5
$C_8H_{18}O$	Di-*sec*-butyl ether			-19 e	12.1	55.4	120.6	5
$C_8H_{18}O$	Di-*tert*-butyl ether			-33 e	-2 e	41.7	106.8	1
$C_8H_{18}O_2$	Ethylene glycol monohexyl ether	-13 e	14 e	46 e	86 e	137.7	206.9	5
$C_8H_{18}O_2$	1,2-Dipropoxyethane			-44.2	-2.0	63.6	179.2	5
$C_8H_{18}O_2$	Di-*tert*-butyl peroxide			-26 e	4.3	46.6	110.5	5
$C_8H_{18}O_3$	Diethylene glycol monobutyl ether	14 e	37 e	66.8	104.9	153 e	230.4	5
$C_8H_{18}O_3$	Diethylene glycol diethyl ether	-32 e	-7 e	25 e	64.9	117.1	189 e	5
$C_8H_{18}O_5$	Tetraethylene glycol	89 e	117 e	151.1	192.2	242.9	307.3	5
$C_8H_{18}S$	1-Octanethiol	-15 e	6 e	34 e	71 e	122.1	198.5	5
$C_8H_{18}S$	Dibutyl sulfide	-22 e	0 e	27 e	63 e	113.5	188.4	5

VAPOR PRESSURE (continued)

Mol. Form.	Name	Temperature in °C for the indicated pressure 1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
$C_8H_{19}N$	Dibutylamine	-37 e	-16 e	10 e	44 e	90.8	159.1	5
$C_8H_{19}N$	Diisobutylamine	-57 e	-36 e	-9.0	25.5	72.2	139.0	5
$C_8H_{20}O_4Si$	Ethyl silicate	-77 e	-52 e	-21 e	21.6	80.5	164.1	5
$C_8H_{20}Si$	Tetraethylsilane			-6.5	30.5	80.6	152.6	5
C_9F_{20}	Perfluorononane					40 e	114.7	5
$C_9H_6N_2O_2$	Toluene-2,4-diisocyanate		39 e	72 e	113.9	169.7	247 e	5
C_9H_7N	Quinoline	-1.3	23.7	55.4	96.8	153.4	236.5	1,5
C_9H_7N	Isoquinoline		30.2	60.7	101.3	157.9	242.7	1,5
C_9H_8	Indene			12 e	53.0	106.8	181.0	5
C_9H_{10}	*cis*-1-Propenylbenzene	-38 e	-15.4	13.3	51.4	103.7	178.4	5
C_9H_{10}	*trans*-1-Propenylbenzene		-16 e	13.3	51.6	103.7	178.4	5
C_9H_{10}	Isopropenylbenzene			3.2	41.5	92.8	164.9	5
C_9H_{10}	Indan	-33 e	-12 e	16 e	52 e	102.3	177.5	1
$C_9H_{10}O$	2,4-Dimethylbenzaldehyde	-3 e	23 e	54 e	93.2	144.6	214.5	5
$C_9H_{10}O_2$	Ethyl benzoate	-18 e	8 e	39 e	80.1	135.1	212.8	5
$C_9H_{10}O_2$	Benzyl acetate	-11 e	15 e	46.6	86.9	139.5	211 e	5
$C_9H_{11}Br$	1-Bromo-4-isopropylbenzene	-8 e	15 e	45 e	84 e	138.1	218.5	5
$C_9H_{11}Cl$	1-Chloro-2-isopropylbenzene	-23 e	-1 e	27 e	64 e	114.6	190.5	5
$C_9H_{11}Cl$	1-Chloro-4-isopropylbenzene		3 e	31 e	69 e	120.5	197.8	5
C_9H_{12}	Propylbenzene	-43 e	-23 e	4 e	38 e	86.7	158.8	1
C_9H_{12}	Isopropylbenzene	-46 e	-26 e	-1 e	33 e	80.9	152.0	1
C_9H_{12}	*o*-Ethyltoluene	-40 e	-19 e	8 e	43 e	92.1	164.7	5
C_9H_{12}	*m*-Ethyltoluene	-42 e	-21 e	5 e	40.4	88.9	160.8	5
C_9H_{12}	*p*-Ethyltoluene	-41 e	-21 e	6 e	41 e	89.2	161.5	5
C_9H_{12}	1,2,3-Trimethylbenzene		-12 e	15 e	52 e	101.5	175.6	1
C_9H_{12}	1,2,4-Trimethylbenzene	-37 e	-16 e	11 e	47 e	95.9	168.9	1
C_9H_{12}	1,3,5-Trimethylbenzene	-39 e	-18 e	9 e	43.7	92.4	164.3	1
$C_9H_{12}O$	Benzyl ethyl ether		-10 e	20.4	59.3	111.3	184.5	5
$C_9H_{12}O$	Phenyl propyl ether		-10 e	21 e	61 e	113.9	189.3	5
$C_9H_{12}O$	Phenyl isopropyl ether	-20 e	-1 e	23 e	56 e	103.7	176.9	5
$C_9H_{13}N$	2,4,6-Trimethylaniline	12 e	36 e	66 e	104.1	154.9	226 e	5
$C_9H_{13}N$	*N*,*N*-Dimethyl-*o*-toluidine	-25 e	-3 e	24.4	60.6	110.7	184.5	5
$C_9H_{13}N$	Amphetamine			33 e	70.1	118 e	202.0	5
$C_9H_{14}O$	Isophorone		1 e	33.1	75.1	132.4	215.1	5
$C_9H_{14}O_6$	Triacetin	37.6	62 e	90 e	124 e	165 e	214 e	5
$C_9H_{16}O_4$	Diethyl glutarate	-1 e	26 e	60.2	103.3	159.6	236.5	5
$C_9H_{17}N$	Nonanenitrile	-3 e	21 e	50.9	90.7	145.4	225.1	5
C_9H_{18}	1-Nonene	-50.1	-29.4	-3.3	30.4	77.1	146.4	1,5
C_9H_{18}	2-Methyl-1-octene	-53 e	-34 e	-9 e	25 e	72 e	144.1	5
C_9H_{18}	Butylcyclopentane	-45 e	-24 e	1 e	36 e	84 e	156.1	5
C_9H_{18}	Propylcyclohexane	-46 e	-26 e	0 e	35.1	83.6	156.2	5
C_9H_{18}	Isopropylcyclohexane	-48 e	-28 e	-2 e	33 e	81.3	154.0	5
C_9H_{18}	*trans*-1-Ethyl-4-methylcyclohexane	-53 e	-33 e	-8 e	25 e	71.8	141.5	5
C_9H_{18}	1,1,2-Trimethylcyclohexane			-12 e	23 e	71.5	145.5	5
C_9H_{18}	1,1,3-Trimethylcyclohexane	-60 e	-41 e	-16 e	18 e	65.2	136.1	5
C_9H_{18}	1′,2a,4a-1,2,4-Trimethylcyclohexane	-71 e	-50 e	-22 e	15 e	65.7	140.7	5
C_9H_{18}	1′,3′,5′-1,3,5-Trimethylcyclohexane	-72 e	-50 e	-22 e	14 e	65.1	140.0	5
C_9H_{18}	Isobutylcyclopentane	-105 e	-88 e	-64 e	-28 e	31 e	147.0	5
C_9H_{18}	*cis*-1-Methyl-2-propylcyclopentane	-52 e	-33 e	-7 e	28 e	77 e	152.0	5
C_9H_{18}	*trans*-1-Methyl-2-propylcyclopentane	-56 e	-36 e	-11 e	23 e	72 e	145.8	5
C_9H_{18}	1,1,3,3-Tetramethylcyclopentane	-72 e	-54 e	-30 e	2 e	47 e	117.4	5
$C_9H_{18}O$	Nonanal		-3 e	27.4	65.5	115.6	184.6	5
$C_9H_{18}O$	2-Nonanone		8 e	35 e	71 e	121.0	194.0	5
$C_9H_{18}O$	5-Nonanone			-1 e	39.1	94 e	188 e	5
$C_9H_{18}O$	2,6-Dimethyl-4-heptanone	-32 e	-12 e	14 e	48 e	96.2	167.7	5
$C_9H_{18}O_2$	Nonanoic acid	48 e	69 e	97 e	133 e	182.7	255.1	5
$C_9H_{18}O_2$	Heptyl acetate	-16 e	6 e	34 e	70 e	119.9	191.9	5
$C_9H_{18}O_2$	Isopentyl butanoate				55 e	105.6	178.4	5
$C_9H_{18}O_2$	Isobutyl 3-methylbutanoate			11.3	48.3	97.9	168.3	5
$C_9H_{18}O_2$	Propyl hexanoate	-26 e	-2 e	28 e	65.1	113.4	178 e	5
$C_9H_{18}O_2$	Methyl octanoate	-26 e	-9 e	13 e	40 e	76 e	127.9	5

Mol. Form.	Name	Temperature in °C for the indicated pressure 1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
$C_9H_{19}Cl$	1-Chlorononane	-11 e	11 e	39 e	76 e	127.8	204.7	5
C_9H_{20}	Nonane	-46.8	-26.0	0.0	34.0	80.8	150.3	16
C_9H_{20}	2-Methyloctane	-49 e	-30 e	-5 e	28 e	73.9	142.8	5
C_9H_{20}	3-Methyloctane	-49 e	-29 e	-5 e	29 e	74.7	143.7	5
C_9H_{20}	4-Methyloctane	-50 e	-30 e	-6 e	27 e	73.2	141.9	5
C_9H_{20}	2,2-Dimethylheptane	-58 e	-39 e	-15 e	18 e	63.6	132.3	5
C_9H_{20}	2,3-Dimethylheptane	-53 e	-33 e	-9 e	25 e	70.8	140.0	5
C_9H_{20}	2,6-Dimethylheptane	-55 e	-36 e	-12 e	21 e	66.4	134.7	5
C_9H_{20}	3-Ethyl-4-methylhexane			-9 e	24 e	70.6	139.9	5
C_9H_{20}	2,2,4-Trimethylhexane	-66.1	-46.4	-21.3	11.8	57.7	126.0	5
C_9H_{20}	2,2,5-Trimethylhexane	-65.1	-45.8	-21.2	11.2	56.2	123.7	1,5
C_9H_{20}	2,3,3-Trimethylhexane	-58 e	-38 e	-13 e	20 e	66.7	137.2	5
C_9H_{20}	2,3,5-Trimethylhexane	-60 e	-41 e	-16 e	17 e	62.3	130.9	5
C_9H_{20}	2,4,4-Trimethylhexane	-62 e	-43 e	-18 e	15 e	61.0	130.2	5
C_9H_{20}	3,3,4-Trimethylhexane	-53 e	-33 e	-7 e	28 e	76.3	148.9	5
C_9H_{20}	3,3-Diethylpentane			-9 e	26 e	73.7	145.7	1
C_9H_{20}	3-Ethyl-2,4-dimethylpentane	-58 e	-38 e	-13 e	20 e	66.7	136.2	5
C_9H_{20}	2,2,3,3-Tetramethylpentane				21 e	68.5	139.8	1
C_9H_{20}	2,2,3,4-Tetramethylpentane	-61 e	-42 e	-17 e	16 e	62.5	132.6	1
C_9H_{20}	2,2,4,4-Tetramethylpentane		-49 e	-25 e	8 e	53.2	121.8	1
C_9H_{20}	2,3,3,4-Tetramethylpentane	-57 e	-37 e	-12 e	22 e	69.7	141.1	1
$C_9H_{20}O$	1-Nonanol		40 e	64 e	96.9	141.0	213.0	5,39
$C_9H_{20}O$	3-Nonanol		24 e	47 e	78 e	123.0	194.2	5
$C_9H_{20}O$	4-Nonanol			45 e	76.4	121.3	192.0	5
$C_9H_{20}O$	5-Nonanol	13 e	31 e	54 e	84.5	128.1	194.7	5
$C_9H_{20}O$	2,2,4,4-Tetramethyl-3-pentanol				58	100	167	5
$C_9H_{20}S$	1-Nonanethiol	-2 e	21 e	49 e	87 e	140.4	219.2	5
$C_9H_{21}BO_3$	Triisopropyl borate					73.1	139.0	5
$C_9H_{21}N$	Nonylamine		9 e	37 e	75 e	126.2	202.1	5
$C_9H_{21}N$	Tripropylamine	-39 e	-18 e	8 e	42 e	88.2	156.0	5
$C_{10}F_8$	Perfluoronaphthalene	5.2 s	25.1 s	48.1 s				5
$C_{10}F_{22}$	Perfluorodecane					52 e	132.9	5
$C_{10}H_7Br$	1-Bromonaphthalene	17 e	45 e	80.3	126.7	189.8	280.5	5
$C_{10}H_7Cl$	1-Chloronaphthalene	14 e	39 e	70.5	112.8	171.6	258.6	5
$C_{10}H_8$	Naphthalene**	3.2 s	24.1 s	49.3 s	80.7	135.6	217.5	1,5
$C_{10}H_8$	Azulene	24.1 s	46 s	71.5 s	103.3	162.6	244.0	5
$C_{10}H_8O$	1-Naphthol				137.2	196.7	281.8	5
$C_{10}H_8O$	2-Naphthol				140.7	200.5	286.8	5
$C_{10}H_9N$	1-Naphthalenamine		62 e	99.0	146.9	210.7	300.1	5
$C_{10}H_9N$	2-Naphthalenamine	36.3 s	65.9 s	103 s	150.9	215.1	305.5	5
$C_{10}H_9N$	2-Methylquinoline	5.3	31.9	63.8	102.9	165.8	247.2	5
$C_{10}H_9N$	4-Methylquinoline	29 e	54 e	85 e	127 e	183.0	265.1	5
$C_{10}H_9N$	6-Methylquinoline	27 e	51 e	81 e	122 e	179.2	264.5	5
$C_{10}H_9N$	8-Methylquinoline	15 e	40 e	70 e	111 e	166.1	247.3	5
$C_{10}H_{10}$	*m*-Divinylbenzene	-29 e	-4 e	27.1	67.6	122.1	199 e	5
$C_{10}H_{10}O_4$	Dimethyl phthalate	27 e	56 e	92.7	137.8	195.8	272.7	5
$C_{10}H_{10}O_4$	Dimethyl isophthalate			85 e	129.5	189.2	273 e	5
$C_{10}H_{10}O_4$	Dimethyl terephthalate	56.6 s	79.4 s	106.1 s	137.9 s	197.9	282 e	5
$C_{10}H_{12}$	1,2,3,4-Tetrahydronaphthalene	-21 e	3 e	33.2	74.1	127.4	207.8	5
$C_{10}H_{12}$	2-Ethylstyrene	-31 e	-8 e	21 e	60 e	111.7	187 e	5
$C_{10}H_{12}$	3-Ethylstyrene	-28 e	-5.3	24.1	62.6	116 e	193 e	5
$C_{10}H_{12}$	4-Ethylstyrene	-31 e	-8.2	21.3	60.5	115 e	196 e	5
$C_{10}H_{12}O$	Estragole			48.5	88.0	140.7	214.6	5
$C_{10}H_{12}O$	4-Isopropylbenzaldehyde			54.1	96.0	152.2	231.5	5
$C_{10}H_{12}O_2$	4-Allyl-2-methoxyphenol	9 e	37 e	72 e	115.9	173.8	252.9	5
$C_{10}H_{12}O_2$	2-Phenylethyl acetate	-4 e	22 e	54 e	96 e	152.3	232.0	5
$C_{10}H_{12}O_2$	Propyl benzoate	-8 e	18 e	50.2	92.3	149.2	230.5	5
$C_{10}H_{12}O_2$	Ethyl phenylacetate	-9 e	19 e	52 e	95 e	150.2	225 e	5
$C_{10}H_{12}O_2$	Isoeugenol				125 e	185.3	267.1	5
$C_{10}H_{14}$	Butylbenzene	-28 e	-7 e	21 e	56.9	107.6	182.8	1,5
$C_{10}H_{14}$	*sec*-Butylbenzene	-35 e	-14 e	13 e	48 e	98.3	172.8	5
$C_{10}H_{14}$	*tert*-Butylbenzene	-37 e	-16 e	10 e	46 e	94.9	168.6	5
$C_{10}H_{14}$	Isobutylbenzene	-36 e	-15 e	12 e	47.9	97.8	172.3	5
$C_{10}H_{14}$	*o*-Cymene	-39 e	-16 e	13 e	51 e	103.1	177.8	5
$C_{10}H_{14}$	*m*-Cymene	-34 e	-13 e	14 e	50 e	99.9	174.6	5
$C_{10}H_{14}$	*p*-Cymene	-33 e	-12 e	16 e	52 e	102.2	176.6	5
$C_{10}H_{14}$	*o*-Diethylbenzene	-28 e	-6 e	21 e	58 e	107.9	182.9	5

Mol. Form.	Name	Temperature in °C for the indicated pressure 1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
$C_{10}H_{14}$	*m*-Diethylbenzene	-28 e	-7 e	20 e	56 e	106.2	180.6	5
$C_{10}H_{14}$	*p*-Diethylbenzene	-28 e	-6 e	21 e	57 e	108.1	183.3	5
$C_{10}H_{14}$	3-Ethyl-1,2-dimethylbenzene	-22 e	0 e	28 e	66 e	117.2	193.4	5
$C_{10}H_{14}$	4-Ethyl-1,2-dimethylbenzene	-24 e	-2 e	26 e	63 e	113.6	189.2	5
$C_{10}H_{14}$	2-Ethyl-1,3-dimethylbenzene		-2 e	26 e	63 e	113.7	189.5	5
$C_{10}H_{14}$	2-Ethyl-1,4-dimethylbenzene	-27 e	-5 e	23 e	60 e	110.6	186.4	5
$C_{10}H_{14}$	1-Ethyl-2,4-dimethylbenzene	-25 e	-4 e	24 e	61 e	112.2	187.9	5
$C_{10}H_{14}$	1-Ethyl-3,5-dimethylbenzene	-28 e	-6 e	21 e	58 e	108.3	183.2	5
$C_{10}H_{14}$	1-Methyl-2-propylbenzene	-27 e	-6 e	22 e	58.2	108.9	184.3	5
$C_{10}H_{14}$	1-Methyl-3-propylbenzene	-29 e	-8 e	20 e	56.1	106.5	181.3	5
$C_{10}H_{14}$	1-Methyl-4-propylbenzene	-29 e	-7 e	20 e	56.6	107.4	182.8	5
$C_{10}H_{14}$	1,2,3,4-Tetramethylbenzene		7 e	36 e	74 e	126.6	204.5	5
$C_{10}H_{14}$	1,2,3,5-Tetramethylbenzene	-19 e	3 e	32 e	69 e	120.9	197.5	5
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene					119.9	196.3	5
$C_{10}H_{14}O$	2-Butylphenol	7 e	31 e	61 e	101 e	155.2	234.4	5
$C_{10}H_{14}O$	Butyl phenyl ether	-16 e	8 e	38 e	77 e	131.3	209.7	5
$C_{10}H_{14}O$	Thymol	18.9 s	37.9 s	59.5	101.2	155.0	230.4	5
$C_{10}H_{15}N$	2-Methyl-5-isopropylaniline	19 e	43 e	72 e	107.4	150 e	204 e	5
$C_{10}H_{15}N$	*N*-Butylaniline	11 e	35 e	66 e	106 e	160.9	241.0	5
$C_{10}H_{15}N$	*N,N*-Diethylaniline	-11 e	14 e	44.3	84.2	138.4	216.3	5
$C_{10}H_{16}$	Dipentene	-42 e	-19 e	10.6	48.7	100.2	173.9	5
$C_{10}H_{16}$	*d*-Limonene	-45 e	-21 e	9.1	48.0	100.4	174.5	5
$C_{10}H_{16}$	*l*-Limonene	-33 e	-12 e	16 e	52.0	102.3	177.0	21
$C_{10}H_{16}$	β-Myrcene			9.4	47.3	98.3	171.0	5
$C_{10}H_{16}$	α-Pinene	-48 e	-27 e	-1 e	33.6	82.2	155.1	21
$C_{10}H_{16}$	β-Pinene	-43 e	-22 e	5.0	40.6	90.5	165.5	21
$C_{10}H_{16}$	Camphene					90.7	160.1	4
$C_{10}H_{16}$	Terpinolene			26.5	64.9	115.4	184.6	5
$C_{10}H_{16}$	β-Phellandrene			16 e	53.2	104 e	171.0	5
$C_{10}H_{16}O$	(+)-Camphor	-15.8 s	10 s	41.5 s	80.8 s	131.4 s	207.6	5
$C_{10}H_{16}O$	Pulegone	37 e	49.1	66.4	92.2	135.1	220.2	5
$C_{10}H_{18}$	1-Decyne	-34 e	-13 e	14 e	51 e	100.3	173.5	5
$C_{10}H_{18}$	*cis*-Decahydronaphthalene	-26 e	-4 e	24 e	62.4	115.5	195.3	1
$C_{10}H_{18}$	*trans*-Decahydronaphthalene		-10 e	18 e	55.3	107.9	186.8	1
$C_{10}H_{18}O$	α-Terpineol			48	89	142	217	4
$C_{10}H_{18}O$	Eucalyptol			10.6	48.5	100.3	175.4	5
$C_{10}H_{18}O$	*trans*-Geraniol	4 e	31 e	63.2	104.3	157.7	229.6	5
$C_{10}H_{18}O_4$	Sebacic acid	125.9 s						5
$C_{10}H_{18}O_4$	Dipropyl succinate	11 e	38 e	72.1	115.4	172.3	250.4	5
$C_{10}H_{18}O_4$	Diethyl adipate	4 e	35 e	72 e	116.6	171.2	239.5	5
$C_{10}H_{19}N$	Decanenitrile	13 e	36 e	66 e	105.8	160.6	241.6	5
$C_{10}H_{20}$	1-Decene	-35.5	-13.7	13.7	49.0	97.9	170.1	1,5
$C_{10}H_{20}$	Cyclodecane			29 e	68 e	121.3	201.8	1
$C_{10}H_{20}$	Butylcyclohexane	-31 e	-9 e	18 e	54 e	104.7	180.4	5
$C_{10}H_{20}$	Isobutylcyclohexane	-37 e	-16 e	10 e	46 e	95.9	170.8	5
$C_{10}H_{20}$	*tert*-Butylcyclohexane	-39 e	-18 e	9 e	45 e	95.3	171.1	5
$C_{10}H_{20}O$	Decanal		16 e	47.2	86.3	137.7	208.0	5
$C_{10}H_{20}O_2$	Decanoic acid	58 e	80 e	108 e	145 e	195.2	269.5	5
$C_{10}H_{20}O_2$	Octyl acetate	-26 e	-3 e	27 e	66.3	120.0	198.2	5
$C_{10}H_{20}O_2$	2-Ethylhexyl acetate	-11 e	5 e	26 e	57.6	107.1	197.2	5
$C_{10}H_{20}O_2$	Isopentyl isopentanoate			22 e	62.8	116.9	193.6	5
$C_{10}H_{20}O_2$	Ethyl octanoate	-17 e	9 e	41 e	81.4	133.2	203 e	5
$C_{10}H_{20}O_4$	Diethylene glycol monobutyl ether acetate	6 e	34 e	69 e	112.6	169.2	245.4	5
$C_{10}H_{21}Br$	1-Bromodecane	9 e	33 e	63 e	104 e	159.2	240.0	5
$C_{10}H_{21}Cl$	1-Chlorodecane	2 e	25 e	54 e	92 e	145.7	225.3	5
$C_{10}H_{21}F$	1-Fluorodecane	-22 e	0 e	27 e	64 e	113.3	185.7	5
$C_{10}H_{22}$	Decane		-10.6	16.7	52.3	101.1	173.7	16
$C_{10}H_{22}$	2-Methylnonane	-34 e	-14 e	12 e	47 e	94.8	166.5	5
$C_{10}H_{22}$	3-Methylnonane	-34 e	-14 e	12 e	47 e	95.1	167.3	5
$C_{10}H_{22}$	4-Methylnonane	-36 e	-16 e	10 e	45 e	93.1	165.2	5
$C_{10}H_{22}$	5-Methylnonane	-36 e	-16 e	10 e	45 e	92.6	164.6	5
$C_{10}H_{22}$	2,4-Dimethyloctane				38 e	84.9	155.4	5
$C_{10}H_{22}$	2,7-Dimethyloctane	-39 e	-19 e	7 e	41 e	88.4	159.4	5
$C_{10}H_{22}$	2,2,6-Trimethylheptane	-46 e	-27 e	-2 e	32 e	78.5	148.4	5
$C_{10}H_{22}$	3,3,5-Trimethylheptane			0 e	35 e	82.7	155.2	5
$C_{10}H_{22}$	2,2,3,3-Tetramethylhexane	-46 e	-25 e	1 e	36 e	85.6	159.8	5

Mol. Form.	Name	1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
		Temperature in °C for the indicated pressure						
$C_{10}H_{22}$	2,2,5,5-Tetramethylhexane			-10 e	22 e	68.3	137.0	5
$C_{10}H_{22}$	2,4-Dimethyl-3-isopropylpentane	-46 e	-26 e	0 e	35 e	83.2	156.5	5
$C_{10}H_{22}$	2,2,3,3,4-Pentamethylpentane		-24 e	3 e	39 e	89.1	165.5	5
$C_{10}H_{22}$	2,2,3,4,4-Pentamethylpentane		-29 e	-3 e	33 e	82.8	158.7	5
$C_{10}H_{22}O$	1-Decanol	30 e	50 e	75 e	109 e	157.3	230.6	1,39
$C_{10}H_{22}O$	4-Decanol	18 e	37 e	61 e	93 e	139 e	210 e	5
$C_{10}H_{22}O$	Dipentyl ether	-31 e	-8 e	22 e	60 e	111.6	186.2	5
$C_{10}H_{22}O$	Diisopentyl ether			14.0	51.5	101.8	172.8	5
$C_{10}H_{22}O_2$	Ethylene glycol dibutyl ether	0 e	20 e	44 e	78.4	127.1	202.9	5
$C_{10}H_{22}O_5$	Tetraethylene glycol dimethyl ether				138 e	200.9	275.3	5
$C_{10}H_{22}S$	1-Decanethiol	11 e	34 e	64 e	103 e	157.5	238.6	5
$C_{10}H_{22}S$	Diisopentylsulfide			7 e	82 e	118 e	139 e	5
$C_{10}H_{23}N$	Dipentylamine				77 e	127.7	202.0	5
$C_{10}H_{30}O_3Si_4$	Decamethyltetrasiloxane	-31 e	-6 e	26 e	66.8	118.8	193.9	5
$C_{10}H_{30}O_5Si_5$	Decamethylcyclopentasiloxane	-2 e	19 e	46 e	82 e	132.9	210.4	5
$C_{11}H_8O_2$	1-Naphthalenecarboxylic acid				191.9	239.3	299.6	5
$C_{11}H_8O_2$	2-Naphthalenecarboxylic acid				197.9	246.0	308.1	5
$C_{11}H_{10}$	1-Methylnaphthalene	5 e	29 e	60 e	102 e	159.1	244.1	1
$C_{11}H_{10}$	2-Methylnaphthalene			57 e	99 e	156.0	240.5	1
$C_{11}H_{12}O_2$	Ethyl *trans*-cinnamate			79	125	187	271	4
$C_{11}H_{12}O_3$	Myristicin	23 e	53 e	88.9	135.2	196.0	279.4	5
$C_{11}H_{14}$	4-Isopropylstyrene	-25 e	-1 e	30.2	70.3	124.5	202.1	5
$C_{11}H_{14}$	1,2,3,4-Tetrahydro-5-methylnaphthalene	9 e	31 e	60 e	99 e	153.1	233.8	5
$C_{11}H_{14}$	1,2,3,4-Tetrahydro-6-methylnaphthalene	17 e	36 e	62 e	97 e	147.8	228.5	5
$C_{11}H_{14}O_2$	Butyl benzoate	6 e	34 e	67.9	110.3	165 e	237 e	5
$C_{11}H_{16}$	Pentylbenzene	-14 e	8 e	37 e	74 e	126.7	204.9	5
$C_{11}H_{16}$	*p-tert*-Butyltoluene	-24 e	-2 e	27 e	64.1	115.5	190.8	5
$C_{11}H_{16}$	1,3-Diethyl-5-methylbenzene	-26 e	-1 e	29.5	69.5	123.5	200.2	5
$C_{11}H_{16}$	2-Ethyl-1,3,5-trimethylbenzene		6 e	36 e	75.7	129.6	207.6	5
$C_{11}H_{16}$	1-Ethyl-2,4,5-trimethylbenzene	-13 e	11 e	40 e	79.4	132.1	207.7	5
$C_{11}H_{20}$	1-Undecyne	-22 e	0 e	29 e	67 e	118.5	194.5	5
$C_{11}H_{20}$	2-Undecyne	-17 e	6 e	35 e	74 e	127.4	205.4	5
$C_{11}H_{20}O_2$	10-Undecenoic acid	35 e	67 e	105 e	150.0	205.4	274.5	5
$C_{11}H_{20}O_4$	Ethyl diethylmalonate			74 e	105 e	149.4	219 e	5
$C_{11}H_{21}N$	Undecanenitrile			78.6	120.3	177.3	259.9	5
$C_{11}H_{22}$	1-Undecene	-21.6	1.2	29.7	66.4	117.1	192.2	5
$C_{11}H_{22}$	*cis*-2-Undecene	-14 e	7 e	34 e	70.2	120.6	196 e	5
$C_{11}H_{22}$	*trans*-2-Undecene	-14 e	7 e	33 e	69.3	119.6	195 e	5
$C_{11}H_{22}$	*cis*-4-Undecene	-19 e	3 e	30 e	66.6	117.1	192 e	5
$C_{11}H_{22}$	*trans*-4-Undecene	-17 e	4 e	31 e	67.1	117.4	193 e	5
$C_{11}H_{22}$	*cis*-5-Undecene	-19 e	2 e	30 e	66.2	116.7	191 e	5
$C_{11}H_{22}$	*trans*-5-Undecene	-18 e	3 e	31 e	67.0	117.4	192 e	5
$C_{11}H_{22}$	Pentylcyclohexane	-17 e	6 e	34 e	72 e	124.2	202.7	5
$C_{11}H_{22}$	Hexylcyclopentane	-15 e	7 e	36 e	73 e	125.0	202.5	5
$C_{11}H_{22}O$	2-Undecanone	17 e	37 e	64.3	103.0	153.6	232.6	1,5
$C_{11}H_{22}O$	6-Undecanone		28 e	57 e	95 e	148.4	226.9	1
$C_{11}H_{22}O_2$	Undecanoic acid	68 e	90 e	118 e	156 e	207.2	283.6	5
$C_{11}H_{22}O_2$	Heptyl butanoate	2 e	29 e	62 e	102.6	155.1	224.7	5
$C_{11}H_{22}O_2$	Propyl octanoate	-2 e	23 e	55 e	94.0	145.2	215 e	5
$C_{11}H_{22}O_2$	Methyl decanoate	10 e	33 e	62 e	100.9	154.0	232 e	5
$C_{11}H_{24}$	Undecane	-18.4	4.3	32.6	69.5	120.2	195.4	16
$C_{11}H_{24}$	2-Methyldecane	-20 e	1 e	28 e	64 e	114.0	188.7	5
$C_{11}H_{24}$	3-Methyldecane	-35 e	-10 e	22 e	61.9	115.6	190.4	5
$C_{11}H_{24}$	4-Methyldecane	-38 e	-12 e	20 e	60.8	113.9	186.4	5
$C_{11}H_{24}$	2,4,7-Trimethyloctane				43 e	94 e	170.4	5
$C_{11}H_{24}O$	1-Undecanol	52.2	80.0	82 e	118 e	167.6	244.1	5
$C_{11}H_{24}S$	1-Undecanethiol	23 e	47 e	77 e	118 e	173.6	256.8	5
$C_{12}F_{27}N$	Trinonafluorobutylamine		3 e	29.0	63.3	109.9	176.8	5
$C_{12}H_8$	Acenaphthylene	24 s	49.8 s	80.6 s				5
$C_{12}H_9N$	Carbazole					254.7	354.0	5
$C_{12}H_{10}$	Acenaphthene				126.2	187 e	276 e	1
$C_{12}H_{10}$	Biphenyl			69.0	111.1	169.5	254.7	1
$C_{12}H_{10}N_2$	Azobenzene			98.1	144.8	206.7	292.7	4
$C_{12}H_{10}O$	Diphenyl ether		44 e	75 e	116 e	173 e	257.4	5

Mol. Form.	Name	Temperature in °C for the indicated pressure 1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	Ref.
$C_{12}H_{10}O$	1-Acetonaphthone	37 e	69 e	107.0	154.6	215.2	294.9	5
$C_{12}H_{10}O$	2-Acetonaphthone	48.3 s		118.7	163.0	221.1	300.3	5
$C_{12}H_{10}S$	Diphenyl sulfide	20 e	51 e	88.7	137.5	202.2	291.8	5
$C_{12}H_{11}N$	Diphenylamine	48 s		102.8	150.5	213.7	301.4	5
$C_{12}H_{12}$	1-Ethylnaphthalene	16 e	41 e	72 e	114 e	171.8	257.7	5
$C_{12}H_{12}$	2-Ethylnaphthalene	14 e	39 e	71 e	113 e	171.2	257.3	5
$C_{12}H_{12}$	1,2-Dimethylnaphthalene	26 e	51 e	82 e	123 e	180.5	265.7	5
$C_{12}H_{12}$	2,7-Dimethylnaphthalene	31.5 s	53.1 s	78.8 s	115.9	175 e	260 e	5
$C_{12}H_{14}O_4$	Diethyl phthalate	12 e	51 e	96 e	150.5	215.9	296.2	5
$C_{12}H_{16}$	*p*-Isopropenylisopropylbenzene	-11 e	15 e	46 e	87 e	142.4	221 e	5
$C_{12}H_{16}$	Cyclohexylbenzene		28 e	58 e	98 e	154.7	239.5	5
$C_{12}H_{16}O_2$	3-Methylbutyl benzoate			66 e	115.0	177.7	261.4	5
$C_{12}H_{18}$	Hexylbenzene	-2 e	22 e	51 e	90 e	144.5	225.5	5
$C_{12}H_{18}$	1,2-Diisopropylbenzene	-14 e	9 e	37 e	74 e	125.9	203.2	5
$C_{12}H_{18}$	1,3-Diisopropylbenzene	-14 e	8 e	36 e	74 e	125.5	202.6	5
$C_{12}H_{18}$	1,4-Diisopropylbenzene	-6 e	18 e	49 e	90 e	148.8	238 e	5
$C_{12}H_{18}$	Hexamethylbenzene	46.3 s	72.5 s	81.7 s	121.8 s	178.3	263.7	5
$C_{12}H_{18}$	1,5,9-Cyclododecatriene	-14 e	11 e	44 e	87 e	145.0	229.8	5
$C_{12}H_{20}O_2$	Geranyl acetate			67.7	110.8	166.9	242.9	5
$C_{12}H_{20}O_4$	Dibutyl maleate	12.3	50.4	94.0	144.2	203 e	272 e	5
$C_{12}H_{22}$	1-Dodecyne	-11 e	13 e	43 e	82 e	135.8	214.4	5
$C_{12}H_{22}$	Cyclohexylcyclohexane		20 e	53.1	96.0	154.1	237.2	5
$C_{12}H_{22}O_2$	Methyl 10-undecenoate	10 e	38 e	73 e	116 e	172.2	247.1	5
$C_{12}H_{22}O_4$	Dimethyl sebacate		53 e	97	150	214	293	4
$C_{12}H_{23}N$	Dodecanenitrile	36 e	60 e	92 e	133 e	190.5	275.5	5
$C_{12}H_{24}$	1-Dodecene	-8.3	15.2	44.8	82.9	135.4	212.8	5
$C_{12}H_{24}$	Hexylcyclohexane	-3 e	20 e	50 e	89 e	143.1	224.2	5
$C_{12}H_{24}$	Heptylcyclopentane	-1 e	22 e	51 e	90 e	143.5	223.5	5
$C_{12}H_{24}O$	Dodecanal			70 e	116.2	175.9	256.6	5
$C_{12}H_{24}O_2$	Dodecanoic acid	78 e	100 e	128 e	166 e	219.1	298.1	5
$C_{12}H_{24}O_2$	Decyl acetate	12 e	40 e	74 e	115.1	168.1	238 e	5
$C_{12}H_{24}O_2$	Ethyl decanoate	8 e	35 e	69 e	111.8	166.1	238 e	5
$C_{12}H_{25}Br$	1-Bromododecane	31 e	57 e	90 e	132 e	190.8	275.3	5
$C_{12}H_{25}Cl$	1-Chlorododecane	27 e	51 e	81 e	122 e	178.7	262.6	5
$C_{12}H_{26}$	Dodecane	-5.4	18.2	47.6	85.8	138.2	215.8	16
$C_{12}H_{26}O$	1-Dodecanol				133 e	185.0	264.1	1
$C_{12}H_{26}O_3$	Diethylene glycol dibutyl ether	5 e	34.4	70.2	115.3	174.1	253.8	5
$C_{12}H_{27}N$	Tributylamine	-26 e	1 e	35 e	77.7	134.5	213.4	5
$C_{12}H_{27}N$	Triisobutylamine		1 e	28.9	64.9	112.5	178.5	5
$C_{12}H_{27}O_4P$	Tributyl phosphate					205 e	288.3	5
$C_{12}H_{36}O_6Si_6$	Dodecamethylcyclohexasiloxane	18 e	41 e	69 e	108 e	162.2	244.7	5
$C_{13}H_9N$	Acridine			124.4	176.2	246.0	345.4	5
$C_{13}H_9N$	Phenanthridine	79 s						5
$C_{13}H_{10}$	Fluorene	48.4 s			137.4	205.4	295 e	5
$C_{13}H_{10}O_2$	Phenyl benzoate			102.3	151.4	217.9	313.3	5
$C_{13}H_{10}O_3$	Phenyl salicylate				166.0	224.8	312.4	5
$C_{13}H_{12}$	Diphenylmethane		45 e	77 e	119.3	177.7	263.6	1,5
$C_{13}H_{13}N$	Methyldiphenylamine	35 e	63 e	98.4	143.1	201.6	281.6	5
$C_{13}H_{14}$	1-Isopropylnaphthalene	27 e	51 e	82 e	123.2	180.8	267.3	5
$C_{13}H_{20}$	Heptylbenzene	12 e	36 e	66 e	107 e	162.7	246.2	5
$C_{13}H_{24}O_2$	Ethyl 10-undecenoate	32 e	55 e	86 e	125.2	179.5	258.4	5
$C_{13}H_{26}$	1-Tridecene	4.1	28.5	59.0	98.3	152.5	232.3	5
$C_{13}H_{26}$	Heptylcyclohexane	11 e	34 e	65 e	105 e	160.9	244.3	5
$C_{13}H_{26}$	Octylcyclopentane	13 e	36 e	66 e	106 e	160.9	243.1	5
$C_{13}H_{26}O_2$	Tridecanoic acid	87 e	109 e	138 e	176 e	230.3	311.5	5
$C_{13}H_{26}O_2$	Methyl dodecanoate	38 e	61 e	90 e	130 e	184.9	269 e	5
$C_{13}H_{28}$	Tridecane	7.2	31.5	61.8	101.1	155.1	234.9	16
$C_{13}H_{28}O$	1-Tridecanol	71.6	101.0	103 e	140 e	192.3	273.1	5
$C_{14}H_{10}$	Anthracene	89.2 s	125.9 s	151.5 s	165 s	238.8	340.2	1,5
$C_{14}H_{10}$	Phenanthrene	53 s	83 s	120.8	170.4	238.4	337.7	5
$C_{14}H_{10}O_2$	Benzil			123	175	246	346	4
$C_{14}H_{12}$	*cis*-Stilbene	26 e	54 e	88 e	130.4	183 e	253 e	5
$C_{14}H_{12}$	*trans*-Stilbene				155.6	218.1	305.8	5
$C_{14}H_{12}O_2$	Benzoin				181	248	342	4
$C_{14}H_{14}$	1,1-Diphenylethane	19 e	47 e	82.0	125.3	181 e	254 e	5
$C_{14}H_{15}N$	Dibenzylamine	48 e	77 e	113.1	158.9	218.5	299.4	5
$C_{14}H_{16}$	1-Butylnaphthalene	67 e	82 e	103 e	135 e	186.7	288.6	5

Mol. Form.	Name	Temperature in °C for the indicated pressure						Ref.
		1 Pa	10 Pa	100 Pa	1 kPa	10 kPa	100 kPa	
$C_{14}H_{16}$	2-Butylnaphthalene	44 e	67 e	98 e	139 e	197.5	287.4	5
$C_{14}H_{22}$	Octylbenzene	20.1	46.2	79.1	121.9	178.1	263.8	5
$C_{14}H_{26}O_4$	Diethyl sebacate		83 e	120	166	225	305	4
$C_{14}H_{27}N$	Tetradecanenitrile	52 e	79 e	114.0	159.0	219.7	306.3	5
$C_{14}H_{28}$	1-Tetradecene	16.1	41.3	72.7	113.2	168.7	250.6	5
$C_{14}H_{28}$	Octylcyclohexane	16.9	44.3	77.8	120.0	177.6	263.2	5
$C_{14}H_{28}$	Nonylcyclopentane	25 e	49 e	80 e	120 e	177.2	261.5	5
$C_{14}H_{28}O_2$	Tetradecanoic acid	96 e	118 e	147 e	186 e	241.3	325.6	5
$C_{14}H_{30}$	Tetradecane	19.1	44.1	75.3	115.7	171.1	253.0	16
$C_{14}H_{30}O$	1-Tetradecanol	80.0	110.5	149.6	152 e	205.3	286.7	5
$C_{14}H_{31}N$	Tetradecylamine			104 e	147 e	206.1	290.9	5
$C_{14}H_{42}O_5Si_6$	Tetradecamethylhexasiloxane	6 e	36 e	72 e	117 e	176.0	259.1	5
$C_{15}H_{18}$	1-Pentylnaphthalene	34 e	62 e	96 e	141.3	202.2	289 e	5
$C_{15}H_{24}$	Nonylbenzene	33.0	58.9	92.0	135.4	193.7	281.4	5
$C_{15}H_{30}$	Nonylcyclohexane	35 e	60 e	92 e	134 e	193.4	280.9	5
$C_{15}H_{30}$	Decylcyclopentane	37 e	61 e	93 e	134 e	192.5	278.8	5
$C_{15}H_{30}O_2$	Methyl tetradecanoate		75 e	110	155	214	295	4
$C_{15}H_{32}$	Pentadecane	30.5	56.1	88.1	129.6	186.3	270.1	16
$C_{16}H_{22}O_4$	Dibutyl phthalate		104.0	142.7	191.5	254.5	339.4	4
$C_{16}H_{32}$	1-Hexadecene	38.4	65.0	98.1	140.5	198.8	284.3	5
$C_{16}H_{32}O_2$	Hexadecanoic acid		136 e	165 e	205 e	261.9	350.2	5
$C_{16}H_{34}$	Hexadecane	41.1	67.4	100.3	142.7	200.7	286.3	16
$C_{16}H_{34}O$	1-Hexadecanol	99.5	130.6	171.9	175 e	229.0	311.7	5
$C_{16}H_{35}N$	Hexadecylamine	63 e	91 e	126 e	171 e	232.6	320.5	5
$C_{17}H_{10}O$	Benzanthrone		184 e	229.3	290.3	377.2	511 e	5
$C_{17}H_{34}O_2$	Methyl hexadecanoate	65 e	93	129	177			4
$C_{17}H_{36}$	Heptadecane	51.5	78.5	112.0	155.3	214.5	302 e	16
$C_{17}H_{36}O$	1-Heptadecanol	94 e	117 e	146 e	185 e	240.1	323.3	5
$C_{18}H_{14}$	*o*-Terphenyl	66 e	94 e	129 e	176 e	241.3	336.3	5
$C_{18}H_{14}$	*m*-Terphenyl	87 e	118 e	156 e	206.6	275.3	374.6	5
$C_{18}H_{14}$	*p*-Terphenyl	127.1 s	154.7 s		217.2	284.0	383.0	5
$C_{18}H_{30}$	Hexaethylbenzene				144.1	206.8	297.5	5
$C_{18}H_{34}O_2$	Oleic acid	94 e	126 e	165.5	214.5	277.0	359.7	5
$C_{18}H_{34}O_2$	Elaidic acid		124 e	166	216	280	361	4
$C_{18}H_{36}O$	Stearaldehyde			142 e	186 e	246.9	336.7	5
$C_{18}H_{36}O_2$	Stearic acid		153 e	183 e	223 e	281.6	374.5	5
$C_{18}H_{38}$	Octadecane	61.5	89.0	123.1	167.3	227.6	316 e	16
$C_{18}H_{38}O$	1-Octadecanol	106 e	130 e	160 e	200.5	257.3	343.0	5
$C_{19}H_{16}$	Triphenylmethane	81 s		112 e	175 e	254.6	360.0	5
$C_{19}H_{36}O_2$	Methyl oleate	85 e	114 e	149.7	195.6	256 e	340 e	5
$C_{19}H_{40}$	Nonadecane	71.1	99.1	133.8	178.8	240.1	330 e	16
$C_{20}H_{42}$	Eicosane	80.4	108.9	144.2	189.8	252.1	344 e	16
$C_{20}H_{42}O$	1-Eicosanol	119 e	143 e	173 e	213 e	270.0	355.1	5
$C_{20}H_{60}O_8Si_9$	Eicosamethylnonasiloxane			141 e	183.1	236.7	307.1	5
$C_{21}H_{21}O_4P$	Tri-*o*-cresyl phosphate	119.0	156.1	201.0	256.3	326.3	418 e	5
$C_{21}H_{21}O_4P$	Tri-*m*-cresyl phosphate	147.8	177.3	211.4	251.3	298 e	355 e	5
$C_{21}H_{21}O_4P$	Tri-*p*-cresyl phosphate	140.6	174 e	214 e	262 e	320 e	392 e	5
$C_{21}H_{44}$	Heneicosane	82.3	113.5	152.2	201.6	263.8	355.9	5
$C_{22}H_{42}O_2$	Brassidic acid	134 e	166 e	203.6	249.8	307.6	382.0	5
$C_{22}H_{42}O_2$	Erucic acid	126 e	160 e	199.4	247.4	306.5	381.1	5
$C_{22}H_{42}O_2$	Butyl oleate	95.5	124.2	158 e	198 e	245 e	304 e	5
$C_{22}H_{44}O_2$	Behenic acid	145.4	176.5	213.7	259.3	316.2	390 e	5
$C_{22}H_{44}O_2$	Butyl stearate	99.6	128 e	162 e	201 e	249 e	307 e	5
$C_{22}H_{46}$	Docosane	83.5	115.0	154.0	203.6	274.8	368.0	5
$C_{23}H_{48}$	Tricosane	102.9	135.1	174.8	221 e	285.3	379.5	5
$C_{24}H_{38}O_4$	Dioctyl phthalate	130 e	163.7	203.8	252 e	311 e	385 e	5
$C_{24}H_{38}O_4$	Bis(2-ethylhexyl) phthalate	122.0	153.2	189.2	231.3	281.1	341.1	5
$C_{24}H_{50}$	Tetracosane	115.0	148.1	188.5	239.1	295.4	390.6	5
$C_{25}H_{52}$	Pentacosane	119.7	152.7	193.2	244.4	305.0	401.1	5
$C_{26}H_{54}$	Hexacosane	125.1	158.8	200.1	252.1	314.3	411.3	5
$C_{27}H_{56}$	Heptacosane	136.7	168.8	206.5	255.8	323.3	421.2	5
$C_{28}H_{58}$	Octacosane	136.5	169.8	210.9	263.1	332.0	430.6	5
$C_{29}H_{60}$	Nonacosane	148.2	182.8	221.2	271.5	340.2	439.7	5
$C_{30}H_{62}$	Squalane	66 e	84 e	105.8	131.9	163.7	203.2	5
C_{70}	Carbon (fullerene-C_{70})	598 s	662 s					22

VAPOR PRESSURE OF FLUIDS AT TEMPERATURES BELOW 300 K

This table gives vapor pressures of 67 important fluids in the temperature range 2 to 300 K. Helium (^4He), hydrogen (H_2), and neon (Ne) are covered on this page. The remaining fluids are listed on subsequent pages by molecular formula in the Hill order (see Introduction). The data have been taken from evaluated sources; references are listed at the end of the table.

Pressures are given in kilopascals (kPa). Note that:

1 kPa = 7.50062 Torr
100 kPa = 1 bar
101.325 kPa = 1 atmos

s following an entry indicates that the compound is solid at that temperature.

Helium		Hydrogen		Neon	
***T*/K**	***P*/kPa**	***T*/K**	***P*/kPa**	***T*/K**	***P*/kPa**
2.2	5.3	14.0	7.90	25.0	51.3
2.3	6.7	14.5	10.38	26.0	71.8
2.4	8.3	15.0	13.43	27.0	98.5
2.5	10.2	15.5	17.12	28.0	132.1
2.6	12.4	16.0	21.53	29.0	173.5
2.7	14.8	16.5	26.74	30.0	223.8
2.8	17.5	17.0	32.84	31.0	284.0
2.9	20.6	17.5	39.92	32.0	355.2
3.0	24.0	18.0	48.08	33.0	438.6
3.1	27.8	18.5	57.39	34.0	535.2
3.2	32.0	19.0	67.96	35.0	646.2
3.3	36.5	19.5	79.89	36.0	772.8
3.4	41.5	20.0	93.26	37.0	916.4
3.5	47.0	20.5	108.2	38.0	1078
3.6	52.9	21.0	124.7	39.0	1260
3.7	59.3	21.5	143.1	40.0	1462
3.8	66.1	22.0	163.2	41.0	1688
3.9	73.5	22.5	185.3	42.0	1939
4.0	81.5	23.0	209.4	43.0	2216
4.1	90.0	23.5	235.7	44.0	2522
4.2	99.0	24.0	264.2		
4.3	108.7	24.5	295.1		
4.4	119.0	25.0	328.5		
4.5	129.9	25.5	364.3		
4.6	141.6	26.0	402.9		
4.7	153.9	26.5	444.3		
4.8	167.0	27.0	488.5		
4.9	180.8	27.5	535.7		
5.0	195.4	28.0	586.1		
5.1	210.9	28.5	639.7		
		29.0	696.7		
		29.5	757.3		
		30.0	821.4		
		30.5	889.5		
		31.0	961.5		
		31.5	1038.0		
		32.0	1119.0		
		32.5	1204.0		
Ref.	17,18		1		13

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VAPOR PRESSURE OF FLUIDS AT TEMPERATURES BELOW 300 K (continued)

T/K	Ar Argon	BCl_3 Boron trichloride	BF_3 Boron trifluoride	BrH Hydrogen bromide	Br_2 Bromine	ClF Chlorine fluoride	ClH Hydrogen chloride
50	0.1 s						
55	0.2 s						
60	0.8 s						
65	2.8 s						
70	7.7 s						
75	18.7 s						
80	40.7 s						
85	79.0						
90	134						
95	213						
100	324						
105	473						
110	666						
115	910					0.1	
120	1214					0.3	0.1 s
125	1584					0.6	0.3 s
130	2027					1.2	0.5 s
135	2553			0.1 s		2.1	1.0 s
140	3170			0.3 s		3.6	1.9 s
145	3892		7.7	0.6 s		6.0	3.4 s
150	4736		13.4	1.1 s		9.5	5.8 s
155			22.3	1.9 s		14.6	9.5 s
160			35.2	3.3 s		21.8	14.7
165			53.7	5.4 s		31.7	22.0
170			79.1	8.7 s		44.8	31.9
175			113	13.4 s		62.0	45.1
180		0.1	157	20.1 s		84.2	62.5
185		0.2	214	29.5 s		112	84.7
190		0.3	285	37.9		147	113
195		0.5	372	51.8		190	148
200		0.8	479	69.5		242	190
205		1.2	608	91.8		304	242
210		1.8	762	119		378	304
215		2.6	944	153		464	377
220		3.8	1160	194	0.1 s	564	463
225		5.2	1413	242	0.2 s	680	563
230		7.2	1709	299	0.3 s	812	678
235		9.7	2056	366	0.4 s	961	811
240		12.9	2460	443	0.7 s	1130	961
245		17.0	2913	532	1.1 s	1319	1132
250		22.0	3481	633	1.7 s	1529	1325
255		28.1	4123	748	2.6 s	1762	1542
260		35.6	4874	878	3.8 s	2019	1784
265		44.5		1023	5.5 s	2301	2054
270		55.1		1185	7.3	2608	2354
275		67.6		1364	9.5	2941	2686
280		82.2		1562	12.3	3303	3053
285		99.1		1780	15.6	3693	3457
290		119		2018	19.7	4111	3901
295		141		2278	24.6	4560	4388
300		166		2561	30.5	5039	4921
Ref.	8,15	12	12	12	12	12	12

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VAPOR PRESSURE OF FLUIDS AT TEMPERATURES BELOW 300 K (continued)

T/K	ClO_2 Chlorine dioxide	Cl_2 Chlorine	Cl_4Si Silicon tetrachloride	FH Hydrogen fluoride	F_2 Fluorine	F_2O Difluorine oxide	F_3N Nitrogen trifluoride
50							
55					0.4		
60					1.5		
65					4.8		
70					12.3		
75					27.6	0.1	
80					55.3	0.2	
85					101	0.5	0.1
90					172	1.2	0.2
95					276	2.6	0.4
100					420	5.3	0.9
105					615	10.1	2.0
110					870	18.0	4.0
115					1196	30.5	7.3
120					1605	49.3	12.8
125					2108	76.7	21.1
130					2721	115	33.5
135					3458	168	51.1
140					4339	237	75.4
145						328	108
150						444	150
155						588	205
160						766	273
165						981	357
170						1238	459
175		1.8				1541	581
180		2.8				1895	726
185		4.2				2303	896
190		6.1		0.3		2771	1092
195	0.1	8.7		0.5		3302	1319
200	0.3	12.3		0.8		3899	1578
205	0.5	16.9		1.2		4567	1871
210	0.9	22.9	0.1	1.7		5308	2203
215	1.4	30.5	0.2	2.3			2577
220	2.3	40.1	0.3	3.2			2995
225	3.5	51.9	0.5	4.4			3464
230	5.3	66.4	0.7	5.9			3991
235	7.6	84.0	1.0	7.9			
240	10.8	105	1.5	10.3			
245	14.9	130	2.0	13.4			
250	20.1	160	2.8	17.2			
255	26.6	194	3.8	21.8			
260	34.6	234	5.0	27.4			
265	44.4	280	6.6	34.2			
270	56.1	332	8.6	42.2			
275	69.9	392	11.1	51.8			
280	86.2	459	14.2	63.1			
285	105	535	17.9	76.3			
290	127	619	22.3	91.7			
295	151	714	27.7	110			
300	179	818	34.0	130			
Ref.	12	5	12	12	12	12	1

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VAPOR PRESSURE OF FLUIDS AT TEMPERATURES BELOW 300 K (continued)

T/K	F_3P Phosphorous trifluoride	F_4Si Silicon tetrafluoride	F_6S Sulfur hexafluoride	HI Hydrogen iodide	H_2S Hydrogen sulfide	H_3N Ammonia	H_3P Phosphine
50							
55							
60							
65							
70							
75							
80							
85							
90							
95							
100							
105	0.1						
110	0.2						0.1
115	0.5						0.2
120	1.0						0.4
125	1.9	0.1 s					0.7
130	3.5	0.2 s					1.3
135	5.9	0.4 s			0.1 s		2.3
140	9.5	0.9 s	0.1 s		0.2 s		3.9
145	14.9	1.9 s	0.2 s		0.3 s		6.2
150	22.5	3.8 s	0.4 s		0.6 s		9.6
155	33.1	7.5 s	0.8 s	0.1 s	1.1 s		14.5
160	47.3	14.0 s	1.5 s	0.2 s	1.9 s	0.1 s	21.1
165	66.0	25.2 s	2.6 s	0.4 s	3.2 s	0.2 s	30.0
170	90.1	43.8 s	4.4 s	0.8 s	5.2 s	0.3 s	41.6
175	121	74.2 s	7.1 s	1.3 s	8.3 s	0.6 s	56.6
180	159	122 s	11.3 s	2.2 s	12.7 s	1.2 s	75.6
185	206	197 s	17.3 s	3.4 s	18.9 s	2.1 s	99.2
190	262	280	25.9 s	5.3 s	26.6	3.5 s	128
195	330	376	38.0 s	8.0 s	36.7	5.8 s	163
200	410	488	54.4 s	11.7 s	49.8	8.7	205
205	503	618	76.6 s	16.8 s	66.4	12.6	254
210	611	766	106 s	23.6 s	87.1	17.9	312
215	736	932	145 s	32.5 s	113	24.9	379
220	877	1117	195 s	44.0 s	144	34.1	456
225	1037	1324	249	56.2	182	45.9	544
230	1217	1555	305	71.4	227	60.8	644
235	1418	1816	371	89.7	281	79.6	756
240	1640	2111	448	112	344	103	881
245	1885	2449	536	137	416	131	1019
250	2154	2841	636	168	500	165	1172
255	2448	3301	750	203	597	207	1341
260	2767		878	244	706	256	1525
265	3112		1021	290	830	313	1725
270			1181	343	969	381	1942
275			1358	404	1124	460	2176
280			1554	472	1297	552	2428
285			1768	548	1488	655	2699
290			2003	633	1698	774	2987
295			2258	727	1929	909	3295
300			2534	831	2181	1062	3621
Ref.	12	12	12,15	12	12,15	11	12

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VAPOR PRESSURE OF FLUIDS AT TEMPERATURES BELOW 300 K (continued)

T/K	H_4Si Silane		Kr Krypton		NO Nitric oxide		N_2 Nitrogen		N_2O Nitrous oxide	O_2 Oxygen	O_2S Sulfur dioxide
50							0.4	s			
55							1.8	s		0.2	
60							6.3	s		0.7	
65							17.4			2.3	
70							38.6			6.3	
75			0.1	s			76.1			14.5	
80			0.4	s			137			30.1	
85			1.1	s	0.1	s	229			56.8	
90			2.7	s	0.4	s	361			99.3	
95	0.1		6.0	s	1.3	s	541			163	
100	0.2		12.1	s	3.8	s	779			254	
105	0.4		22.8	s	10.0	s	1084			379	
110	1.0		40.4	s	23.5		1467			543	
115	1.9		68.0	s	46.8		1939		0.1	756	
120	3.5		103		86.5		2513		0.1	1022	
125	6.1		150		151		3209		0.3	1351	
130	10.0		211		248				0.7	1749	
135	15.8		290		391				1.3	2225	
140	24.1		388		592				2.5	2788	
145	35.3		509		867				4.3	3448	
150	50.3		655		1231				7.1	4219	
155	69.8		830		1703				11.4		
160	94.6		1037		2302				17.6		
165	126		1278		3050				26.4		
170	164		1557		3971				38.5		0.1
175	210		1877		5089				54.7		0.2
180	265		2241		6433				75.9		0.3
185	331		2655						103		0.5
190	408		3120						138		0.8
195	498		3641						181		1.3
200	602		4223						234		2.0
205	722		4870						298		3.0
210	859								374		4.4
215	1017								465		6.3
220	1196								571		9.0
225	1398								694		12.6
230	1628								835		17.3
235	1888								996		23.3
240	2180								1179		31.1
245	2509								1385		40.9
250	2880								1615		53.2
255	3296								1870		68.3
260	3763								2152		86.7
265	4288								2462		109
270									2802		136
275									3172		168
280									3573		205
285									4006		249
290									4473		300
295									4973		359
300									5508		426
Ref.	12		13, 15		12, 15		1		12	3	12

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VAPOR PRESSURE OF FLUIDS AT TEMPERATURES BELOW 300 K (continued)

T/K	O_3 Ozone	Rn Radon	Xe Xenon	$CBrF_3$ Bromotri-fluoromethane	$CClF_3$ Chlorotri-fluoromethane	CCl_2F_2 Dichlorodi-fluoromethane	CCl_3F Trichloro-fluoromethane
50							
55							
60							
65							
70							
75							
80							
85							
90							
95							
100	0.1		0.1 s				
105	0.2		0.1 s				
110	0.4		0.3 s				
115	1.0		0.7 s		0.1		
120	2.0		1.5 s		0.2		
125	3.8		2.7 s		0.3		
130	6.8	0.1	4.9 s		0.6		
135	11.5	0.3	8.5 s	0.1	1.1		
140	18.7	0.5	14.0 s	0.3	2.0		
145	29.1	0.9	22.2 s	0.5	3.3		
150	43.7	1.5	34.2 s	0.9	5.3		
155	63.6	2.4	51.1 s	1.5	8.3	0.1	
160	89.9	3.8	74.2 s	2.5	12.6	0.3	
165	124	5.8	101	3.9	18.6	0.5	
170	168	8.6	134	5.9	26.8	0.8	
175	222	12.5	173	8.8	37.6	1.3	
180	289	17.7	222	12.8	51.7	2.1	
185	367	24.5	280	18.1	69.7	3.2	
190	468	33.2	348	25.1	92.3	4.8	0.2
195	584	44.4	428	34.1	120	6.9	0.3
200	721	58.2	521	45.6	155	9.9	0.4
205	881	75.3	628	60.0	196	13.7	0.6
210	1068	96	750	77.8	246	18.8	1.0
215	1285	121	889	99.5	304	25.2	1.4
220	1536	151	1045	126	372	33.3	2.0
225	1824	185	1220	157	451	43.3	2.9
230	2155		1416	194	542	55.5	4.1
235	2534		1633	237	646	70.4	5.6
240	2968		1872	287	763	88.1	7.6
245	3464		2136	344	896	109	10.1
250	4031		2425	410	1044	134	13.3
255	4678		2742	485	1210	163	17.2
260	5417		3087	570	1394	196	22.1
265			3462	665	1598	234	28.0
270			3869	771	1823	278	35.1
275			4310	889	2071	327	43.7
280			4786	1021	2343	383	53.8
285			5299	1166	2641	445	65.7
290				1325	2968	515	79.6
295				1501	3325	593	95.6
300				1692	3716	679	114.1
Ref.	12	15	12,13	12	12	12	12

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VAPOR PRESSURE OF FLUIDS AT TEMPERATURES BELOW 300 K (continued)

T/K	CCl_4 Tetrachloro-methane	CF_4 Tetrafluoro-methane	CO Carbon monoxide	COS Carbon oxysulfide	CO_2 Carbon dioxide	$CHClF_2$ Chlorodifluo-methane	$CHCl_3$ Trichloro-methane
50			0.1 s				
55			0.6 s				
60			2.6 s				
65			8.2 s				
70			21.0				
75			44.4				
80			83.7				
85			147				
90		0.1	239				
95		0.3	371				
100		0.8	545				
105		1.7	771				
110		3.4	1067				
115		6.5	1428				
120		11.5	1877				
125		19.3	2400				
130		30.8	3064				
135		47.4			0.1 s		
140		70.2		0.1	0.2 s		
145		101		0.2	0.4 s		
150		141		0.4	0.8 s	0.1	
155		191		0.8	1.7 s	0.3	
160		254		1.3	3.1 s	0.5	
165		332		2.2	5.7 s	0.8	
170		425		3.4	9.9 s	1.4	
175		537		5.2	16.8 s	2.3	
180		669		7.8	27.6 s	3.6	
185		824		11.3	44.0 s	5.5	
190		1005		15.9	68.4 s	8.1	
195		1216		22.1	104 s	11.8	
200		1460		30.0	155 s	16.7	
205		1743		40.1	227 s	23.1	
210		2073		52.7	327 s	31.5	
215		2457		68.2	465 s	42.1	0.1
220		2907		87.2	600	55.3	0.2
225		3438		110	735	71.7	0.3
230				137	894	91.6	0.4
235				169	1075	116	0.7
240				207	1283	144	1.0
245				250	1519	178	1.4
250				301	1786	218	2.0
255	1.5			358	2085	264	2.7
260	2.1			423	2419	317	3.7
265	2.8			497	2790	377	5.0
270	3.7			580	3203	446	6.6
275	4.9			673	3658	525	8.7
280	6.4			777	4160	613	11.3
285	8.2			892	4712	711	14.4
290	10.5			1019	5315	821	18.3
295	13.2			1159	5984	944	22.9
300	16.5			1313	6710	1080	28.5
Ref.	12	12	9	12	6	12	12

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VAPOR PRESSURE OF FLUIDS AT TEMPERATURES BELOW 300 K (continued)

T/K	CHF_3 Trifluoro-methane	CHN Hydrogen cyanide	CH_2Cl_2 Dichloro-methane	CH_2F_2 Difluoro methane	CH_2O Formaldehyde	CH_3Cl Chloromethane	CH_3F Fluoromethane
50							
55							
60							
65							
70							
75							
80							
85							
90							
95							
100							
105							
110							
115							
120	0.1						
125	0.2						
130	0.4						
135	0.7						0.6
140	1.4			0.1			1.2
145	2.5			0.2			2.1
150	4.3			0.3			3.6
155	7.1			0.6			5.9
160	11.1			1.0			9.3
165	17.0			1.7			14.1
170	25.3			2.8			20.9
175	36.5			4.4			29.9
180	51.4			6.8			42.0
185	70.9			10.2	1.3	2.1	57.6
190	95.8			14.8	2.0	3.1	77.4
195	127			21.2	3.0	4.6	102
200	166	0.1 s	0.1	29.5	4.4	6.7	133
205	214	0.2 s	0.2	40.5	6.4	9.5	171
210	271	0.4 s	0.3	54.5	9.1	13.1	216
215	340	0.6 s	0.4	72.1	12.7	17.9	270
220	421	1 s	0.6	94.1	17.4	24.0	333
225	516	1.5 s	0.9	121	23.4	31.8	408
230	626	2.2 s	1.4	154	31.0	41.4	495
235	754	3.3 s	2.0	193	40.6	53.3	595
240	900	4.7 s	2.8	240	52.5	67.7	711
245	1067	6.8 s	3.8	295	67.0	85.1	843
250	1257	9.7 s	5.3	360	84.6	106	993
255	1472	13.6 s	7.1	434	106	131	1163
260	1713	18.8	9.5	521	131	159	1355
265	1984	24.1	12.4	620	161	193	1571
270	2287	30.5	16.1	732	196	232	1813
275	2624	38.3	20.7	860	236	277	2084
280	3000	47.7	26.3	1004	283	327	2387
285	3418	58.8	33.0	1165	337	385	2724
290	3881	72.1	41.1	1346	399	450	3099
295	4393	87.6	50.8	1547	470	524	3516
300		105.9	62.1	1770	549	606	3978
Ref.	12	12,16	12	12	12	12	12

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VAPOR PRESSURE OF FLUIDS AT TEMPERATURES BELOW 300 K (continued)

T/K	CH_4 Methane	CH_4O Methanol	C_2H_2 Acetylene	C_2H_4 Ethylene	C_2H_6 Ethane	C_2H_6O Dimethyl ether	C_3H_4 Propadiene
50							
55							
60							
65	0.1						
70	0.3						
75	0.8						
80	2.1						
85	4.9						
90	10.6						
95	20.0						
100	34.5						
105	57.0						
110	88.4			0.3			
115	133			0.8	0.1		
120	192			1.4	0.4		
125	269			2.7	0.7		
130	368		0.1 s	4.5	1.3		
135	491		0.3 s	7.7	2.2		
140	642		0.7 s	11.9	3.8		
145	824		1.3 s	18.3	6.0		
150	1041		2.6 s	27.5	9.7		0.1
155	1297		4.6 s	39.9	15.0	0.1	0.2
160	1594		7.8 s	56.4	21.5	0.2	0.3
165	1937		12.8 s	77.9	31.0	0.3	0.6
170	2331		20.6 s	105	42.9	0.5	1.0
175	2779		32.2 s	140	59.0	0.9	1.7
180	3288		49.0 s	182	78.7	1.4	2.7
185	3865		72.9 s	234	104	2.1	4.1
190	4520		106 s	296	135	3.2	6.1
195			146	369	172	4.7	8.9
200			190	456	217	6.8	12.5
205			244	557	271	9.6	17.4
210			309	673	334	13.3	23.7
215			385	806	407	18.1	31.6
220			475	958	492	24.3	41.4
225			579	1128	590	32.1	53.5
230		0.1	699	1321	700	41.9	68.2
235		0.2	837	1535	826	53.9	85.8
240		0.4	993	1774	967	68.6	107
245		0.5	1170	2039	1125	86.3	131
250		0.8	1370	2331	1301	108	160
255		1.2	1593	2652	1496	133	193
260		1.7	1843	3005	1712	162	230
265		2.4	2121	3391	1949	197	273
270		3.3	2429	3813	2210	237	322
275		4.5	2771	4275	2495	283	376
280		6.2	3150		2806	335	438
285		8.3	3567		3146	395	506
290		11	4028		3515	463	582
295		14.4	4535		3917	538	666
300		18.7	5093		4355	623	759
Ref.	2,16	12	12,16	4	2	12	12

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VAPOR PRESSURE OF FLUIDS AT TEMPERATURES BELOW 300 K (continued)

T/K	C_3H_6 Propylene	C_3H_8 Propane	C_4H_6 Buta-1,3-diene	C_4H_{10} *n*-Butane	C_4H_{10} Isobutane	C_5H_{12} *n*-Pentane	C_5H_{12} Neopentane
50							
55							
60							
65							
70							
75							
80							
85							
90							
95							
100							
105							
110							
115							
120							
125							
130							
135							
140	0.1						
145	0.2						
150	0.4						
155	0.7						
160	1.2	0.8			0.1		
165	2.0	1.4			0.1		
170	3.1	2.2	0.1	0.1	0.3		
175	4.7	3.3	0.2	0.2	0.4		
180	7.0	5.0	0.4	0.3	0.7		
185	10.1	7.3	0.6	0.5	1.1		0.1 s
190	14.2	10.5	1.0	0.8	1.7		0.2 s
195	19.7	15.0	1.5	1.3	2.5		0.4 s
200	26.9	20.1	2.3	1.9	3.7		0.7 s
205	35.9	27.0	3.4	2.8	5.3		1.1 s
210	47.3	36.0	4.8	4.0	7.4		1.6 s
215	61.3	47.0	6.7	5.7	10.2		2.4 s
220	78.5	60.0	9.2	7.8	13.8	1.0	3.6 s
225	99.2	77.0	12.5	10.6	18.3	1.5	5.2 s
230	124	97.0	16.7	14.1	24.0	2.1	7.3 s
235	153	120	21.9	18.5	31.1	3.0	10.2 s
240	188	148	28.4	24.1	39.8	4.2	13.9 s
245	228	180	36.3	30.9	50.3	5.7	18.7 s
250	274	218	46.0	39.1	62.9	7.6	24.8 s
255	327	261	57.6	49.1	77.8	10.0	32.4 s
260	387	311	71.3	61.0	95.4	13.0	41.6
265	456	367	87.6	75.0	116	16.6	51.4
270	533	431	107	91.5	140	21.1	63.0
275	619	502	129	111	167	26.6	76.6
280	715	582	154	133	198	33.1	92.3
285	822	671	184	159	234	40.8	111
290	940	769	217	188	274	50.0	131
295	1069	878	255	221	319	60.7	155
300	1212	998	297	258	370	73.2	182
Ref.	7	2	12	2	2	14	12,16

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REFERENCES

1. B. A. Younglove, Thermophysical properties of fluids. I. Ethylene, parahydrogen, nitrogen trifluoride, and oxygen, *J. Phys. Chem. Ref. Data*, 11, Supp. 1, 1982.
2. B. A. Younglove and J. F. Ely, Thermophysical properties of fluids. II. Methane, ethane, propane, isobutane, and normal butane, *J. Phys. Chem. Ref. Data*, 16, 577, 1987.
3. W. Wagner, et al., *International Tables for the Fluid State: Oxygen*, Blackwell Scientific Publications, Oxford, 1987.
4. R. T. Jacobsen, et al., *International Tables for the Fluid State: Ethylene*, Blackwell Scientific Publications, Oxford, 1988.
5. S. Angus, et al., *International Tables for the Fluid State: Chlorine*, Pergamon Press, Oxford, 1985.
6. S. Angus, et al., *International Tables for the Fluid State: Carbon Dioxide*, Pergamon Press, Oxford, 1976.
7. S. Angus, et al., *International Tables for the Fluid State: Propylene*, Pergamon Press, Oxford, 1980.
8. R. B. Stewart and R. T. Jacobsen, Thermophysical properties of argon, *J. Phys. Chem. Ref. Data*, 18, 639, 1989.
9. R. D. Goodwin, Carbon monoxide thermophysical properties, *J. Phys. Chem. Ref. Data,* 14, 849, 1985.
10. R. D. Goodwin, Methanol thermophysical properties, *J. Phys. Chem. Ref. Data*, 16, 799, 1987.
11. L. Haar, Thermodynamic properties of ammonia, *J. Phys. Chem. Ref. Data*, 7, 635, 1978.
12. DIPPR Data Compilation of Pure Compound Properties, Design Institute for Physical Properties Data, American Institute of Chemical Engineers, 1987.
13. V. A. Rabinovich, et al., *Thermophysical Properties of Neon, Argon, Krypton, and Xenon*, Hemisphere Publishing Corp., New York, 1987.
14. K. N. Marsh, *Recommended Reference Methods for the Realization of Physicochemical Properties*, Blackwell Scientific Publications, Oxford, 1987.
15. TRC Thermodynamic Tables: Non-Hydrocarbons, Thermodynamic Research Center, Texas A & M University, College Station, Texas, 1985.
16. R. M. Stevenson and S. Malanowski, *Handbook of the Thermodynamics of Organic Compounds*, Elsevier, New York, 1987.
17. S. Angus and K. M. de Reuck, *International Tables of the Fluid State: Helium-4*, Pergamon Press, Oxford, 1977.
18. R. D. McCarty, *J. Phys. Chem. Ref. Data*, 2, 923, 1973.

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IUPAC RECOMMENDED DATA FOR VAPOR PRESSURE CALIBRATION

Vapor pressures are given in kPa (1 kPa = 0.0098692 atmos = 7.5006 Torr). Reprinted with permission if IUPAC.

REFERENCE

Marsh, K.N., Ed., *Recommended Reference Materials for the Realization of Physicochemical Properties*, Blackwell Scientific Publications,Oxford (1987).

T/K	$CO_2(s)$	$H_2O(s)$	$C_{10}H_8(s)$	n-C_5H_{12}	C_6H_6	C_6F_6	H_2O	Hg
180	27.62							
190	68.44							
200	155.11	0.0002						
210	327.17	0.0007						
220		0.0026						
230		0.0089						
240		0.0273						
250		0.0760		7.60				
260		0.1958	0.0001	12.98				
270		0.4701	0.0005	21.15			0.485	
280			0.0017	33.11	5.148	4.322	0.991	
290			0.0049	50.01	8.606	7.463	1.919	
300			0.0134	73.17	13.816	12.328	3.535	
310			0.0341	104.07	21.389	19.576	6.228	
320			0.0814	144.3	32.054	30.009	10.540	
330			0.1829	195.7	46.656	44.578	17.202	
340			0.3899	260.1	66.152	64.380	27.167	
350			0.7920	339.4	91.609	90.664	41.647	
360				435.9	124.192	124.816	62.139	
370				551.5	165.2	168.4	90.453	
380				688.8	215.9	223.0	128.74	
390				850.2	277.7	290.4	179.48	
400				1038	353.2	372.6	245.54	0.138
410				1256	441.0	471.5	330.15	0.215
420				1507	545.5	589.3	436.89	0.329
430				1793	667.6	728.3	569.73	0.493
440				2120	808.8	890.9	732.99	0.724
450				2490	971.1	1080	931.36	1.045
460				2910	1156	1297	1169.9	1.485
470					1366	1547	1453.9	2.078
480					1602	1833	1789.0	2.866
490					1868	2159	2181.4	3.899
500					2164	2530	2637.3	5.239
510					2494	2954	3163.3	6.955
520					2861		3766.4	9.131
530					3267		4453.9	11.861
540					3717		5233.5	15.256
550					4216		6113.4	19.438
560					4770		7102.0	25.547
570							8208.6	30.74
580							9443.0	38.19
590							10816	47.09
600							12339	57.64

ENTHALPY OF VAPORIZATION

The molar enthalpy (heat) of vaporization $\Delta_{vap}H$, which is defined as the enthalpy change in the conversion of one mole of liquid to gas at constant temperature, is tabulated here for approximately 850 inorganic and organic compounds. Values are given, when available, both at the normal boiling point t_b, referred to a pressure of 101.325 kPa (760 mmHg), and at 25°C. Substances are listed by molecular formula in the modified Hill order (see Preface).

The values in this table were measured either by calorimetric techniques or by application of the Claperyon equation to the variation of vapor pressure with temperature. See Reference 1 for a discussion of the accuracy of different experimental techniques and for methods of estimating enthalpy of vaporization at other temperatures.

REFERENCES

1. Majer, V. and Svoboda, V., *Enthalpies of Vaporization of Organic Compounds,* Blackwell Scientific Publications, Oxford, 1985.
2. Chase, M. W., Davies, C. A., Downey, J. R., Frurip, D. J., McDonald, R. A., and Syverud, A. N., *JANAF Thermochemical Tables, Third Edition, J. Phys. Chem. Ref. Data,* Vol. 14, Suppl. 1, 1985.
3. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, Sixth Edition,* II/4, *Caloric Quantities of State*, Springer-Verlag, Heidelberg, 1961.
4. Daubert, T. E., Danner, R. P., Sibul, H. M., and Stebbins, C. C., *Physical and Thermodynamic Properties of Pure Compounds: Data Compilation,* extant 1994 (core with 4 supplements), Taylor & Francis, Bristol, PA.
5. Ruzicka, K. and Majer, V., "Simultaneous Treatment of Vapor Pressures and Related Thermal Data Between the Triple and Normal Boiling Temperatures for *n*-Alkanes C_5 - C_{20}", *J. Phys. Chem. Ref. Data*, 23, 1, 1994.
6. Verevkin, S. P., "Thermochemistry of Amines: Experimental Standard Molar Enthalpies of Formation of Some Aliphatic and Aromatic Amines", *J. Chem. Thermodynamics*, 29, 891, 1997.
7. Cady, G. H. and Hargreaves, G. B., "The Vapor Pressure of Some Heavy Transition Metal Hexafluorides", *J. Chem. Soc.*, 1961, 1563; 1961, 1578.
8. Steele, W. V., Chirico, R. D., Knipmeyer, S. E., and Nguyen, A., *J. Chem. Eng. Data*, 41, 1255, 1996.

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H$(25°C) kJ/mol
AgBr	Silver(I) bromide	1502	198	
AgCl	Silver(I) chloride	1547	199	
AgI	Silver(I) iodide	1506	143.9	
Al	Aluminum	2519	294	
AlB_3H_{12}	Aluminum borohydride	44.5	30	
$AlBr_3$	Aluminum tribromide	255	23.5	
AlI_3	Aluminum triiodide	382	32.2	
Ar	Argon	-185.85	6.43	
$AsBr_3$	Arsenic(III) bromide	221	41.8	
$AsCl_3$	Arsenic(III) chloride	130	35.01	
AsF_3	Arsenic(III) fluoride	57.8	29.7	
AsF_5	Arsenic(V) fluoride	-52.8	20.8	
AsH_3	Arsine	-62.5	16.69	
AsI_3	Arsenic(III) iodide	424	59.3	
Au	Gold	2856	324	
B	Boron	4000	480	
BBr_3	Boron tribromide	91	30.5	
BCl_3	Boron trichloride	12.65	23.77	23.1
BF_3	Boron trifluoride	-101	19.33	
BI_3	Boron triiodide	210	40.5	
B_2F_4	Tetrafluorodiborane	-34	28	
B_2H_6	Diborane	-92.4	14.28	
B_4H_{10}	Tetraborane	18	27.1	
B_5H_{11}	Pentaborane(11)	63	31.8	
Ba	Barium	1897	140	
$BeCl_2$	Beryllium chloride	482	105	
BeI_2	Beryllium iodide	487	70.5	
Bi	Bismuth	1564	151	
$BiBr_3$	Bismuth tribromide	453	75.4	
$BiCl_3$	Bismuth trichloride	447	72.61	
BrF	Bromine fluoride	20	25.1	
BrF_3	Bromine trifluoride	125.8	47.57	

ENTHALPY OF VAPORIZATION (continued)

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H$(25°C) kJ/mol
BrF_5	Bromine pentafluoride	40.76	30.6	
BrH	Hydrogen bromide	-66.38		12.69
BrH_3Si	Bromosilane	1.9	24.4	
BrIn	Indium(I) bromide	656	92	
BrTl	Thallium(I) bromide	819	99.56	
Br_2	Bromine	58.8	29.96	30.91
Br_2Cd	Cadmium bromide	844	115	
Br_2H_2Si	Dibromosilane	66	31	
Br_2Hg	Mercury(II) bromide	322	58.89	
Br_2Pb	Lead(II) bromide	892	133	
Br_2Sn	Tin(II) bromide	639	102	
Br_2Zn	Zinc bromide	697	118	
Br_3Ga	Gallium(III) bromide	279	38.9	
Br_3HSi	Tribromosilane	109	34.8	
Br_3OP	Phosphorus(V) oxybromide	191.7	38	
Br_3P	Phosphorus(III) bromide	172.95	38.8	
Br_3Sb	Antimony(III) bromide	280	59	
Br_4Ge	Germanium(IV) bromide	186.35	41.4	
Br_4Si	Tetrabromosilane	154	37.9	
Br_4Sn	Tin(IV) bromide	205	43.5	
Br_4Ti	Titanium(IV) bromide	230	44.37	
Br_5Ta	Tantalum(V) bromide	349	62.3	
Cd	Cadmium	767	99.87	
$CdCl_2$	Cadmium chloride	960	124.3	
CdF_2	Cadmium fluoride	1748	214	
CdI_2	Cadmium iodide	742	115	
ClF	Chlorine fluoride	-101.1	24	
$ClFO_3$	Perchloryl fluoride	-46.75	19.33	
ClF_2P	Phosphorus(III) chloride difluoride	-47.25	17.6	
ClF_3	Chlorine trifluoride	11.75	27.53	
ClF_3Si	Chlorotrifluorosilane	-70.0	18.7	
ClH	Hydrogen chloride	-85	16.15	9.08
ClH_3Si	Chlorosilane	-30.4	21	
ClNO	Nitrosyl chloride	-5.5	25.78	
$ClNO_2$	Nitryl chloride	-15	25.7	
ClO_2	Chlorine dioxide	11	30	
ClTl	Thallium(I) chloride	720	102.2	
Cl_2	Chlorine	-34.04	20.41	17.65
Cl_2Cr	Chromium(II) chloride	1300	197	
Cl_2CrO_2	Chromyl chloride	117	35.1	
Cl_2FP	Phosphorus(III) dichloride fluoride	14	24.9	
Cl_2F_2Si	Dichlorodifluorosilane	-32	21.2	
Cl_2H_2Si	Dichlorosilane	8.3	25	24.2
Cl_2Hg	Mercury(II) chloride	304	58.9	
Cl_2O	Chlorine monoxide	2.2	25.9	
Cl_2OS	Thionyl chloride	75.6	31.7	31
Cl_2O_2S	Sulfuryl chloride	69.4	31.4	30.1
Cl_2Pb	Lead(II) chloride	951	127	
Cl_2Sn	Tin(II) chloride	623	86.8	
Cl_2Ti	Titanium(II) chloride	1500	232	
Cl_2Zn	Zinc chloride	732	126	
Cl_3Ga	Gallium(III) chloride	201	23.9	
Cl_3HSi	Trichlorosilane	33		25.7
Cl_3OP	Phosphorus(V) oxychloride	105.5	34.35	38.6
Cl_3OV	Vanadyl trichloride	127	36.78	
Cl_3P	Phosphorus(III) chloride	75.95	30.5	32.1
Cl_3Sb	Antimony(III) chloride	220.3	45.19	
Cl_3Ti	Titanium(III) chloride	960	124	

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H$(25°C) kJ/mol
Cl_4Ge	Germanium(IV) chloride	86.55	27.9	
Cl_4OW	Tungsten(VI) oxytetrachloride	227.55	67.8	
Cl_4Si	Tetrachlorosilane	57.65	28.7	29.7
Cl_4Sn	Tin(IV) chloride	114.15	34.9	
Cl_4Te	Tellurium tetrachloride	387	77	
Cl_4Th	Thorium(IV) chloride	921	146.4	
Cl_4Ti	Titanium(IV) chloride	136.45	36.2	
Cl_4V	Vanadium(IV) chloride	148	41.4	42.5
Cl_5Mo	Molybdenum(V) chloride	268	62.8	
Cl_5Nb	Niobium(V) chloride	254.0	52.7	
Cl_5Ta	Tantalum(V) chloride	239.35	54.8	
Cl_6W	Tungsten(VI) chloride	346.75	52.7	
FH_3Si	Fluorosilane	-98.6	18.8	
FLi	Lithium fluoride	1673	147	
FNO	Nitrosyl fluoride	-59.9	19.28	
FNO_2	Nitryl fluoride	-72.4	18.05	
FNS	Thionitrosyl fluoride (NSF)	4.8	22.2	
F_2	Fluorine	-188.12	6.62	
F_2H_2Si	Difluorosilane	-77.8	16.3	
F_2O	Fluorine monoxide	-144.75	11.09	
F_2OS	Thionyl fluoride	-43.8	21.8	
F_2O_2	Fluorine dioxide	-57	19.1	
F_2Pb	Lead(II) fluoride	1293	160.4	
F_2Zn	Zinc fluoride	1500	190.1	
F_3HSi	Trifluorosilane	-95	16.2	
F_3N	Nitrogen trifluoride	-128.75	11.56	
F_3O_2Re	Rhenium(VII) dioxytrifluoride	185.4	65.7	
F_3P	Phosphorus(III) fluoride	-101.5	16.5	
F_3PS	Phosphorus(V) sulfide trifluoride	-52.25	19.6	
F_4MoO	Molybdenum(VI) oxytetrafluoride	186.0	50.6	
F_4N_2	Tetrafluorohydrazine	-74	13.27	
F_4ORe	Rhenium(VI) oxytetrafluoride	171.7	61.0	
F_4OW	Tungsten(VI) oxytetrafluoride	185.9	59.5	
F_4S	Sulfur tetrafluoride	-40.45	26.44	
F_4Se	Selenium tetrafluoride	106	47.2	
F_4Th	Thorium(IV) fluoride	1680	258	
F_5I	Iodine pentafluoride	100.5	41.3	
F_5Mo	Molybdenum(V) fluoride	213.6	51.8	
F_5Nb	Niobium(V) fluoride	229	52.3	
F_5Os	Osmium(V) fluoride	225.9	65.6	
F_5P	Phosphorus(V) fluoride	-84.6	17.2	
F_5Re	Rhenium(V) fluoride	221.3	58.1	
F_5Ta	Tantalum(V) fluoride	229.2	56.9	
F_5V	Vanadium(V) fluoride	48.3	44.52	
F_6Ir	Iridium(VI) fluoride	53.6	30.9	
F_6Mo	Molybdenum(VI) fluoride	34.0	29.0	
F_6Os	Osmium(VI) fluoride	47.5	28.1	
F_6Re	Rhenium(VI) fluoride	33.8	28.7	
F_6S	Sulfur hexafluoride			8.99
F_6W	Tungsten(VI) fluoride	17.1	26.5	
Ga	Gallium	2204	254	
GaI_3	Gallium(III) iodide	340	56.5	
Ge	Germanium	2833	334	
GeH_4	Germane	-88.1	14.06	
Ge_2H_6	Digermane	30.8	25.1	
Ge_3H_8	Trigermane	110.5	32.2	
HI	Hydrogen iodide	-35.55	19.76	17.36
HLiO	Lithium hydroxide	1626	188	

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H$(25°C) kJ/mol
HNO_3	Nitric acid	83		39.1
HN_3	Hydrazoic acid	35.7	30.5	
HNaO	Sodium hydroxide	1388	175	
H_2	Hydrogen	-252.87	0.90	
H_2O	Water	100.0	40.65	43.98
H_2O_2	Hydrogen peroxide	150.2		51.6
H_2S	Hydrogen sulfide	-59.55	18.67	14.08
H_2S_2	Hydrogen disulfide	70.7		33.78
H_2Se	Hydrogen selenide	-41.25	19.7	
H_2Te	Hydrogen telluride	-2	19.2	
H_3N	Ammonia	-33.33	23.33	19.86
H_3P	Phosphine	-87.75	14.6	
H_3Sb	Stibine	-17	21.3	
H_4N_2	Hydrazine	113.55	41.8	44.7
H_4P_2	Diphosphine	63.5	28.8	
H_4Si	Silane	-111.9	12.1	
H_4Sn	Stannane	-51.8	19.05	
H_6Si_2	Disilane	-14.3	21.2	
H_8Si_3	Trisilane	52.9	28.5	
He	Helium	-268.93	0.08	
Hg	Mercury	356.73	59.11	
HgI_2	Mercury(II) iodide	354	59.2	
IIn	Indium(I) iodide	712	90.8	
ITl	Thallium(I) iodide	824	104.7	
I_2	Iodine	184.4	41.57	
I_2Pb	Lead(II) iodide	872	104	
I_2Sn	Tin(II) iodide	714	105	
I_3P	Phosphorus(III) iodide	227	43.9	
I_3Sb	Antimony(III) iodide	401	68.6	
I_4Si	Tetraiodosilane	287.35	50.2	
I_4Sn	Tin(IV) iodide	364.35	56.9	
I_4Ti	Titanium(IV) iodide	377	58.4	
Kr	Krypton	-153.22	9.08	
MoO_3	Molybdenum(VI) oxide	1155	138	
NO	Nitric oxide	-151.74	13.83	
N_2	Nitrogen	-195.79	5.57	
N_2O	Nitrous oxide	-88.48	16.53	
N_2O_4	Nitrogen tetroxide	21.15	38.12	
Ne	Neon	-246.08	1.71	
O_2	Oxygen	-182.95	6.82	
O_2S	Sulfur dioxide	-10.05	24.94	22.92
O_3S	Sulfur trioxide	45	40.69	43.14
P	Phosphorus	280.5	12.4	14.2
Pb	Lead	1749	179.5	
S	Sulfur	444.60	45	
STl_2	Thallium(I) sulfide	1367	154	
Se	Selenium	685	95.48	
Te	Tellurium	988	114.1	
Xe	Xenon	-108.11	12.57	
$CClF_3$	Chlorotrifluoromethane	-81.4	15.8	
CCl_2F_2	Dichlorodifluoromethane	-29.8	20.1	
CCl_3F	Trichlorofluoromethane	23.7	25.1	
CCl_4	Tetrachloromethane	76.8	29.82	32.43
$CHBr_3$	Tribromomethane	149.1	39.66	46.05
$CHClF_2$	Chlorodifluoromethane	-40.7	20.2	
$CHCl_2F$	Dichlorofluoromethane	8.9	25.2	
$CHCl_3$	Trichloromethane	61.17	29.24	31.28
CH_2BrCl	Bromochloromethane	68.0	30.0	

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H(25°C)$ kJ/mol
CH_2Br_2	Dibromomethane	97	32.92	36.97
CH_2Cl_2	Dichloromethane	40	28.06	28.82
CH_2I_2	Diiodomethane	182	42.5	
CH_2O_2	Formic acid	101	22.69	20.10
CH_3Br	Bromomethane	3.5	23.91	22.81
CH_3Cl	Chloromethane	-24.09	21.40	18.92
CH_3I	Iodomethane	42.55	27.34	27.97
CH_3NO	Formamide	220		60.15
CH_3NO_2	Nitromethane	101.19	33.99	38.27
CH_4	Methane	-161.48	8.19	
CH_4O	Methanol	64.6	35.21	37.43
CH_5N	Methylamine	-6.32	25.60	23.37
CH_6N_2	Methylhydrazine	87.5	36.12	40.37
CN_4O_8	Tetranitromethane	126.1	40.74	49.93
CO	Carbon monoxide	-191.5	6.04	
CS_2	Carbon disulfide	46	26.74	27.51
$C_2Br_2ClF_3$	1,2-Dibromo-1-chloro-1,2,2-trifluoroethane	93	31.17	35.04
$C_2Br_2F_4$	1,2-Dibromotetrafluoroethane	47.35	27.03	28.39
C_2ClF_5	Chloropentafluoroethane	-37.95	19.41	
$C_2Cl_2F_4$	1,2-Dichlorotetrafluoroethane	3.8	23.3	
$C_2Cl_3F_3$	1,1,1-Trichlorotrifluoroethane	46.1	26.85	28.08
$C_2Cl_3F_3$	1,1,2-Trichloro-1,2,2-trifluoroethane	47.7	27.04	28.40
C_2Cl_4	Tetrachloroethylene	121.3	34.68	39.68
C_2F_6	Hexafluoroethane	-78.1	16.15	
$C_2HBrClF_3$	2-Bromo-2-chloro-1,1,1-trifluoroethane	50.2	28.08	29.61
C_2HCl_3	Trichloroethylene	87.21	31.40	34.54
C_2HCl_5	Pentachloroethane	159.8	36.9	
$C_2HF_3O_2$	Trifluoroacetic acid	73	33.3	
$C_2H_2Br_4$	1,1,2,2-Tetrabromoethane	243.5	48.7	
$C_2H_2Cl_2$	1,1-Dichloroethylene	31.6	26.14	26.48
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethylene	60.1	30.2	
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethylene	48.7	28.9	
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane	146.5	37.64	45.71
C_2H_3Br	Bromoethylene	15.8	23.4	
C_2H_3Cl	Chloroethylene	-13.3	20.8	
$C_2H_3Cl_2F$	1,1-Dichloro-1-fluoroethane	32.0	26.06	26.48
$C_2H_3Cl_3$	1,1,1-Trichloroethane	74.09	29.86	32.50
$C_2H_3Cl_3$	1,1,2-Trichloroethane	113.8	34.82	40.24
$C_2H_3F_3$	1,1,1-Trifluoroethane	-47.25	18.99	
C_2H_3N	Acetonitrile	81.65	29.75	32.94
C_2H_4	Ethylene	-103.77	13.53	
$C_2H_4Br_2$	1,2-Dibromoethane	131.6	34.77	41.73
$C_2H_4Cl_2$	1,1-Dichloroethane	57.4	28.85	30.62
$C_2H_4Cl_2$	1,2-Dichloroethane	83.5	31.98	35.16
$C_2H_4F_2$	1,1-Difluoroethane	-24.95	21.56	19.08
C_2H_4O	Acetaldehyde	20.1	25.76	25.47
C_2H_4O	Ethylene oxide	10.6	25.54	24.75
$C_2H_4O_2$	Acetic acid	117.9	23.70	23.36
$C_2H_4O_2$	Methyl formate	31.7	27.92	28.35
C_2H_5Br	Bromoethane	38.5	27.04	28.03
C_2H_5Cl	Chloroethane	12.3	24.65	
C_2H_5ClO	2-Chloroethanol	128.6	41.4	
C_2H_5I	Iodoethane	72.5	29.44	31.93
C_2H_5NO	*N*-Methylformamide	199.51		56.19
$C_2H_5NO_2$	Nitroethane	114.0	38.0	
C_2H_6	Ethane	-88.6	14.69	5.16
C_2H_6O	Ethanol	78.29	38.56	42.32
C_2H_6O	Dimethyl ether	-24.8	21.51	18.51

ENTHALPY OF VAPORIZATION (continued)

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H$(25°C) kJ/mol
C_2H_6OS	Dimethyl sulfoxide	189	43.1	
$C_2H_6O_2$	Ethylene glycol	197.3	50.5	
C_2H_6S	Ethanethiol	35.1	26.79	27.30
C_2H_6S	Dimethyl sulfide	37.33	27.0	27.65
$C_2H_6S_2$	1,2-Ethanedithiol	146.1	37.93	44.68
$C_2H_6S_2$	Dimethyl disulfide	109.8	33.78	37.86
C_2H_7N	Dimethylamine	6.88	26.40	25.05
C_2H_7NO	Ethanolamine	171	49.83	
$C_2H_8N_2$	1,2-Ethanediamine	117	37.98	44.98
$C_2H_8N_2$	1,1-Dimethylhydrazine	63.9	32.55	35.0
C_2N_2	Cyanogen	-21.1	23.33	19.75
$C_3Cl_2F_6$	1,2-Dichlorohexafluoropropane	34.1	26.28	26.93
$C_3H_3Cl_3O_2$	Methyl trichloroacetate	153.8		48.33
C_3H_3N	Acrylonitrile	77.3	32.6	
$C_3H_4Cl_2O_2$	Methyl dichloroacetate	142.9	39.28	47.72
C_3H_4O	Acrolein	52.6	28.3	
$C_3H_4O_2$	2-Oxetanone	162		47.03
C_3H_5Br	3-Bromopropene	70.1	30.24	32.73
C_3H_5Cl	3-Chloropropene	45.1	29.0	
$C_3H_5ClO_2$	Methyl chloroacetate	129.5	39.23	46.73
$C_3H_5Cl_3$	1,2,3-Trichloropropane	157	37.1	
C_3H_5N	Propanenitrile	97.14	31.81	36.03
C_3H_6	Propene	-47.69	18.42	14.24
C_3H_6	Cyclopropane	-32.81	20.05	16.93
$C_3H_6Br_2$	1,2-Dibromopropane	141.9	35.61	41.67
$C_3H_6Br_2$	1,3-Dibromopropane	167.3		47.45
$C_3H_6Cl_2$	1,3-Dichloropropane	120.9	35.18	40.75
C_3H_6O	Allyl alcohol	97.0	40.0	
C_3H_6O	Propanal	48	28.31	29.62
C_3H_6O	Acetone	56.05	29.10	30.99
C_3H_6O	Methyloxirane	35	27.35	27.89
C_3H_6O	Oxetane	47.6	28.67	29.85
$C_3H_6O_2$	Propanoic acid	141.15		32.14
$C_3H_6O_2$	Ethyl formate	54.4	29.91	31.96
$C_3H_6O_2$	Methyl acetate	56.87	30.32	32.29
C_3H_6S	Thiacyclobutane	95	32.32	35.97
C_3H_7Br	1-Bromopropane	71.1	29.84	32.01
C_3H_7Br	2-Bromopropane	59.5	28.33	30.17
C_3H_7Cl	1-Chloropropane	46.5	27.18	28.35
C_3H_7Cl	2-Chloropropane	35.7	26.30	26.90
C_3H_7I	1-Iodopropane	102.6	32.08	36.25
C_3H_7I	2-Iodopropane	89.5	30.68	34.06
C_3H_7NO	*N*-Ethylformamide	198		58.44
C_3H_7NO	*N*,*N*-Dimethylformamide	153		46.89
$C_3H_7NO_2$	1-Nitropropane	131.1	38.5	
$C_3H_7NO_2$	2-Nitropropane	120.2	36.8	
C_3H_8	Propane	-42.1	19.04	14.79
C_3H_8O	1-Propanol	97.2	41.44	47.45
C_3H_8O	2-Propanol	82.3	39.85	45.39
$C_3H_8O_2$	1,2-Propylene glycol	187.6	52.4	
$C_3H_8O_2$	1,3-Propylene glycol	214.4	57.9	
$C_3H_8O_2$	Ethylene glycol monomethyl ether	124.1	37.54	45.17
$C_3H_8O_3$	Glycerol	290	61.0	
C_3H_8S	1-Propanethiol	67.8	29.54	31.89
C_3H_8S	2-Propanethiol	52.6	27.91	29.45
C_3H_8S	Ethyl methyl sulfide	66.7	29.53	31.85
$C_3H_8S_2$	1,3-Propanedithiol	172.9		49.66
C_3H_9N	Propylamine	47.22	29.55	31.27

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H(25°C)$ kJ/mol
C_3H_9N	Isopropylamine	31.76	27.83	28.36
C_3H_9N	Trimethylamine	2.87	22.94	21.66
$C_3H_{10}N_2$	1,3-Propanediamine	139.8	40.85	50.16
C_4F_8	Perfluorocyclobutane	-5.9	23.2	
C_4F_{10}	Perfluorobutane	-1.9	22.9	
$C_4H_4N_2$	Succinonitrile	266	48.5	
$C_4H_4N_2$	Pyrimidine	123.8	43.09	49.79
$C_4H_4N_2$	Pyridazine	208		53.47
C_4H_4O	Furan	31.5	27.10	27.45
$C_4H_4O_2$	Diketene	126.1	36.80	42.89
C_4H_4S	Thiophene	84.0	31.48	34.70
$C_4H_5Cl_3O_2$	Ethyl trichloroacetate	167.5		50.97
C_4H_5N	2-Methylacrylonitrile	90.3	31.8	
C_4H_5N	Pyrrole	129.79	38.75	45.09
C_4H_5N	Cyclopropanecarbonitrile	135.1	35.55	41.94
$C_4H_5NO_2$	Methyl cyanoacetate	200.5	48.2	
C_4H_5NS	4-Methylthiazole	133.3	37.58	43.85
C_4H_6	1,2-Butadiene	10.9	24.02	23.21
C_4H_6	1,3-Butadiene	-4.41	22.47	20.86
C_4H_6	1-Butyne	8.08	24.52	23.35
$C_4H_6Cl_2O_2$	Ethyl dichloroacetate	155		50.60
$C_4H_6O_2$	Vinyl acetate	72.5	34.6	
$C_4H_6O_2$	Methyl acrylate	80.7	33.1	
$C_4H_6O_2$	γ-Butyrolactone	204	52.2	
$C_4H_6O_3$	Acetic anhydride	139.5	38.2	
C_4H_6S	2,3-Dihydrothiophene	112.1	33.24	37.74
C_4H_6S	2,5-Dihydrothiophene	122.4	34.83	39.95
$C_4H_7ClO_2$	Ethyl chloroacetate	144.3	40.43	49.47
C_4H_7N	Butanenitrile	117.6	33.68	39.33
C_4H_7N	2-Methylpropanenitrile	103.9	32.39	37.13
C_4H_8	1-Butene	-6.26	22.07	20.22
C_4H_8	*cis*-2-Butene	3.71	23.34	22.16
C_4H_8	*trans*-2-Butene	0.88	22.72	21.40
C_4H_8	Cyclobutane	12.6	24.19	23.51
$C_4H_8Br_2$	1,4-Dibromobutane	197		53.09
$C_4H_8Cl_2$	1,2-Dichlorobutane	124.1	33.90	39.58
$C_4H_8Cl_2$	1,4-Dichlorobutane	161		46.36
$C_4H_8Cl_2O$	Bis(2-chloroethyl) ether	178.5	45.2	
C_4H_8O	Ethyl vinyl ether	35.5	26.2	
C_4H_8O	1,2-Epoxybutane	63.4	30.3	
C_4H_8O	Butanal	74.8	31.5	
C_4H_8O	2-Butanone	79.59	31.30	34.79
C_4H_8O	Tetrahydrofuran	65	29.81	31.99
$C_4H_8O_2$	Butanoic acid	163.75		40.45
$C_4H_8O_2$	2-Methylpropanoic acid	154.45		35.30
$C_4H_8O_2$	Propyl formate	80.9	33.61	37.53
$C_4H_8O_2$	Ethyl acetate	77.11	31.94	35.60
$C_4H_8O_2$	Methyl propanoate	79.8	32.24	35.85
$C_4H_8O_2$	1,3-Dioxane	106.1	34.37	39.09
$C_4H_8O_2$	1,4-Dioxane	101.5	34.16	38.60
C_4H_8S	Tetrahydrothiophene	121.0	34.66	39.43
C_4H_9Br	1-Bromobutane	101.6	32.51	36.64
C_4H_9Br	2-Bromobutane	91.3	30.77	34.41
C_4H_9Br	1-Bromo-2-methylpropane	91.1	31.33	34.82
C_4H_9Br	2-Bromo-2-methylpropane	73.3	29.23	31.81
C_4H_9Cl	1-Chlorobutane	78.6	30.39	33.51
C_4H_9Cl	2-Chlorobutane	68.2	29.17	31.53
C_4H_9Cl	1-Chloro-2-methylpropane	68.5	29.22	31.67

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H(25°C)$ kJ/mol
C_4H_9Cl	2-Chloro-2-methylpropane	50.9	27.55	28.98
C_4H_9I	1-Iodobutane	130.6	34.66	40.63
C_4H_9I	2-Iodobutane	120.1	33.27	38.46
C_4H_9I	1-Iodo-2-methylpropane	121.1	33.54	38.83
C_4H_9I	2-Iodo-2-methylpropane	100.1	31.43	35.41
C_4H_9N	Pyrrolidine	86.56	33.01	37.52
C_4H_9NO	*N*-Ethylacetamide	205		64.89
C_4H_9NO	*N,N*-Dimethylacetamide	165		50.24
C_4H_9NO	Morpholine	128	37.1	
C_4H_{10}	Butane	-0.5	22.44	21.02
C_4H_{10}	Isobutane	-11.73	21.30	19.23
$C_4H_{10}O$	1-Butanol	117.73	43.29	52.35
$C_4H_{10}O$	2-Butanol	99.51	40.75	49.72
$C_4H_{10}O$	2-Methyl-1-propanol	107.89	41.82	50.82
$C_4H_{10}O$	2-Methyl-2-propanol	82.4	39.07	46.69
$C_4H_{10}O$	Diethyl ether	34.5	26.52	27.10
$C_4H_{10}O$	Methyl propyl ether	39.1	26.75	27.60
$C_4H_{10}O$	Isopropyl methyl ether	30.77	26.05	26.41
$C_4H_{10}O_2$	1,2-Butanediol	190.5	52.84	71.55
$C_4H_{10}O_2$	1,3-Butanediol	207.5	54.31	74.46
$C_4H_{10}O_2$	Ethylene glycol monoethyl ether	135	39.22	48.21
$C_4H_{10}O_2$	Ethylene glycol dimethyl ether	85	32.42	36.39
$C_4H_{10}O_3$	Diethylene glycol	245.8	52.3	
$C_4H_{10}S$	1-Butanethiol	98.5	32.23	36.63
$C_4H_{10}S$	2-Butanethiol	85	30.59	33.99
$C_4H_{10}S$	2-Methyl-1-propanethiol	88.5	31.01	34.63
$C_4H_{10}S$	2-Methyl-2-propanethiol	64.3	28.45	30.78
$C_4H_{10}S$	Diethyl sulfide	92.1	31.77	35.80
$C_4H_{10}S$	Methyl propyl sulfide	95.6	32.08	36.24
$C_4H_{10}S$	Isopropyl methyl sulfide	84.8	30.71	34.15
$C_4H_{10}S_2$	1,4-Butanedithiol	195.5		55.10
$C_4H_{10}S_2$	Diethyl disulfide	154.1	37.58	45.18
$C_4H_{11}N$	Butylamine	77.00	31.81	35.72
$C_4H_{11}N$	*sec*-Butylamine	62.73	29.92	32.85
$C_4H_{11}N$	*tert*-Butylamine	44.04	28.27	29.64
$C_4H_{11}N$	Isobutylamine	67.75	30.61	33.85
$C_4H_{11}N$	Diethylamine	55.5	29.06	31.31
$C_4H_{11}N$	Isopropylmethylamine	50.4	28.71	30.69
$C_4H_{11}NO$	2-Amino-2-methyl-1-propanol	165.5	50.6	
$C_4H_{11}NO_2$	Diethanolamine	268.8	65.2	
$C_5H_2F_6O_2$	Hexafluoroacetylacetone	54.15	27.05	30.58
$C_5H_4O_2$	Furfural	161.7	43.2	
C_5H_5N	Pyridine	115.23	35.09	40.21
$C_5H_6O_2$	Furfuryl alcohol	171	53.6	
C_5H_6S	2-Methylthiophene	112.6	33.90	38.87
C_5H_6S	3-Methylthiophene	115.5	34.24	39.43
C_5H_7N	*trans*-3-Pentenenitrile	142.6	37.09	44.77
C_5H_7N	Cyclobutanecarbonitrile	149.6	36.88	44.34
C_5H_8	Spiropentane	39	26.76	27.49
C_5H_8O	Cyclopropyl methyl ketone	111.3	34.07	39.41
C_5H_8O	Cyclopentanone	130.57	36.35	42.72
$C_5H_8O_2$	Methyl cyclopropanecarboxylate	114.9	35.25	41.27
$C_5H_8O_2$	Allyl acetate	103.5	36.3	
$C_5H_8O_2$	Ethyl acrylate	99.4	34.7	
$C_5H_8O_2$	Methyl methacrylate	100.5	36.0	
$C_5H_8O_2$	2,4-Pentanedione	138	34.30	41.77
C_5H_9N	Pentanenitrile	141.3	36.09	43.60
C_5H_9N	3-Methylbutanenitrile	127.5	35.10	41.64

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H(25°C)$ kJ/mol
C_5H_9N	2,2-Dimethylpropanenitrile	106.1	32.40	37.35
C_5H_{10}	1-Pentene	29.96	25.20	25.47
C_5H_{10}	*cis*-2-Pentene	36.93		26.86
C_5H_{10}	*trans*-2-Pentene	36.34		26.76
C_5H_{10}	2-Methyl-1-butene	31.2	25.50	25.92
C_5H_{10}	3-Methyl-1-butene	20.1		23.77
C_5H_{10}	2-Methyl-2-butene	38.56	26.31	27.06
C_5H_{10}	Cyclopentane	49.3	27.30	28.52
$C_5H_{10}Cl_2$	1,2-Dichloropentane	148.3	36.45	43.89
$C_5H_{10}Cl_2$	1,5-Dichloropentane	179		50.71
$C_5H_{10}O$	Cyclopentanol	140.42		57.05
$C_5H_{10}O$	2-Pentanone	102.26	33.44	38.40
$C_5H_{10}O$	3-Pentanone	101.96	33.45	38.52
$C_5H_{10}O$	3-Methyl-2-butanone	94.33	32.35	36.78
$C_5H_{10}O$	3,3-Dimethyloxetane	80.6	30.85	33.94
$C_5H_{10}O$	Tetrahydropyran	88	31.17	34.58
$C_5H_{10}O_2$	Pentanoic acid	186.1	44.1	
$C_5H_{10}O_2$	2-Methylbutanoic acid	177		46.91
$C_5H_{10}O_2$	Butyl formate	106.1	36.58	41.11
$C_5H_{10}O_2$	Isobutyl formate	98.2	33.6	
$C_5H_{10}O_2$	Propyl acetate	101.54	33.92	39.72
$C_5H_{10}O_2$	Isopropyl acetate	88.6	32.93	37.20
$C_5H_{10}O_2$	Ethyl propanoate	99.1	33.88	39.21
$C_5H_{10}O_2$	Methyl butanoate	102.8	33.79	39.28
$C_5H_{10}O_2$	Methyl isobutanoate	92.5	32.61	37.32
$C_5H_{10}O_2$	Tetrahydrofurfuryl alcohol	178	45.2	
$C_5H_{10}O_3$	Diethyl carbonate	126		43.60
$C_5H_{10}O_3$	Ethylene glycol monomethyl ether acetate	143	43.9	
$C_5H_{10}S$	Thiacyclohexane	141.8	35.96	42.58
$C_5H_{10}S$	Cyclopentanethiol	132.1	35.32	41.42
$C_5H_{11}Br$	1-Bromopentane	129.8	35.01	41.28
$C_5H_{11}Cl$	1-Chloropentane	107.8	33.15	38.24
$C_5H_{11}Cl$	2-Chloropentane	97.0	31.79	36.03
$C_5H_{11}Cl$	1-Chloro-3-methylbutane	98.9	32.02	36.24
$C_5H_{11}I$	1-Iodopentane	155		45.27
$C_5H_{11}N$	Piperidine	106.22		39.29
C_5H_{12}	Pentane	36.06	25.79	26.43
C_5H_{12}	Isopentane	27.88	24.69	24.85
C_5H_{12}	Neopentane	9.48	22.74	21.84
$C_5H_{12}O$	1-Pentanol	137.98	44.36	57.02
$C_5H_{12}O$	2-Pentanol	119.3	41.40	54.21
$C_5H_{12}O$	3-Pentanol	116.25		54.0
$C_5H_{12}O$	2-Methyl-1-butanol	128		55.16
$C_5H_{12}O$	3-Methyl-1-butanol	131.1	44.07	55.61
$C_5H_{12}O$	2-Methyl-2-butanol	102.4	39.04	50.10
$C_5H_{12}O$	3-Methyl-2-butanol	112.9		53.0
$C_5H_{12}O$	Butyl methyl ether	70.16	29.55	32.37
$C_5H_{12}O$	*sec*-Butyl methyl ether	59.1	28.09	30.23
$C_5H_{12}O$	Methyl *tert*-butyl ether	55.2	27.94	29.82
$C_5H_{12}O$	Isobutyl methyl ether	58.6	28.02	30.13
$C_5H_{12}O$	Ethyl propyl ether	63.21	28.94	31.43
$C_5H_{12}O$	Ethyl isopropyl ether	54.1	28.21	30.08
$C_5H_{12}O_2$	1-Ethoxy-2-methoxyethane	102.1	34.33	39.83
$C_5H_{12}O_2$	1,5-Pentanediol	239	60.7	
$C_5H_{12}O_2$	Ethylene glycol monopropyl ether	149.8	41.40	52.12
$C_5H_{12}O_2$	Diethoxymethane	88	31.33	35.65
$C_5H_{12}O_3$	Diethylene glycol monomethyl ether	193	46.6	
$C_5H_{12}S$	1-Pentanethiol	126.6	34.88	41.24

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H$(25°C) kJ/mol
$C_5H_{12}S$	2-Methyl-1-butanethiol	119.1	33.79	39.45
$C_5H_{12}S$	2-Methyl-2-butanethiol	99.1	31.37	35.67
$C_5H_{12}S$	Butyl methyl sulfide	123.5	34.47	40.46
$C_5H_{12}S$	*tert*-Butyl methyl sulfide	99	31.47	35.84
$C_5H_{12}S$	Ethyl propyl sulfide	118.6	34.24	39.97
$C_5H_{12}S$	Ethyl isopropyl sulfide	107.5	32.74	37.78
$C_5H_{13}N$	Pentylamine	104.3	34.01	40.08
$C_5H_{13}N$	Ethylisopropylamine	69.6	29.94	33.13
C_6ClF_5	Chloropentafluorobenzene	117.96	34.76	41.07
C_6F_6	Hexafluorobenzene	80.26	31.66	35.71
C_6HF_5	Pentafluorobenzene	85.74	32.15	36.27
$C_6H_4Cl_2$	*o*-Dichlorobenzene	180	39.66	50.21
$C_6H_4Cl_2$	*m*-Dichlorobenzene	173	38.62	48.58
$C_6H_4Cl_2$	*p*-Dichlorobenzene	174	38.79	49.0
$C_6H_4F_2$	*o*-Difluorobenzene	94	32.21	36.18
$C_6H_4F_2$	*m*-Difluorobenzene	82.6	31.10	34.59
$C_6H_4F_2$	*p*-Difluorobenzene	89	31.77	35.54
C_6H_5Br	Bromobenzene	156.06		44.54
C_6H_5Cl	Chlorobenzene	131.72	35.19	40.97
C_6H_5F	Fluorobenzene	84.73	31.19	34.58
C_6H_5I	Iodobenzene	188.4	39.5	
$C_6H_5NO_2$	Nitrobenzene	210.8		55.01
C_6H_6	Benzene	80.09	30.72	33.83
C_6H_6ClN	*o*-Chloroaniline	208.8	44.4	
C_6H_6O	Phenol	181.87	45.69	57.82
C_6H_6S	Benzenethiol	169.1	39.93	47.56
C_6H_7N	Aniline	184.17	42.44	55.83
C_6H_7N	2-Methylpyridine	129.38	36.17	42.48
C_6H_7N	3-Methylpyridine	144.14	37.35	44.44
C_6H_7N	4-Methylpyridine	145.36	37.51	44.56
C_6H_7N	1-Cyclopentenecarbonitrile			44.98
C_6H_9N	Cyclopentanecarbonitrile			43.43
$C_6H_9NO_3$	Triacetamide			60.41
C_6H_{10}	Cyclohexene	82.98	30.46	33.47
$C_6H_{10}O$	Cyclohexanone	155.43		45.06
$C_6H_{10}O$	Mesityl oxide	130	36.1	
$C_6H_{10}O_2$	Methyl cyclobutanecarboxylate	135.5	37.13	44.72
$C_6H_{10}O_3$	Propanoic anhydride	170	41.7	
$C_6H_{10}O_4$	Diethyl oxalate	185.7	42.0	
$C_6H_{10}O_4$	Ethylene glycol diacetate	190		61.44
$C_6H_{11}N$	Hexanenitrile	163.65		47.91
C_6H_{12}	1-Hexene	63.48		30.61
C_6H_{12}	*cis*-2-Hexene	68.8		32.19
C_6H_{12}	*trans*-2-Hexene	67.9		31.60
C_6H_{12}	*cis*-3-Hexene	66.4		31.23
C_6H_{12}	*trans*-3-Hexene	67.1		31.55
C_6H_{12}	2-Methyl-1-pentene	62.1		30.48
C_6H_{12}	3-Methyl-1-pentene	54.2		28.62
C_6H_{12}	4-Methyl-1-pentene	53.9		28.71
C_6H_{12}	2-Methyl-2-pentene	67.3		31.60
C_6H_{12}	3-Methyl-*cis*-2-pentene	67.7		32.09
C_6H_{12}	3-Methyl-*trans*-2-pentene	70.4		31.35
C_6H_{12}	4-Methyl-*cis*-2-pentene	56.3		29.48
C_6H_{12}	4-Methyl-*trans*-2-pentene	58.6		29.97
C_6H_{12}	2-Ethyl-1-butene	64.7		31.13
C_6H_{12}	2,3-Dimethyl-1-butene	55.6		29.18
C_6H_{12}	3,3-Dimethyl-1-butene	41.2		26.61
C_6H_{12}	2,3-Dimethyl-2-butene	73.3	29.64	32.51

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H(25°C)$ kJ/mol
C_6H_{12}	Cyclohexane	80.73	29.97	33.01
C_6H_{12}	Methylcyclopentane	71.8	29.08	31.64
C_6H_{12}	Ethylcyclobutane	70.8	28.67	31.24
$C_6H_{12}Cl_2$	1,2-Dichlorohexane	173		48.16
$C_6H_{12}O$	Butyl vinyl ether	94	31.58	36.17
$C_6H_{12}O$	2-Hexanone	127.6	36.35	43.14
$C_6H_{12}O$	3-Hexanone	123.5	35.36	42.47
$C_6H_{12}O$	3-Methyl-2-pentanone	117.5	34.16	40.53
$C_6H_{12}O$	4-Methyl-2-pentanone	116.5	34.49	40.61
$C_6H_{12}O$	2-Methyl-3-pentanone	113.5	33.84	39.79
$C_6H_{12}O$	3,3-Dimethyl-2-butanone	106.1	33.39	37.91
$C_6H_{12}O$	Cyclohexanol	160.84		62.01
$C_6H_{12}O_2$	Butyl acetate	126.1	36.28	43.86
$C_6H_{12}O_2$	*tert*-Butyl acetate	95.1	33.07	38.03
$C_6H_{12}O_2$	Isobutyl acetate	116.5	35.9	
$C_6H_{12}O_2$	Propyl propanoate	122.5	35.54	43.45
$C_6H_{12}O_2$	Ethyl butanoate	121.5	35.47	42.68
$C_6H_{12}O_2$	Ethyl 2-methylpropanoate	110.1	33.67	39.83
$C_6H_{12}O_2$	Methyl pentanoate	127.4	35.36	43.10
$C_6H_{12}O_2$	Methyl 2,2-dimethylpropanoate	101.1	33.42	38.76
$C_6H_{12}O_3$	Ethylene glycol monoethyl ether acetate	156.4	40.76	52.61
$C_6H_{12}S$	Cyclohexanethiol	158.9	37.06	44.57
$C_6H_{13}Br$	1-Bromohexane	155.3		45.89
$C_6H_{13}Cl$	1-Chlorohexane	135	35.67	42.83
$C_6H_{13}I$	1-Iodohexane	181		49.75
$C_6H_{13}N$	Cyclohexylamine	134	36.14	43.67
C_6H_{14}	Hexane	68.73	28.85	31.56
C_6H_{14}	2-Methylpentane	60.26	27.79	29.89
C_6H_{14}	3-Methylpentane	63.27	28.06	30.28
C_6H_{14}	2,2-Dimethylbutane	49.73	26.31	27.68
C_6H_{14}	2,3-Dimethylbutane	57.93	27.38	29.12
$C_6H_{14}N_2$	Azopropane	114		39.88
$C_6H_{14}O$	1-Hexanol	157.6	44.50	61.61
$C_6H_{14}O$	2-Hexanol	140	41.01	58.46
$C_6H_{14}O$	2-Methyl-1-pentanol	149	50.2	
$C_6H_{14}O$	4-Methyl-1-pentanol	151.9	44.46	60.47
$C_6H_{14}O$	2-Methyl-2-pentanol	121.1	39.59	54.77
$C_6H_{14}O$	4-Methyl-2-pentanol	131.6	44.2	
$C_6H_{14}O$	2-Ethyl-1-butanol	147	43.2	
$C_6H_{14}O$	Dipropyl ether	90.08	31.31	35.69
$C_6H_{14}O$	Diisopropyl ether	68.51	29.10	32.12
$C_6H_{14}O$	Butyl ethyl ether	92.3	31.63	36.32
$C_6H_{14}O$	Methyl pentyl ether	99	32.02	36.85
$C_6H_{14}O_2$	2-Methyl-2,4-pentanediol	197.1	57.3	
$C_6H_{14}O_2$	Ethylene glycol monobutyl ether	168.4		56.59
$C_6H_{14}O_2$	1,1-Diethoxyethane	102.25	36.28	43.20
$C_6H_{14}O_2$	Ethylene glycol diethyl ether	119.4	36.28	43.20
$C_6H_{14}O_3$	Bis(ethoxymethyl) ether	140.6	36.17	44.69
$C_6H_{14}O_3$	Diethylene glycol monoethyl ether	196	47.5	
$C_6H_{14}O_3$	Diethylene glycol dimethyl ether	162	36.17	44.69
$C_6H_{14}O_4$	Triethylene glycol	285	71.4	
$C_6H_{14}S$	Dipropyl sulfide	142.9	36.60	44.21
$C_6H_{14}S$	Diisopropyl sulfide	120.1	33.80	39.60
$C_6H_{14}S$	Isopropyl propyl sulfide	132.1	35.11	41.78
$C_6H_{14}S$	Butyl ethyl sulfide	144.3	37.01	44.51
$C_6H_{14}S$	Methyl pentyl sulfide	145.1	37.41	45.24
$C_6H_{15}N$	Hexylamine	132.8	36.54	45.10
$C_6H_{15}N$	Butylethylamine	107.5	33.97	40.15

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H(25°C)$ kJ/mol
$C_6H_{15}N$	Dipropylamine	109.3	33.47	40.04
$C_6H_{15}N$	Diisopropylamine	83.9	30.40	34.61
$C_6H_{15}N$	Isopropylpropylamine	96.9	32.14	37.23
$C_6H_{15}N$	Triethylamine	89	31.01	34.84
C_6MoO_6	Molybdenum hexacarbonyl	701	72.51	
$C_7H_3F_5$	2,3,4,5,6-Pentafluorotoluene	117.5	34.75	41.12
$C_7H_5F_3$	(Trifluoromethyl)benzene	102.1	32.63	37.60
C_7H_5N	Benzonitrile	191.1	45.9	
C_7H_6O	Benzaldehyde	179.0	42.5	
$C_7H_6O_2$	Salicylaldehyde	197	38.2	
C_7H_7Cl	*o*-Chlorotoluene	159.0	37.5	
C_7H_7Cl	*p*-Chlorotoluene	162.4	38.7	
C_7H_7F	*o*-Fluorotoluene	115	35.4	
C_7H_7F	*p*-Fluorotoluene	116.6	34.08	39.42
C_7H_8	Toluene	110.63	33.18	38.01
C_7H_8O	*o*-Cresol	191.04	45.19	
C_7H_8O	*m*-Cresol	202.27	47.40	61.71
C_7H_8O	*p*-Cresol	201.98	47.45	
C_7H_8O	Benzyl alcohol	205.31	50.48	
C_7H_8O	Anisole	153.7	38.97	46.90
C_7H_9N	Benzylamine	185		60.16
C_7H_9N	*o*-Methylaniline	200.3	44.6	
C_7H_9N	*m*-Methylaniline	203.3	44.9	
C_7H_9N	*p*-Methylaniline	200.4	44.3	
C_7H_9N	1-Cyclohexenecarbonitrile			53.55
C_7H_9N	2,3-Dimethylpyridine	161.12	39.08	47.82
C_7H_9N	2,4-Dimethylpyridine	158.38	38.53	47.49
C_7H_9N	2,5-Dimethylpyridine	156.98	38.68	47.04
C_7H_9N	2,6-Dimethylpyridine	144.01	37.46	45.34
C_7H_9N	3,4-Dimethylpyridine	179.10	39.99	50.50
C_7H_9N	3,5-Dimethylpyridine	171.84	39.46	49.33
$C_7H_{10}O$	Dicyclopropyl ketone	161		53.70
$C_7H_{11}N$	Cyclohexanecarbonitrile			51.92
C_7H_{12}	1-Methylbicyclo(3,1,0)hexane	93.1	31.07	34.77
$C_7H_{12}O_4$	Diethyl malonate	200	54.8	
C_7H_{14}	1-Heptene	93.64		35.49
C_7H_{14}	*cis*-2-Heptene	98.4		36.26
C_7H_{14}	*trans*-2-Heptene	98		36.27
C_7H_{14}	*cis*-3-Heptene	95.8		35.81
C_7H_{14}	*trans*-3-Heptene	95.7		35.84
C_7H_{14}	*cis*-3-Methyl-3-hexene	95.4		36.31
C_7H_{14}	*trans*-3-Methyl-3-hexene	93.5		35.70
C_7H_{14}	2,4-Dimethyl-1-pentene	81.6		33.03
C_7H_{14}	4,4-Dimethyl-1-pentene	72.5		31.13
C_7H_{14}	2,4-Dimethyl-2-pentene	83.4		34.19
C_7H_{14}	*cis*-4,4-Dimethyl-2-pentene	80.4		32.56
C_7H_{14}	*trans*-4,4-Dimethyl-2-pentene	76.7		32.81
C_7H_{14}	2-Ethyl-3-methyl-1-butene	89		34.35
C_7H_{14}	2,3,3-Trimethyl-1-butene	77.9		32.09
C_7H_{14}	Methylcyclohexane	100.93	31.27	35.36
C_7H_{14}	Ethylcyclopentane	103.5	31.96	36.40
C_7H_{14}	*cis*-1,3-Dimethylcyclopentane	90.8	30.40	34.20
$C_7H_{14}O$	2-Heptanone	151.05		47.24
$C_7H_{14}O$	2,2-Dimethyl-3-pentanone	125.6	36.09	42.34
$C_7H_{14}O$	2,4-Dimethyl-3-pentanone	125.4	34.64	41.51
$C_7H_{14}O$	1-Methylcyclohexanol	155	79.0	
$C_7H_{14}O$	*cis*-2-Methylcyclohexanol	165	48.5	
$C_7H_{14}O$	*trans*-2-Methylcyclohexanol	167.5	53.0	

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H(25°C)$ kJ/mol
$C_7H_{14}O_2$	Pentyl acetate	149.2	38.42	48.56
$C_7H_{14}O_2$	Isopentyl acetate	142.5	37.5	
$C_7H_{14}O_2$	Ethyl pentanoate	146.1	36.96	47.01
$C_7H_{14}O_2$	Ethyl 3-methylbutanoate	135.0	37.0	
$C_7H_{14}O_2$	Ethyl 2,2-dimethylpropanoate	118.4	34.51	41.25
$C_7H_{14}O_2$	Methyl hexanoate	149.5	38.55	48.04
$C_7H_{15}Br$	1-Bromoheptane	179		50.60
$C_7H_{15}Cl$	1-Chloroheptane	159		47.66
C_7H_{16}	Heptane	98.5	31.77	36.57
C_7H_{16}	2-Methylhexane	90.04	30.62	34.87
C_7H_{16}	3-Methylhexane	92	30.9	
C_7H_{16}	3-Ethylpentane	93.5	31.12	35.22
C_7H_{16}	2,2-Dimethylpentane	79.2	29.23	32.42
C_7H_{16}	2,3-Dimethylpentane	89.78	30.46	34.26
C_7H_{16}	2,4-Dimethylpentane	80.49	29.55	32.88
C_7H_{16}	3,3-Dimethylpentane	86.06	29.62	33.03
C_7H_{16}	2,2,3-Trimethylbutane	80.86	28.90	32.05
$C_7H_{16}O$	Hexyl methyl ether	126.1	34.93	42.07
$C_7H_{16}O$	1-Heptanol	176.45		66.81
$C_7H_{16}O$	3-Heptanol	157	42.5	
$C_7H_{16}O$	Butyl propyl ether	118.1	33.72	40.22
$C_7H_{16}O$	Ethyl pentyl ether	117.6	34.41	41.01
$C_7H_{17}N$	Heptylamine	156		49.96
C_8F_{18}	Perfluorooctane	105.9	33.38	41.13
C_8H_8	Styrene	145	38.7	
C_8H_8O	Acetophenone	202	43.98	55.40
$C_8H_8O_2$	Methyl benzoate	199		55.57
$C_8H_8O_3$	Methyl salicylate	222.9	46.7	
C_8H_{10}	Ethylbenzene	136.19	35.57	42.24
C_8H_{10}	*o*-Xylene	144.5	36.24	43.43
C_8H_{10}	*m*-Xylene	139.12	35.66	42.65
C_8H_{10}	*p*-Xylene	138.37	35.67	42.40
$C_8H_{10}O$	2,4-Xylenol	210.98		64.96
$C_8H_{10}O$	2,5-Xylenol	211.1	46.9	
$C_8H_{10}O$	2,6-Xylenol	201.07		75.31
$C_8H_{10}O$	3,4-Xylenol	227		85.03
$C_8H_{10}O$	3,5-Xylenol	221.74		82.01
$C_8H_{10}O$	Phenetole	169.81		51.04
$C_8H_{11}N$	*N*-Ethylaniline	203.0		58.3
$C_8H_{11}N$	*N,N*-Dimethylaniline	194.15		52.83
$C_8H_{11}N$	2,4-Dimethylaniline	214		61.3
$C_8H_{11}N$	2,5-Dimethylaniline	214		61.7
$C_8H_{11}N$	2,3,6-Trimethylpyridine	171.6	39.95	50.61
$C_8H_{11}N$	2,4,6-Trimethylpyridine	170.6	39.87	50.33
C_8H_{14}	1-Octyne	126.3	35.83	42.30
C_8H_{14}	2-Octyne	137.6	37.26	44.49
C_8H_{14}	3-Octyne	133.1	36.94	43.92
C_8H_{14}	4-Octyne	131.6	36.0	42.73
$C_8H_{14}O_3$	Butanoic anhydride	200	50.0	
$C_8H_{15}N$	Octanenitrile	205.25		56.80
C_8H_{16}	1-Octene	121.29	34.07	40.34
C_8H_{16}	*cis*-2,2-Dimethyl-3-hexene	105.5		36.86
C_8H_{16}	*trans*-2,2-Dimethyl-3-hexene	100.8		37.03
C_8H_{16}	3-Ethyl-2-methyl-1-pentene	109.5		37.27
C_8H_{16}	2,4,4-Trimethyl-1-pentene	101.4		35.59
C_8H_{16}	2,4,4-Trimethyl-2-pentene	104.9		37.23
C_8H_{16}	Ethylcyclohexane	131.9	34.04	40.56
C_8H_{16}	1,1-Dimethylcyclohexane	119.6	32.51	37.92

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H(25°C)$ kJ/mol
C_8H_{16}	*cis*-1,2-Dimethylcyclohexane	129.8	33.47	39.70
C_8H_{16}	*trans*-1,2-Dimethylcyclohexane	123.5	32.96	38.36
C_8H_{16}	*cis*-1,3-Dimethylcyclohexane	120.1	32.91	38.26
C_8H_{16}	*trans*-1,3-Dimethylcyclohexane	124.5	33.39	39.16
C_8H_{16}	*cis*-1,4-Dimethylcyclohexane	124.4	33.28	39.02
C_8H_{16}	*trans*-1,4-Dimethylcyclohexane	119.4	32.56	37.90
C_8H_{16}	Propylcyclopentane	131	34.70	41.08
C_8H_{16}	Isopropylcyclopentane	126.5	33.56	39.44
C_8H_{16}	1-Ethyl-1-methylcyclopentane	121.6	33.20	38.85
$C_8H_{16}O$	2,2,4-Trimethyl-3-pentanone	135.1	35.64	43.30
$C_8H_{16}O_2$	Octanoic acid	239	58.5	
$C_8H_{16}O_2$	2-Ethylhexanoic acid	228		75.60
$C_8H_{16}O_2$	Isobutyl isobutanoate	148.6	38.2	
$C_8H_{16}O_2$	Ethyl hexanoate	167		51.72
$C_8H_{16}O_2$	Methyl heptanoate	174		51.62
$C_8H_{17}Br$	1-Bromooctane	200		55.77
$C_8H_{17}Cl$	1-Chlorooctane	181.5		52.42
$C_8H_{17}F$	1-Fluorooctane	142.4	40.43	49.65
C_8H_{18}	Octane	125.67	34.41	41.49
C_8H_{18}	2-Methylheptane	117.66	33.26	39.67
C_8H_{18}	3-Methylheptane	118.9	33.66	39.83
C_8H_{18}	4-Methylheptane	117.72	33.35	39.69
C_8H_{18}	3-Ethylhexane	118.6	33.59	39.64
C_8H_{18}	2,2-Dimethylhexane	106.86	32.07	37.28
C_8H_{18}	2,3-Dimethylhexane	115.62	33.17	38.78
C_8H_{18}	2,4-Dimethylhexane	109.5	32.51	37.76
C_8H_{18}	2,5-Dimethylhexane	109.12	32.54	37.85
C_8H_{18}	3,3-Dimethylhexane	111.97	32.31	37.53
C_8H_{18}	3,4-Dimethylhexane	117.73	33.24	38.97
C_8H_{18}	3-Ethyl-2-methylpentane	115.66	32.93	38.52
C_8H_{18}	3-Ethyl-3-methylpentane	118.27	32.78	37.99
C_8H_{18}	2,2,3-Trimethylpentane	110	31.94	36.91
C_8H_{18}	2,2,4-Trimethylpentane	99.22	30.79	35.14
C_8H_{18}	2,3,3-Trimethylpentane	114.8	32.12	37.27
C_8H_{18}	2,3,4-Trimethylpentane	113.5	32.36	37.75
C_8H_{18}	2,2,3,3-Tetramethylbutane	106.45		42.90
$C_8H_{18}N_2$	Azobutane			49.31
$C_8H_{18}O$	1-Octanol	195.16		70.98
$C_8H_{18}O$	2-Octanol	180	44.4	
$C_8H_{18}O$	2-Ethyl-1-hexanol	184.6	54.2	
$C_8H_{18}O$	Dibutyl ether	140.28	36.49	44.97
$C_8H_{18}O$	Di-*sec*-butyl ether	121.1	34.06	40.84
$C_8H_{18}O$	Di-*tert*-butyl ether	107.23	32.15	37.61
$C_8H_{18}O_2$	1,2-Dipropoxyethane			50.62
$C_8H_{18}O_3$	Diethylene glycol diethyl ether	188		58.40
$C_8H_{18}S$	Dibutyl sulfide	185		52.96
$C_8H_{18}S$	Di-*tert*-butyl sulfide	149.1	33.26	43.76
$C_8H_{18}S$	Diisobutyl sulfide	171		48.71
$C_8H_{19}N$	Dibutylamine	159.6	38.44	49.45
$C_8H_{19}N$	2-Ethylhexylamine	169.2	40.0	
C_9H_7N	Quinoline	237.16	49.7	59.30
C_9H_7N	Isoquinoline	243.22	49.0	60.26
C_9H_{10}	Cyclopropylbenzene	173.6		50.22
C_9H_{10}	Indan	177.97	39.63	48.79
$C_9H_{10}O_2$	Benzyl acetate	213	49.4	
C_9H_{12}	Propylbenzene	159.24		46.22
C_9H_{12}	Isopropylbenzene	152.41		45.13
C_9H_{12}	1,2,3-Trimethylbenzene	176.12		49.05

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H(25°C)$ kJ/mol
C_9H_{12}	1,2,4-Trimethylbenzene	169.38		47.93
C_9H_{12}	1,3,5-Trimethylbenzene	164.74		47.50
$C_9H_{14}O_6$	Triacetin	259		85.74
C_9H_{18}	Butylcyclopentane	156.6	36.16	45.89
C_9H_{18}	Propylcyclohexane	156.7		45.08
C_9H_{18}	Isopropylcyclohexane	154.8		44.02
$C_9H_{18}O$	2-Nonanone	195.3		56.44
$C_9H_{18}O$	5-Nonanone	188.45		53.30
$C_9H_{18}O$	2,6-Dimethyl-4-heptanone	169.4		50.92
$C_9H_{18}O_2$	Methyl octanoate	192.9		56.41
C_9H_{20}	Nonane	150.82	37.18	46.55
C_9H_{20}	2,2,5-Trimethylhexane	124.09	33.65	40.16
C_9H_{20}	2,3,5-Trimethylhexane	131.4	34.43	41.41
C_9H_{20}	3,3-Diethylpentane	146.3	34.61	42.0
C_9H_{20}	2,2,4,4-Tetramethylpentane	122.29	32.51	38.49
$C_9H_{20}O$	1-Nonanol	213.37		76.86
$C_{10}H_7Br$	1-Bromonaphthalene	281	39.3	
$C_{10}H_7Cl$	1-Chloronaphthalene	259	52.1	
$C_{10}H_8$	Naphthalene	217.9	43.2	
$C_{10}H_9N$	2-Methylquinoline	246.5		66.1
$C_{10}H_9N$	4-Methylquinoline	262		67.6
$C_{10}H_9N$	6-Methylquinoline	258.6		67.7
$C_{10}H_9N$	8-Methylquinoline	247.5		65.7
$C_{10}H_{12}$	1,2,3,4-Tetrahydronaphthalene	207.6	43.9	
$C_{10}H_{14}$	Butylbenzene	183.31	38.87	51.36
$C_{10}H_{14}$	*sec*-Butylbenzene	173.3		47.98
$C_{10}H_{14}$	*tert*-Butylbenzene	169.1		47.71
$C_{10}H_{14}$	Isobutylbenzene	172.79		47.86
$C_{10}H_{14}$	1-Isopropyl-4-methylbenzene	177.1	38.2	
$C_{10}H_{16}O$	(+)-Camphor	207.4	59.5	
$C_{10}H_{18}$	*cis*-Decahydronaphthalene	195.8	41.0	
$C_{10}H_{18}$	*trans*-Decahydronaphthalene	187.3	40.2	
$C_{10}H_{19}N$	Decanenitrile	243		66.84
$C_{10}H_{20}$	1-Decene	170.5		50.43
$C_{10}H_{20}$	Butylcyclohexane	180.9		49.36
$C_{10}H_{20}O_2$	2-Ethylhexyl acetate	199	43.5	
$C_{10}H_{20}O_2$	Isopentyl isopentanoate	190.4	45.9	
$C_{10}H_{22}$	Decane	174.15	39.58	51.42
$C_{10}H_{22}$	2-Methylnonane	167.1	38.23	49.63
$C_{10}H_{22}$	3-Methylnonane	167.9	38.26	49.71
$C_{10}H_{22}$	5-Methylnonane	165.1	38.14	49.34
$C_{10}H_{22}$	2,4-Dimethyloctane	156	36.47	47.13
$C_{10}H_{22}O$	1-Decanol	231.1		81.50
$C_{10}H_{22}O$	Diisopentyl ether	172.5	35.1	
$C_{10}H_{22}S$	1-Decanethiol	240.6		65.48
$C_{11}H_{10}$	1-Methylnaphthalene	244.7	45.5	
$C_{11}H_{21}N$	Undecanenitrile	253		71.14
$C_{11}H_{22}$	Pentylcyclohexane	203.7		53.88
$C_{11}H_{24}$	Undecane	195.9	41.91	56.58
$C_{11}H_{24}$	2-Methyldecane	189.3	40.25	54.28
$C_{11}H_{24}$	4-Methyldecane	187	40.70	53.76
$C_{11}H_{24}$	2,4,7-Trimethyloctane	168.1	38.22	49.91
$C_{12}F_{27}N$	Tris(perfluorobutyl)amine	178	46.4	
$C_{12}H_{10}O$	Diphenyl ether	258.0	48.2	
$C_{12}H_{16}$	Cyclohexylbenzene	240.1		59.94
$C_{12}H_{22}$	Cyclohexylcyclohexane	238		57.98
$C_{12}H_{23}N$	Dodecanenitrile	277		76.12
$C_{12}H_{24}$	1-Dodecene	213.8		60.78

ENTHALPY OF VAPORIZATION (continued)

Mol. Form.	Name	t_b/°C	$\Delta_{vap}H(t_b)$ kJ/mol	$\Delta_{vap}H(25°C)$ kJ/mol
$C_{12}H_{26}$	2,2,4,6,6-Pentamethylheptane	177.8		48.97
$C_{12}H_{26}$	Dodecane	216.32	44.09	61.52
$C_{12}H_{26}O$	1-Dodecanol	259		91.96
$C_{12}H_{27}BO_3$	Tributyl borate	234	56.1	
$C_{12}H_{27}N$	Tributylamine	216.5	46.9	
$C_{13}H_{13}N$	*N*-Benzylaniline	306.5		79.6
$C_{13}H_{26}O_2$	Methyl dodecanoate	267		77.17
$C_{13}H_{28}$	Tridecane	235.47	46.20	66.68
$C_{14}H_{10}$	Phenanthrene	340		75.50
$C_{14}H_{12}O_2$	Benzyl benzoate	323.5	53.6	
$C_{14}H_{27}N$	Tetradecanenitrile			85.29
$C_{14}H_{30}$	Tetradecane	253.58	48.16	71.73
$C_{14}H_{30}O$	1-Tetradecanol	289		102.20
$C_{15}H_{32}$	Pentadecane	270.6	50.08	76.77
$C_{16}H_{22}O_4$	Dibutyl phthalate	340	79.2	
$C_{16}H_{32}$	1-Hexadecene	284.9		80.25
$C_{16}H_{34}$	Hexadecane	286.86	51.84	81.35
$C_{17}H_{36}$	Heptadecane	302.0	53.58	86.47
$C_{18}H_{34}O_2$	Oleic acid	360	67.4	
$C_{18}H_{38}$	Octadecane	316.3	55.23	91.44
$C_{19}H_{40}$	Nonadecane	329.9	56.93	96.4
$C_{20}H_{42}$	Eicosane	343	58.49	101.81

ENTHALPY OF FUSION

This table lists the molar enthalpy (heat) of fusion, $\Delta_{fus}H$, of over 800 inorganic and organic compounds. All values refer to the enthalpy change at equilibrium between the liquid phase and the most stable solid phase at the transition temperature. Most values of $\Delta_{fus}H$ are given at the normal melting point t_m. However, a "t" following the entry in the melting point column indicate a triple-point temperature, where the solid, liquid, and gas phases are in equilibrium. Substances are listed by molecular formula in the Hill order, with substances containing carbon (except graphite) following those that do not contain carbon.

All temperatures are given on the ITS-90 scale.

A * following an entry indicates that the value includes the enthalpy of transition between crystalline phases whose transformation occurs within 1˚C of the melting point.

REFERENCES

1. Chase, M. W., Davies, C. A., Downey, J. R., Frurip, D. J., McDonald, R. A., and Syverud, A. N., *JANAF Thermochemical Tables, Third Edition, J. Phys. Chem. Ref. Data*, Vol. 14, Suppl. 1, 1985.
2. Gurvich, L. V., Veyts, I. V., and Alcock, C. B., *Thermodynamic Properties of Individual Substances*, *Fourth Edition*; Vol. 2, Hemisphere Publishing Corp., New York, 1991; Vol. 3, CRC Press, Boca Raton, FL, 1994.
3. Dinsdale, A. T., *CALPHAD*, 15, 317, 1991
4. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series*, IV/8A, *Enthalpies of Fusion and Transition of Organic Compounds*, Springer-Verlag, Heidelberg, 1995.
5. *Landolt-Börnstein, Numerical Values and Functions for Physics, Chemistry, Astronomy, Geophysics, and Technology, Sixth Edition*, Vol. 2, Part 4, Springer-Verlag, Heidelberg, 1961.
6. Janz, G. J., et al., *Physical Properties Data Compilations Relevant to Energy Storage. II. Molten Salts*, Nat. Stand. Ref. Data Sys.- Nat. Bur. Standards (U.S.), No. 61, Part 2, 1979.
7. *TRC Thermodynamic Tables*, Thermodynamic Research Center, Texas A&M University, College Station, TX.

Molecular formula	Name	t_m/˚C	$\Delta_{fus}H$/kJ mol^{-1}
Ag	Silver	961.78	11.28
AgBr	Silver(I) bromide	432	9.12
AgCl	Silver(I) chloride	455	13.2
AgI	Silver(I) iodide	558	9.41
$AgNO_3$	Silver(I) nitrate	212	11.5
Ag_2S	Silver(I) sulfide	825	14.1
Al	Aluminum	660.32	10.789
$AlBr_3$	Aluminum bromide	97.5	11.25
$AlCl_3$	Aluminum chloride	192.6	35.4
AlF_3	Aluminum fluoride	2250 t	98
AlI_3	Aluminum iodide	188.28	15.9
Al_2O_3	Aluminum oxide	2053	111.4
Al_2S_3	Aluminum sulfide	1100	55
Am	Americium	1176	14.39
Ar	Argon	-189.36 t	1.18
As	Arsenic (gray)	817 t	24.44
$AsBr_3$	Arsenic(III) bromide	31.1	11.7
$AsCl_3$	Arsenic(III) chloride	-16	10.1
AsF_3	Arsenic(III) fluoride	-5.9	10.4
Au	Gold	1064.18	12.72
B	Boron	2075	50.2
BCl_3	Boron trichloride	-107	2.10
BF_3	Boron trifluoride	-126.8	4.20
BHO_2	Metaboric acid (<gamma> form)	236	14.3
BH_3O_3	Boric acid (orthoboric acid)	170.9	22.3
BN	Boron nitride	2966	81

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Molecular formula	Name	t_m/°C	$\Delta_{fus}H$/kJ mol^{-1}
$BNaO_2$	Sodium metaborate	966	36.2
B_2O_3	Boron oxide	450	24.56
Ba	Barium	727	7.12
$BaBr_2$	Barium bromide	857	32.2
$BaCl_2$	Barium chloride	962	15.85
BaF_2	Barium fluoride	1368	17.8
BaH_2	Barium hydride	1200	25
BaH_2O_2	Barium hydroxide	408	16
BaI_2	Barium iodide	711	26.5
BaO	Barium oxide	1972	46
BaO_4S	Barium sulfate	1580	40
BaS	Barium sulfide	2229	63
Be	Beryllium	1287	7.895
$BeBr_2$	Beryllium bromide	508	18
$BeCl_2$	Beryllium chloride	415	8.66
BeF_2	Beryllium fluoride	552	4.77
BeI_2	Beryllium iodide	470	18
BeO	Beryllium oxide	2577	86
BeO_4S	Beryllium sulfate	1127	6
Bi	Bismuth	271.40	11.145
$BiCl_3$	Bismuth trichloride	230	10.9
BrF_5	Bromine pentafluoride	-60.5	5.67
BrH	Hydrogen bromide	-86.80	2.41
BrIn	Indium(I) bromide	290	15
BrK	Potassium bromide	734	25.5
BrLi	Lithium bromide	552	17.6
BrNa	Sodium bromide	747	26.11
$BrNaO_3$	Sodium bromate	381	28.11
BrRb	Rubidium bromide	682	15.5
BrTl	Thallium(I) bromide	460	16.4
Br_2	Bromine	-7.2	10.57
Br_2Ca	Calcium bromide	742	29.1
Br_2Cd	Cadmium bromide	568	20.9
Br_2Fe	Iron(II) bromide	691	50.2
Br_2Hg	Mercury(II) bromide	236	17.9
Br_2Mg	Magnesium bromide	711	39.3
Br_2Pb	Lead(II) bromide	371	16.44
Br_2Sr	Strontium bromide	657	10.1
Br_2Zn	Zinc bromide	394	16.7
Br_3Ga	Gallium(III) bromide	121.5	12.1
Br_3In	Indium(III) bromide	420	26
Br_3Pu	Plutonium(III) bromide	681	55.2
Br_3U	Uranium(III) bromide	727	43.9
Br_4Sn	Tin(IV) bromide	29.1	12.2
Br_4Th	Thorium(IV) bromide	679	66.9
Br_4Ti	Titanium(IV) bromide	39	12.9
Br_4U	Uranium(IV) bromide	519	55.2
Br_5Ta	Tantalum(V) bromide	265	45.6
C	Carbon (graphite)	4489 t	117
Ca	Calcium	842	8.54
$CaCl_2$	Calcium chloride	775	28.05
CaF_2	Calcium fluoride	1418	30
CaH_2	Calcium hydride	1000	6.7
CaI_2	Calcium iodide	783	41.8
CaO	Calcium oxide	2898	80
CaO_4S	Calcium sulfate	1460	28
CaS	Calcium sulfide	2524	70
Cd	Cadmium	321.07	6.21

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Molecular formula	Name	t_m/°C	$\Delta_{fus}H$/kJ mol^{-1}
$CdCl_2$	Cadmium chloride	564	48.58
CdF_2	Cadmium fluoride	1110	22.6
CdI_2	Cadmium iodide	387	15.3
Ce	Cerium	798	5.46
$CeCl_3$	Cerium(III) chloride	817	54.4
ClCs	Cesium chloride	645	15.9
ClCu	Copper(I) chloride	430	10.2
ClH	Hydrogen chloride	-114.17	2.00
ClI	Iodine chloride	27.39	11.6
ClIn	Indium(I) chloride	211	21.3
ClK	Potassium chloride	771	26.53
ClLi	Lithium chloride	610	19.9
$ClLiO_4$	Lithium perchlorate	236	29
ClNa	Sodium chloride	800.7	28.16
$ClNaO_3$	Sodium chlorate	248	22.1
ClRb	Rubidium chloride	715	18.4
ClTl	Thallium(I) chloride	430	15.56
Cl_2	Chlorine	-101.5	6.40
Cl_2Co	Cobalt(II) chloride	740	45
Cl_2Cr	Chromium(II) chloride	814	32.2
Cl_2Cu	Copper(II) chloride	630	20.4
Cl_2Fe	Iron(II) chloride	677	43.01
Cl_2Hg	Mercury(II) chloride	276	19.41
Cl_2Mg	Magnesium chloride	714	43.1
Cl_2Mn	Manganese(II) chloride	650	30.7
Cl_2Ni	Nickel(II) chloride	1009	71.2
Cl_2Pb	Lead(II) chloride	501	21.75
Cl_2Sn	Tin(II) chloride	247.1	14.52
Cl_2Sr	Strontium chloride	874	17.5
Cl_3Fe	Iron(III) chloride	304	43.1
Cl_3Ga	Gallium(III) chloride	77.9	11.13
Cl_3In	Indium(III) chloride	583	27
Cl_3La	Lanthanum chloride	859	43.1
Cl_3OP	Phosphorus(V) oxychloride	1.18	13.1
Cl_3P	Phosphorus(III) chloride	-112	7.10
Cl_3Sb	Antimony(III) chloride	73.4	12.7
Cl_4OW	Tungsten(VI) oxytetrachloride	211	45
Cl_4Si	Tetrachlorosilane	-68.74	7.60
Cl_4Sn	Tin(IV) chloride	-34.07	9.20
Cl_4Th	Thorium(IV) chloride	770	40.2
Cl_4Ti	Titanium(IV) chloride	-24.12	9.97
Cl_4U	Uranium(IV) chloride	590	45
Cl_4V	Vanadium(IV) chloride	-25.7	2.30
Cl_4Zr	Zirconium(IV) chloride	437 t	50
Cl_5Mo	Molybdenum(V) chloride	194	19
Cl_5Nb	Niobium(V) chloride	204.7	38.3
Cl_5Ta	Tantalum(V) chloride	216	41.6
Cl_6W	Tungsten(VI) chloride	275	6.60
Co	Cobalt	1495	16.06
CoF_2	Cobalt(II) fluoride	1127	59
Cr	Chromium	1907	21.0
Cr_2O_3	Chromium(III) oxide	2329	130
Cs	Cesium	28.5	2.09
CsF	Cesium fluoride	703	21.7
CsHO	Cesium hydroxide	342.3	7.78
Cs_2O_4S	Cesium sulfate	1005	35.7
Cu	Copper	1084.62	12.93
CuF_2	Copper(II) fluoride	836	55

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ENTHALPY OF FUSION (continued)

Molecular formula	Name	t_m/˚C	$\Delta_{fus}H$/kJ mol^{-1}
CuO	Copper(II) oxide	1446	11.8
Dy	Dysprosium	1412	11.06
Er	Erbium	1529	19.9
Eu	Europium	822	9.21
FH	Hydrogen fluoride	-83.35	4.58
FK	Potassium fluoride	858	27.2
FLi	Lithium fluoride	848.2	27.09
FNa	Sodium fluoride	996	33.35
FRb	Rubidium fluoride	833	17.3
FTl	Thallium(I) fluoride	326	13.87
F_2	Fluorine	-219.66	0.51
F_2Fe	Iron(II) fluoride	1100	52
F_2HK	Potassium hydrogen fluoride	238.9	6.62
F_2Mg	Magnesium fluoride	1263	58.5
F_2Pb	Lead(II) fluoride	830	14.7
F_2Sr	Strontium fluoride	1477	28.5
F_3In	Indium(III) fluoride	1170	64
F_3Pu	Plutonium(III) fluoride	1396	59.8
F_4Pu	Plutonium(IV) fluoride	1027	65.3
F_4Th	Thorium(IV) fluoride	1110	44.0
F_4U	Uranium(IV) fluoride	1036	42.7
F_4Zr	Zirconium(IV) fluoride	932 t	64.2
F_5Nb	Niobium(V) fluoride	80	12.2
F_5V	Vanadium(V) fluoride	19.5	49.96
F_6Ir	Iridium(VI) fluoride	44	8.40
F_6Mo	Molybdenum(VI) fluoride	17.5	4.33
F_6Pu	Plutonium(VI) fluoride	52	17.6
F_6S	Sulfur hexafluoride	-50.7 t	5.02
F_6U	Uranium(VI) fluoride	64.0 t	19.1
F_6W	Tungsten(VI) fluoride	2.3	4.10
Fe	Iron	1538	13.81
FeI_2	Iron(II) iodide	587	45
FeO	Iron(II) oxide	1377	24
FeS	Iron(II) sulfide	1188	31.5
Fe_3O_4	Iron(II,III) oxide	1597	138
Ga	Gallium	29.76	5.576
GaI_3	Gallium(III) iodide	212	12.9
GaSb	Gallium antimonide	712	25.1
Ga_2O_3	Gallium(III) oxide	1806	100
Gd	Gadolinium	1313	10.0
Ge	Germanium	938.25	36.94
HI	Hydrogen iodide	-50.76	2.87
HKO	Potassium hydroxide	406	7.9
HLi	Lithium hydride	688.7	22.59
HLiO	Lithium hydroxide	471.1	20.88
HNO_3	Nitric acid	-41.6	10.5
HNaO	Sodium hydroxide	323	6.60
HORb	Rubidium hydroxide	382	8.0
H_2	Hydrogen	-259.34	0.12
H_2Mg	Magnesium hydride	327	14
H_2O	Water	0.00	6.01
H_2O_2	Hydrogen peroxide	-0.43	12.50
H_2O_2Sr	Strontium hydroxide	535	23
H_2O_4S	Sulfuric acid	10.31	10.71
H_2S	Hydrogen sulfide	-85.5	2.38
H_2Sr	Strontium hydride	1050	23
H_3N	Ammonia	-77.73	5.66
H_3O_2P	Hypophosphorous acid	26.5	9.7

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ENTHALPY OF FUSION (continued)

Molecular formula	Name	t_m/˚C	$\Delta_{fus}H$/kJ mol^{-1}
H_3O_3P	Phosphorous acid	74.4	12.8
H_3O_4P	Phosphoric acid	42.4	13.4
H_4IN	Ammonium iodide	551	21
H_4N_2	Hydrazine	1.4	12.6
$H_4N_2O_3$	Ammonium nitrate	210	6.40
Hf	Hafnium	2233	27.2
Hg	Mercury	-38.83	2.29
HgI_2	Mercury(II) iodide	259	18.9
Hg_2I_2	Mercury(I) iodide	290	27
Ho	Holmium	1474	17.0
IIn	Indium(I) iodide	364.4	17.26
IK	Potassium iodide	681	24
ILi	Lithium iodide	469	14.6
INa	Sodium iodide	660	23.6
IRb	Rubidium iodide	642	12.5
ITl	Thallium(I) iodide	441.7	14.73
I_2	Iodine	113.7	15.52
I_2Mg	Magnesium iodide	634	26
I_2Pb	Lead(II) iodide	410	23.4
I_2Sr	Strontium iodide	538	19.7
I_3In	Indium(III) iodide	207	18.48
I_4Si	Tetraiodosilane	120.5	19.7
I_4Th	Thorium(IV) iodide	570	61.4
I_4Ti	Titanium(IV) iodide	150	19.8
I_4U	Uranium(IV) iodide	506	70.7
In	Indium	156.60	3.281
InSb	Indium antimonide	525	25.5
In_2O_3	Indium(III) oxide	1912	105
Ir	Iridium	2446	41.12
K	Potassium	63.5	2.33
KNO_3	Potassium nitrate	337	10.1
K_2O_4S	Potassium sulfate	1069	36.4
K_2S	Potassium sulfide	948	16.15
Kr	Krypton	-157.38 t	1.64
La	Lanthanum	918	6.20
Li	Lithium	180.50	3.00
$LiNO_3$	Lithium nitrate	253	24.9
Li_2O_3Si	Lithium metasilicate	1201	28
Li_2O_4S	Lithium sulfate	859	7.50
Lu	Lutetium	1663	22
Mg	Magnesium	650	8.48
MgO	Magnesium oxide	2825	77
MgO_4S	Magnesium sulfate	1127	14.6
MgS	Magnesium sulfide	2226	63
Mg_2O_4Si	Magnesium orthosilicate	1897	71
Mn	Manganese	1246	12.91
MnO	Manganese(II) oxide	1839	54.4
Mo	Molybdenum	2623	37.48
MoO_3	Molybdenum(VI) oxide	801	48
$NNaO_3$	Sodium nitrate	307	15
NO	Nitric oxide	-163.6	2.30
NO_3Rb	Rubidium nitrate	305	5.60
NO_3Tl	Thallium(I) nitrate	206	9.6
N_2	Nitrogen	-210.0	0.71
N_2O	Nitrous oxide	-90.8	6.54
N_2O_4	Nitrogen tetroxide	-9.3	14.65
Na	Sodium	97.80	2.60
Na_2O	Sodium oxide	1132	48

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Molecular formula	Name	t_m/°C	$\Delta_{fus}H$/kJ mol^{-1}
Na_2O_3Si	Sodium metasilicate	1089	52
Na_2O_4S	Sodium sulfate	884	23.6
Na_2S	Sodium sulfide	1172	19
Nb	Niobium	2477	30
NbO	Niobium(II) oxide	1936	85
NbO_2	Niobium(IV) oxide	1901	92
Nb_2O_5	Niobium(V) oxide	1512	104.3
Nd	Neodymium	1021	7.14
Ne	Neon	-248.61 t	0.328
Ni	Nickel	1455	17.04
NiS	Nickel(II) sulfide	976	30.1
Np	Neptunium	644	3.20
OSr	Strontium oxide	2531	81
OTl_2	Thallium(I) oxide	579	30.3
OV	Vanadium(II) oxide	1789	63
OZn	Zinc oxide	1974	52.3
O_2	Oxygen	-218.79	0.44
O_2Si	Silicon dioxide (cristobalite)	1722	9.6
O_2Zr	Zirconium(IV) oxide	2709	87
O_3S	Sulfur trioxide	16.8	8.60
O_3Tl_2	Thallium(III) oxide	834	53
O_3W	Tungsten(VI) oxide	1472	73
O_3Y_2	Yttrium oxide	2438	105
O_4Os	Osmium(VIII) oxide	41	9.8
O_4SSr	Strontium sulfate	1606	36
O_4STl_2	Thallium(I) sulfate	632	23
O_5P_2	Phosphorus(V) oxide	562	27.2
O_5Ta_2	Tantalum(V) oxide	1784	120
O_5V_2	Vanadium(V) oxide	670	64.5
O_7Re_2	Rhenium(VII) oxide	297	64.2
Os	Osmium	3033	57.85
P	Phosphorus (white)	44.15	0.66
Pa	Protactinium	1572	12.34
Pb	Lead	327.46	4.782
PbS	Lead(II) sulfide	1113	49.4
Pd	Palladium	1554.9	16.74
Pr	Praseodymium	931	6.89
Pt	Platinum	1768.4	22.17
Pu	Plutonium	640	2.82
Rb	Rubidium	39.3	2.19
Re	Rhenium	3186	60.43
Rh	Rhodium	1964	26.59
Ru	Ruthenium	2334	38.59
S	Sulfur (monoclinic)	115.21	1.72
SSr	Strontium sulfide	2226	63
STl_2	Thallium(I) sulfide	448	12
Sb	Antimony	630.63	19.79
Sc	Scandium	1541	14.1
Se	Selenium (gray)	220.5	6.69
Si	Silicon	1414	50.21
Sm	Samarium	1074	8.62
Sn	Tin (white)	231.93	7.173
Sr	Strontium	777	7.43
Ta	Tantalum	3017	36.57
Tb	Terbium	1356	10.15
Tc	Technetium	2157	33.29
Te	Tellurium	449.51	17.49
Th	Thorium	1750	13.81

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ENTHALPY OF FUSION (continued)

Molecular formula	Name	t_m/°C	$\Delta_{fus}H$/kJ mol^{-1}
Ti	Titanium	1668	14.15
Tl	Thallium	304	4.14
Tm	Thulium	1545	16.84
U	Uranium	1135	9.14
V	Vanadium	1910	21.5
W	Tungsten	3422	52.31
Xe	Xenon	-111.79 t	2.27
Y	Yttrium	1522	11.4
Yb	Ytterbium	819	7.66
Zn	Zinc	419.53	7.068
Zr	Zirconium	1855	21.00
$CBaO_3$	Barium carbonate	1555	40
$CBrCl_3$	Bromotrichloromethane	-5.65	2.53
CBr_4	Tetrabromomethane	92.3	3.76
$CCaO_3$	Calcium carbonate (calcite)	1330	36
CCl_2O	Carbonyl chloride	-127.78	5.74
CCl_3F	Trichlorofluoromethane	-110.44	6.89
CCl_4	Tetrachloromethane	-22.62	2.56
CF_4	Tetrafluoromethane	-183.60	0.704
$CHBr_3$	Tribromomethane	8.69	11.05
$CHClF_2$	Chlorodifluoromethane	-157.42	4.12
$CHCl_3$	Trichloromethane	-63.41	9.5
CHF_3	Trifluoromethane	-155.2	4.06
CHI_3	Triiodomethane	121.2	16.44
CHN	Hydrogen cyanide	-13.29	8.41
$CHNaO_2$	Sodium formate	257.3	17.7
CHO_2Tl	Thallium(I) formate	101	10.9
CH_2Cl_2	Dichloromethane	-97.2	4.60
CH_2N_2	Cyanamide	45.56	7.27
CH_2N_4	Tetrazole	157.3	18.2
CH_2O_2	Formic acid	8.3	12.68
CH_3Br	Bromomethane	-93.68	5.98
CH_3Cl	Chloromethane	-97.7	6.43
CH_3NO	Formamide	2.49	8.44
CH_3NO_2	Nitromethane	-28.38	9.70
CH_3NO_3	Methyl nitrate	-83.0	8.24
CH_4	Methane	-182.47	0.94
CH_4N_2O	Urea	133.3	13.9
CH_4N_2S	Thiourea	178	14.0
CH_4O	Methanol	-97.53	3.215
CH_4S	Methanethiol	-123	5.91
CH_5N	Methylamine	-93.5	6.13
CH_6N_2	Methylhydrazine	-52.36	10.42
CK_2O_3	Potassium carbonate	898	27.6
CLi_2O_3	Lithium carbonate	723	41
$CMgO_3$	Magnesium carbonate	990	59
CNa_2O_3	Sodium carbonate	858.1	29.7
CO	Carbon monoxide	-205.02	0.833
COS	Carbon oxysulfide	-138.8	4.73
CO_2	Carbon dioxide	-56.56 t	9.02
CO_3Sr	Strontium carbonate	1494	40
CO_3Tl_2	Thallium(I) carbonate	272	18.4
CS_2	Carbon disulfide	-112.1	4.39
CSe_2	Carbon diselenide	-43.7	6.36
$C_2Br_2F_4$	1,2-Dibromotetrafluoroethane	-110.32	7.04
C_2ClF_3	Chlorotrifluoroethene	-158.2	5.55
C_2ClF_5	Chloropentafluoroethane	-99.4	1.86
$C_2Cl_2F_4$	1,2-Dichloro-1,1,2,2-tetrafluoroethane	-92.53	1.51

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Molecular formula	Name	t_m/°C	$\Delta_{fus}H$/kJ mol^{-1}
$C_2Cl_3F_3$	1,1,2-Trichloro-1,2,2-trifluoroethane	-36.22	2.47
C_2Cl_4	Tetrachloroethene	-22.3	10.88
$C_2Cl_4F_2$	1,1,2,2-Tetrachloro-1,2-difluoroethane	24.8	3.67
C_2Cl_6	Hexachloroethane	186.8 t	9.75
C_2F_4	Tetrafluoroethene	-131.15	7.72
C_2F_6	Hexafluoroethane	-100.05	2.69
C_2HCl_3	Trichloroethylene	-84.7	8.45
$C_2HCl_3O_2$	Trichloroacetic acid	59.2	5.90
C_2HCl_5	Pentachloroethane	-28.78	11.3
$C_2H_2Cl_2$	1,1-Dichloroethene	-122.56	6.51
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethene	-80.0	7.2
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane	-42.4	9.17
C_2H_3Br	Bromoethene	-139.54	5.12
C_2H_3Cl	Chloroethene	-153.84	4.92
$C_2H_3ClO_2$	Chloroacetic acid	63	12.28
$C_2H_3Cl_3$	1,1,1-Trichloroethane	-30.01	2.35
$C_2H_3Cl_3$	1,1,2-Trichloroethane	-36.3	11.46
$C_2H_3F_3$	1,1,1-Trifluoroethane	-111.3	6.19
$C_2H_3KO_2$	Potassium acetate	309	7.65
C_2H_3N	Acetonitrile	-43.82	8.16
$C_2H_3NaO_2$	Sodium acetate	328.2	17.9
C_2H_4	Ethylene	-169.15	3.35
$C_2H_4Br_2$	1,2-Dibromoethane	9.84	10.89
$C_2H_4Cl_2$	1,1-Dichloroethane	-96.9	7.87
$C_2H_4Cl_2$	1,2-Dichloroethane	-35.7	8.84
C_2H_4O	Acetaldehyde	-123.37	2.31
C_2H_4O	Ethylene oxide	-112.5	5.17
$C_2H_4O_2$	Acetic acid	16.64	11.73
C_2H_5Br	Bromoethane	-118.6	7.47
C_2H_5Cl	Chloroethane	-138.4	4.45
C_2H_5NO	Acetamide	80.16	15.59
$C_2H_5NO_2$	Nitroethane	-89.5	9.85
C_2H_6	Ethane	-182.79	2.72*
$C_2H_6N_2O$	*N*-Methylurea	104.9	14.0
C_2H_6O	Ethanol	-114.14	4.931
C_2H_6O	Dimethyl ether	-141.5	4.94
C_2H_6OS	Dimethyl sulfoxide	17.89	14.37
$C_2H_6O_2$	Ethylene glycol	-12.69	9.96
$C_2H_6O_2S$	Dimethyl sulfone	108.9	18.30
C_2H_6S	Ethanethiol	-147.88	4.98
C_2H_6S	Dimethyl sulfide	-98.24	7.99
$C_2H_6S_2$	Dimethyl disulfide	-84.67	9.19
C_2H_6Zn	Dimethyl zinc	-43.0	6.83
C_2H_7N	Dimethylamine	-92.18	5.94
$C_2H_8N_2$	1,2-Ethanediamine	11.14	22.58
$C_2H_8N_2$	1,1-Dimethylhydrazine	-57.20	10.07
$C_2H_8N_2$	1,2-Dimethylhydrazine	-8.9	13.64
C_2N_2	Cyanogen	-27.83	8.11
C_3F_6O	Perfluoroacetone	-125.45	8.38
C_3F_8	Perfluoropropane	-147.70	0.477
C_3H_3N	Acrylonitrile	-83.48	6.23
C_3H_3NS	Thiazole	-33.62	9.57
$C_3H_3N_3$	1,3,5-Triazine	80.3	14.56
C_3H_4	Allene	-136.6	4.40
$C_3H_4N_2$	1*H*-Pyrazole	70.7	14.0
$C_3H_4N_2$	Imidazole	89.5	12.82
$C_3H_4O_2$	Acrylic acid	12.5	9.51
C_3H_5N	Propanenitrile	-92.78	5.03

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Molecular formula	Name	t_m/°C	$\Delta_{fus}H$/kJ mol^{-1}
$C_3H_5N_3O_9$	Trinitroglycerol	13.5	21.87
C_3H_6	Propene	-185.24	3.003
C_3H_6	Cyclopropane	-127.58	5.44
$C_3H_6Br_2$	1,2-Dibromopropane	-55.49	8.94
$C_3H_6Br_2$	1,3-Dibromopropane	-34.5	14.6
$C_3H_6Cl_2$	1,2-Dichloropropane, (±)	-100.53	6.40
$C_3H_6Cl_2$	2,2-Dichloropropane	-33.9	2.30
C_3H_6O	Acetone	-94.7	5.77
C_3H_6O	Methyloxirane	-111.9	6.53
C_3H_6O	Oxetane	-97	6.5
$C_3H_6O_2$	Propanoic acid	-20.5	10.66
$C_3H_6O_2$	Methyl acetate	-98.25	7.49
$C_3H_6O_2$	1,3-Dioxolane	-97.22	6.57
$C_3H_6O_3$	1,3,5-Trioxane	60.29	15.11
C_3H_6S	Thiacyclobutane	-73.24	8.25
C_3H_7Br	1-Bromopropane	-110.3	6.44
C_3H_7Br	2-Bromopropane	-89.0	6.53
C_3H_7Cl	1-Chloropropane	-122.9	5.54
C_3H_7Cl	2-Chloropropane	-117.18	7.39
C_3H_7N	Cyclopropylamine	-35.39	13.18
C_3H_7NO	*N*,*N*-Dimethylformamide	-60.48	7.90
C_3H_8	Propane	-187.63	3.50
$C_3H_8N_2O$	*N*,*N*-Dimethylurea	182.1	23.0
$C_3H_8N_2O$	N,N'-Dimethylurea	106.6	13.0
C_3H_8O	1-Propanol	-124.39	5.37
C_3H_8O	2-Propanol	-87.9	5.41
$C_3H_8O_2$	1,3-Propylene glycol	-27.7	7.1
$C_3H_8O_2$	Dimethoxymethane	-105.1	8.33
$C_3H_8O_3$	Glycerol	18.1	18.3
C_3H_8S	1-Propanethiol	-113.13	5.48
C_3H_8S	2-Propanethiol	-130.5	5.74
C_3H_8S	Ethyl methyl sulfide	-105.93	9.76
C_3H_9N	Propylamine	-84.75	10.97
C_3H_9N	Isopropylamine	-95.13	7.33
C_3H_9N	Trimethylamine	-117.1	7
C_3H_9NO	3-Amino-1-propanol	12.4	19.7
C_4F_8	Perfluorocyclobutane	-40.19	2.77
C_4F_{10}	Perfluorobutane	-129.1	7.66
$C_4H_2O_3$	Maleic anhydride	52.56	13.60
$C_4H_4N_2$	Succinonitrile	57.98	3.70
$C_4H_4N_2$	Pyrazine	51.0	12.9
C_4H_4O	Furan	-85.61	3.80
$C_4H_4O_3$	Succinic anhydride	119	20.4
C_4H_4S	Thiophene	-38.21	5.07
C_4H_5N	Pyrrole	-23.39	7.91
C_4H_6	1,2-Butadiene	-136.2	6.96
C_4H_6	1,3-Butadiene	-108.91	7.98
C_4H_6	1-Butyne	-125.7	6.03
C_4H_6	2-Butyne	-32.2	9.23
C_4H_6O	Divinyl ether	-100.6	7.9
$C_4H_6O_2$	*cis*-Crotonic acid	15	12.6
$C_4H_6O_2$	*trans*-Crotonic acid	71.5	13.0
$C_4H_6O_2$	γ-Butyrolactone	-43.61	9.57
$C_4H_6O_3$	Acetic anhydride	-74.1	10.5
$C_4H_6O_4$	Succinic acid	187.9	32.4
$C_4H_6O_4$	Dimethyl oxalate	54.8	21.1
C_4H_8	1-Butene	-185.34	3.96
C_4H_8	*cis*-2-Butene	-138.88	7.31

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Molecular formula	Name	t_m/°C	$\Delta_{fus}H$/kJ mol^{-1}
C_4H_8	*trans*-2-Butene	-105.52	9.76
C_4H_8	Isobutene	-140.7	5.92
C_4H_8	Cyclobutane	-90.7	1.09
C_4H_8	Methylcyclopropane	-177.6	2.8
C_4H_8O	Butanal	-96.86	10.77
C_4H_8O	2-Butanone	-86.64	8.39
C_4H_8O	Tetrahydrofuran	-108.44	8.54
$C_4H_8O_2$	Butanoic acid	-5.1	11.59
$C_4H_8O_2$	Ethyl acetate	-83.8	10.48
$C_4H_8O_2$	1,4-Dioxane	11.85	12.84
C_4H_8S	Tetrahydrothiophene	-96.2	7.35
C_4H_9Br	1-Bromobutane	-112.6	9.23
C_4H_9Br	2-Bromobutane, (±)	-112.65	6.89
C_4H_9Cl	2-Chloro-2-methylpropane	-25.60	2.07
C_4H_9N	Pyrrolidine	-57.79	8.58
C_4H_9NO	Morpholine	-4.8	14.5
C_4H_{10}	Butane	-138.3	4.66
C_4H_{10}	Isobutane	-159.4	4.54
$C_4H_{10}O$	1-Butanol	-88.6	9.37
$C_4H_{10}O$	2-Butanol	-88.5	5.97
$C_4H_{10}O$	2-Methyl-1-propanol	-101.9	6.32
$C_4H_{10}O$	2-Methyl-2-propanol	25.69	6.70
$C_4H_{10}O$	Diethyl ether	-116.2	7.19
$C_4H_{10}O_2$	1,4-Butanediol	20.4	18.70
$C_4H_{10}O_2$	Ethylene glycol dimethyl ether	-69.20	12.6
$C_4H_{10}S$	1-Butanethiol	-115.7	10.46
$C_4H_{10}S$	Diethyl sulfide	-103.91	10.90
$C_4H_{11}N$	*tert*-Butylamine	-66.94	0.882
$C_4H_{12}Pb$	Tetramethyl lead	-30.2	10.80
$C_4H_{12}Si$	Tetramethylsilane	-99.06	6.87
$C_4H_{12}Sn$	Tetramethylstannane	-55.1	9.30
$C_5H_4O_2$	Furfural	-38.1	14.37
C_5H_5N	Pyridine	-41.70	8.28
C_5H_6O	2-Methylfuran	-91.3	8.55
$C_5H_6O_2$	Furfuryl alcohol	-14.6	13.13
C_5H_8	*cis*-1,3-Pentadiene	-140.8	5.64
C_5H_8	*trans*-1,3-Pentadiene	-87.4	7.14
C_5H_8	1,4-Pentadiene	-148.2	6.12
C_5H_8	2-Methyl-1,3-butadiene	-145.9	4.93
C_5H_8	Cyclopentene	-135.0	3.36
C_5H_8	Spiropentane	-107.0	6.43
$C_5H_8O_2$	Methyl methacrylate	-47.55	14.4
$C_5H_8O_3$	4-Oxopentanoic acid	33	9.22
$C_5H_8O_4$	Glutaric acid	97.8	20.3
C_5H_9N	Pentanenitrile	-96.2	9
C_5H_{10}	1-Pentene	-165.12	5.94
C_5H_{10}	*cis*-2-Pentene	-151.36	7.11
C_5H_{10}	*trans*-2-Pentene	-140.21	8.35
C_5H_{10}	2-Methyl-1-butene	-137.53	7.91
C_5H_{10}	3-Methyl-1-butene	-168.43	5.36
C_5H_{10}	2-Methyl-2-butene	-133.72	7.60
C_5H_{10}	Cyclopentane	-93.4	0.61
$C_5H_{10}O$	Cyclopentanol	-17.5	1.535
$C_5H_{10}O$	2-Pentanone	-76.8	10.63
$C_5H_{10}O$	3-Pentanone	-39	11.59
$C_5H_{10}O$	3-Methyl-2-butanone	-93.1	9.34
$C_5H_{10}O$	Tetrahydropyran	-49.1	1.8
$C_5H_{10}O_2$	Pentanoic acid	-33.6	14.16

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Molecular formula	Name	t_m/°C	$\Delta_{fus}H$/kJ mol^{-1}
$C_5H_{11}Br$	1-Bromopentane	-88.0	14.37
$C_5H_{11}N$	Cyclopentylamine	-82.7	8.31
$C_5H_{11}N$	Piperidine	-11.02	14.85
C_5H_{12}	Pentane	-129.67	8.40
C_5H_{12}	Isopentane	-159.77	5.15
C_5H_{12}	Neopentane	-16.4	3.10
$C_5H_{12}O$	1-Pentanol	-77.6	10.50
$C_5H_{12}O$	2-Methyl-2-butanol	-9.1	4.46
$C_5H_{12}O$	Butyl methyl ether	-115.7	10.85
$C_5H_{12}O$	Methyl *tert*-butyl ether	-108.6	7.60
$C_5H_{12}O_4$	Pentaerythritol	258	4.8
$C_5H_{12}S$	1-Pentanethiol	-75.65	17.53
C_6Cl_6	Hexachlorobenzene	228.83	25.2
C_6F_6	Hexafluorobenzene	5.03	11.59
C_6F_{14}	Perfluorohexane	-88.2	6.84
C_6HF_5	Pentafluorobenzene	-47.4	10.87
C_6HF_5O	Pentafluorophenol	37.5	16.41
$C_6H_2F_4$	1,2,3,5-Tetrafluorobenzene	-46.25	6.36
$C_6H_2F_4$	1,2,4,5-Tetrafluorobenzene	3.88	15.05
$C_6H_3Cl_3$	1,2,3-Trichlorobenzene	51.3	17.9
$C_6H_3Cl_3$	1,2,4-Trichlorobenzene	16.92	16.4
$C_6H_3Cl_3$	1,3,5-Trichlorobenzene	62.8	18.1
$C_6H_3N_3O_6$	1,3,5-Trinitrobenzene	122.9	15.4
$C_6H_4ClNO_2$	1-Chloro-2-nitrobenzene	32.1	17.9
$C_6H_4ClNO_2$	1-Chloro-3-nitrobenzene	44.4	19.4
$C_6H_4ClNO_2$	1-Chloro-4-nitrobenzene	82	14.1
$C_6H_4Cl_2$	*o*-Dichlorobenzene	-17.0	12.4
$C_6H_4Cl_2$	*m*-Dichlorobenzene	-24.8	12.6
$C_6H_4Cl_2$	*p*-Dichlorobenzene	53.09	18.19
$C_6H_4F_2$	*o*-Difluorobenzene	-47.1	11.05
$C_6H_4F_2$	*m*-Difluorobenzene	-69.12	8.58
$C_6H_4O_2$	*p*-Benzoquinone	115	18.5
C_6H_5Br	Bromobenzene	-30.72	10.70
C_6H_5Cl	Chlorobenzene	-45.31	9.6
C_6H_5ClO	*o*-Chlorophenol	9.4	13.0
C_6H_5ClO	*m*-Chlorophenol	32.6	14.9
C_6H_5ClO	*p*-Chlorophenol	42.8	14.1
C_6H_5F	Fluorobenzene	-42.18	11.31
C_6H_5I	Iodobenzene	-31.3	9.75
C_6H_5NO	Nitrosobenzene	67	31.0
$C_6H_5NO_2$	Nitrobenzene	5.7	12.12
$C_6H_5NO_3$	*o*-Nitrophenol	44.8	17.7
$C_6H_5NO_3$	*m*-Nitrophenol	96.8	20.6
$C_6H_5NO_3$	*p*-Nitrophenol	113.6	18.8
C_6H_6	Benzene	5.49	9.87
C_6H_6ClN	*o*-Chloroaniline	-1.9	11.9
C_6H_6ClN	*m*-Chloroaniline	-10.28	10.15
C_6H_6ClN	*p*-Chloroaniline	70.5	20.0
$C_6H_6N_2O_2$	*o*-Nitroaniline	71.0	16.1
$C_6H_6N_2O_2$	*m*-Nitroaniline	113.4	23.6
$C_6H_6N_2O_2$	*p*-Nitroaniline	147.5	21.2
C_6H_6O	Phenol	40.89	11.51
$C_6H_6O_2$	*p*-Hydroquinone	172.4	26.8
$C_6H_6O_2$	Pyrocatechol	104.6	22.8
$C_6H_6O_2$	Resorcinol	109.4	20.4
C_6H_6S	Benzenethiol	-14.93	11.48
C_6H_7N	Aniline	-6.02	10.54
C_6H_7N	2-Methylpyridine	-66.68	9.72

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Molecular formula	Name	t_m/°C	$\Delta_{fus}H$/kJ mol^{-1}
C_6H_7N	3-Methylpyridine	-18.14	14.18
C_6H_7N	4-Methylpyridine	3.67	12.58
$C_6H_8N_2$	*o*-Phenylenediamine	102.1	23.1
$C_6H_8N_2$	*m*-Phenylenediamine	66.0	15.57
$C_6H_8N_2$	*p*-Phenylenediamine	141.1	23.8
$C_6H_8N_2$	Phenylhydrazine	20.6	14.05
C_6H_{10}	Cyclohexene	-103.5	3.29
$C_6H_{10}O$	Cyclohexanone	-27.9	1.328
$C_6H_{10}O_2$	2-Oxepanone	-1.0	13.83
$C_6H_{10}O_4$	Adipic acid	152.5	36.3
$C_6H_{11}Cl$	Chlorocyclohexane	-43.81	2.043
C_6H_{12}	1-Hexene	-139.76	9.35
C_6H_{12}	*cis*-2-Hexene	-141.11	8.88
C_6H_{12}	2,3-Dimethyl-2-butene	-74.19	6.45
C_6H_{12}	Cyclohexane	6.59	2.68
C_6H_{12}	Methylcyclopentane	-142.42	6.93
$C_6H_{12}O$	Hexanal	-56	13.3
$C_6H_{12}O$	2-Hexanone	-55.5	14.9
$C_6H_{12}O$	3-Hexanone	-55.4	13.49
$C_6H_{12}O$	Cyclohexanol	25.93	1.78
$C_6H_{12}O_3$	Paraldehyde	12.6	13.5
$C_6H_{13}Br$	1-Bromohexane	-83.7	18.1
$C_6H_{13}N$	Cyclohexylamine	-17.8	17.5
C_6H_{14}	Hexane	-95.35	13.08
C_6H_{14}	2-Methylpentane	-153.6	6.27
C_6H_{14}	3-Methylpentane	-162.90	5.30
C_6H_{14}	2,2-Dimethylbutane	-98.8	0.58
C_6H_{14}	2,3-Dimethylbutane	-128.10	0.79
$C_6H_{14}O$	1-Hexanol	-47.4	15.38
$C_6H_{14}O$	Dipropyl ether	-114.8	10.8
$C_6H_{14}O$	Diisopropyl ether	-85.4	12.04
$C_6H_{14}O_2$	1,6-Hexanediol	41.5	22.2
C_7F_8	Perfluorotoluene	-65.49	11.54
C_7F_{16}	Perfluoroheptane	-51.2	6.95
$C_7H_3F_5$	2,3,4,5,6-Pentafluorotoluene	-29.78	13.1
C_7H_5ClO	Benzoyl chloride	-0.4	19.2
$C_7H_5ClO_2$	*o*-Chlorobenzoic acid	140.2	25.6
C_7H_5N	Benzonitrile	-13.99	9.1
$C_7H_5N_3O_6$	2,4,6-Trinitrotoluene	80.5	22.9
$C_7H_6O_2$	Benzoic acid	122.35	18.02
$C_7H_6O_3$	*o*-Hydroxybenzoic acid	159.0	14.2
C_7H_7Cl	*o*-Chlorotoluene	-35.8	9.6
C_7H_7NO	Benzamide	127.3	19.5
$C_7H_7NO_2$	*p*-Nitrotoluene	51.63	16.81
C_7H_8	Toluene	-94.95	6.64
C_7H_8O	*o*-Cresol	31.03	15.82
C_7H_8O	*m*-Cresol	12.24	10.71
C_7H_8O	*p*-Cresol	34.77	12.71
C_7H_8O	Benzyl alcohol	-15.4	8.97
C_7H_8O	Anisole	-37.13	12.9
C_7H_9N	*o*-Methylaniline	-14.41	11.66
C_7H_9N	*m*-Methylaniline	-31.3	7.9
C_7H_9N	*p*-Methylaniline	43.6	18.9
C_7H_{14}	1-Heptene	-118.9	12.41
C_7H_{14}	Cycloheptane	-8.46	1.88
C_7H_{14}	Methylcyclohexane	-126.6	6.75
$C_7H_{14}O$	1-Heptanal	-43.4	23.2
$C_7H_{14}O$	Cycloheptanol	7.2	1.60

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ENTHALPY OF FUSION (continued)

Molecular formula	Name	t_m/°C	$\Delta_{fus}H$/kJ mol^{-1}
$C_7H_{14}O_2$	Heptanoic acid	-7.17	15.13
$C_7H_{15}Br$	1-Bromoheptane	-56.1	21.8
C_7H_{16}	Heptane	-90.55	14.03
C_7H_{16}	2-Methylhexane	-118.2	9.19
C_7H_{16}	3-Ethylpentane	-118.55	9.55
C_7H_{16}	2,2-Dimethylpentane	-123.7	5.82
C_7H_{16}	2,4-Dimethylpentane	-119.2	6.85
C_7H_{16}	3,3-Dimethylpentane	-134.4	6.85
C_7H_{16}	2,2,3-Trimethylbutane	-24.6	2.26
$C_7H_{16}O$	1-Heptanol	-33.2	18.17
C_8H_8	Styrene	-30.65	10.9
$C_8H_8O_2$	*o*-Toluic acid	103.5	19.5
$C_8H_8O_2$	*m*-Toluic acid	109.9	15.7
$C_8H_8O_2$	*p*-Toluic acid	179.6	22.7
$C_8H_8O_2$	Benzeneacetic acid	76.5	16.3
$C_8H_8O_2$	Methyl benzoate	-12.4	9.74
C_8H_{10}	Ethylbenzene	-94.96	9.18
C_8H_{10}	*o*-Xylene	-25.2	13.6
C_8H_{10}	*m*-Xylene	-47.8	11.6
C_8H_{10}	*p*-Xylene	13.25	17.12
$C_8H_{10}O$	2,3-Xylenol	72.5	21.0
$C_8H_{10}O$	2,5-Xylenol	74.8	23.4
$C_8H_{10}O$	2,6-Xylenol	45.8	18.9
$C_8H_{10}O$	3,4-Xylenol	65.1	18.1
$C_8H_{10}O$	3,5-Xylenol	63.4	17.4
C_8H_{16}	1-Octene	-101.7	15.31
C_8H_{16}	Cyclooctane	14.59	2.41
C_8H_{16}	Ethylcyclohexane	-111.3	8.33
C_8H_{16}	1,1-Dimethylcyclohexane	-33.3	2.07
C_8H_{16}	*cis*-1,2-Dimethylcyclohexane	-49.8	1.64
C_8H_{16}	*trans*-1,2-Dimethylcyclohexane	-88.15	10.49
C_8H_{16}	*cis*-1,3-Dimethylcyclohexane	-75.53	10.82
C_8H_{16}	*trans*-1,3-Dimethylcyclohexane	-90.07	9.87
C_8H_{16}	*cis*-1,4-Dimethylcyclohexane	-87.39	9.31
C_8H_{16}	*trans*-1,4-Dimethylcyclohexane	-36.93	12.33
$C_8H_{16}O_2$	Octanoic acid	16.5	21.35
$C_8H_{17}Br$	1-Bromooctane	-55.0	24.7
C_8H_{18}	Octane	-56.82	20.73
C_8H_{18}	2-Methylheptane	-109.02	11.92
C_8H_{18}	3-Methylheptane	-120.48	11.69
C_8H_{18}	4-Methylheptane	-121.0	10.8
C_8H_{18}	2,2,4-Trimethylpentane	-107.3	9.20
$C_8H_{18}O$	1-Octanol	-14.8	23.7
C_9H_7N	Quinoline	-14.78	10.66
C_9H_7N	Isoquinoline	26.47	13.54
C_9H_8	Indene	-1.5	10.20
C_9H_{10}	Indan	-51.38	8.60
C_9H_{12}	Propylbenzene	-99.6	9.27
C_9H_{12}	Isopropylbenzene	-96.02	7.33
C_9H_{12}	*o*-Ethyltoluene	-79.83	9.96
C_9H_{12}	*m*-Ethyltoluene	-95.6	7.6
C_9H_{12}	*p*-Ethyltoluene	-62.35	12.7
C_9H_{12}	1,2,3-Trimethylbenzene	-25.4	8.18
C_9H_{12}	1,2,4-Trimethylbenzene	-43.77	13.19
C_9H_{12}	1,3,5-Trimethylbenzene	-44.72	9.51
C_9H_{18}	Propylcyclohexane	-94.9	10.37
$C_9H_{18}O$	Nonanal	-19.3	30.5
$C_9H_{18}O$	5-Nonanone	-3.8	24.93

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Molecular formula	Name	t_m/°C	$\Delta_{fus}H$/kJ mol^{-1}
$C_9H_{18}O_2$	Nonanoic acid	12.4	19.82
C_9H_{20}	Nonane	-53.46	15.47
C_9H_{20}	3,3-Diethylpentane	-33.1	10.09
C_9H_{20}	2,2,3,3-Tetramethylpentane	-9.75	2.33
C_9H_{20}	2,2,4,4-Tetramethylpentane	-66.54	9.74
$C_{10}H_7Br$	1-Bromonaphthalene	6.1	15.2
$C_{10}H_7Br$	2-Bromonaphthalene	55.9	14.4
$C_{10}H_7Cl$	1-Chloronaphthalene	-2.5	12.9
$C_{10}H_7Cl$	2-Chloronaphthalene	58.0	14.0
$C_{10}H_8$	Naphthalene	80.26	19.01
$C_{10}H_8O$	1-Naphthol	95.0	23.1
$C_{10}H_8O$	2-Naphthol	121.5	18.1
$C_{10}H_{14}$	Butylbenzene	-87.85	11.22
$C_{10}H_{14}$	1-Isopropyl-4-methylbenzene	-67.94	9.66
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene	79.3	21
$C_{10}H_{14}O$	Thymol	49.5	21.3
$C_{10}H_{18}$	*cis*-Decahydronaphthalene	-42.9	9.49
$C_{10}H_{18}$	*trans*-Decahydronaphthalene	-30.4	14.41
$C_{10}H_{18}O_4$	Sebacic acid	130.9	40.8
$C_{10}H_{20}$	1-Decene	-66.3	13.81
$C_{10}H_{20}$	Butylcyclohexane	-74.73	14.16
$C_{10}H_{20}O$	Decanal	-4.0	34.5
$C_{10}H_{20}O_2$	Decanoic acid	31.4	27.8
$C_{10}H_{22}$	Decane	-29.6	28.72
$C_{10}H_{22}O$	1-Decanol	6.9	43
$C_{11}H_{10}$	1-Methylnaphthalene	-30.43	6.95
$C_{11}H_{10}$	2-Methylnaphthalene	34.6	12.13
$C_{11}H_{24}$	Undecane	-25.5	22.2
$C_{12}H_8$	Acenaphthylene	91.8	6.9
$C_{12}H_9N$	Carbazole	246.3	24.1
$C_{12}H_{10}$	Acenaphthene	93.4	21.49
$C_{12}H_{10}$	Biphenyl	68.93	18.57
$C_{12}H_{10}N_2$	Azobenzene	67.88	22.52
$C_{12}H_{10}N_2O$	*trans*-Azoxybenzene	34.6	17.9
$C_{12}H_{10}O$	Diphenyl ether	26.87	17.22
$C_{12}H_{11}N$	Diphenylamine	53.2	18.5
$C_{12}H_{16}$	Cyclohexylbenzene	7.07	15.6
$C_{12}H_{18}$	Hexamethylbenzene	165.5	20.6
$C_{12}H_{24}$	1-Dodecene	-35.2	19.9
$C_{12}H_{24}O_2$	Dodecanoic acid	43.8	36.3
$C_{12}H_{26}$	Dodecane	-9.57	36.8
$C_{12}H_{26}O$	1-Dodecanol	23.9	40.2
$C_{13}H_{10}$	9*H*-Fluorene	114.77	19.58
$C_{13}H_{10}O$	Benzophenone	47.9	18.19
$C_{13}H_{12}$	Diphenylmethane	25.4	18.6
$C_{13}H_{28}$	Tridecane	-5.4	28.50
$C_{13}H_{28}O$	1-Tridecanol	31.7	41.4
$C_{14}H_{10}$	Anthracene	215.76	29.4
$C_{14}H_{10}$	Phenanthrene	99.24	16.46
$C_{14}H_{10}O_2$	Benzil	94.87	23.5
$C_{14}H_{12}$	*trans*-Stilbene	124.2	27.7
$C_{14}H_{12}O_2$	α-Phenylbenzeneacetic acid	147.29	31.3
$C_{14}H_{28}O_2$	Tetradecanoic acid	54.2	45.1
$C_{14}H_{30}$	Tetradecane	5.82	45.07
$C_{14}H_{30}O$	1-Tetradecanol	38.2	25.1*
$C_{15}H_{32}$	Pentadecane	9.95	34.6
$C_{16}H_{10}$	Fluoranthene	110.19	18.69
$C_{16}H_{10}$	Pyrene	150.62	17.36

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Molecular formula	Name	t_m/˚C	$\Delta_{fus}H$/kJ mol^{-1}
$C_{16}H_{32}O_2$	Hexadecanoic acid	62.5	53.7
$C_{16}H_{34}$	Hexadecane	18.12	53.36
$C_{16}H_{34}O$	1-Hexadecanol	49.2	33.6
$C_{17}H_{36}$	Heptadecane	22.0	40.16
$C_{18}H_{12}$	Benz[a]anthracene	160.5	21.4
$C_{18}H_{12}$	Benzo[c]phenanthrene	68	16.3
$C_{18}H_{12}$	Chrysene	255.5	26.2
$C_{18}H_{12}$	Triphenylene	197.8	24.74
$C_{18}H_{14}$	*o*-Terphenyl	56.20	17.19
$C_{18}H_{14}$	*p*-Terphenyl	213.9	35.3
$C_{18}H_{15}N$	Triphenylamine	126.5	24.9
$C_{18}H_{36}O_2$	Stearic acid	69.3	61.2
$C_{18}H_{38}$	Octadecane	28.2	61.7
$C_{18}H_{38}O$	1-Octadecanol	57.9	45
$C_{19}H_{40}$	Nonadecane	32.0	45.8
$C_{20}H_{12}$	Perylene	277.76	31.9
$C_{20}H_{12}$	Benzo[a]pyrene	181.1	17.3
$C_{20}H_{12}$	Benzo[e]pyrene	181.4	16.6
$C_{20}H_{14}$	2,2'-Binaphthalene	187.9	38.9
$C_{20}H_{42}$	Eicosane	36.6	69.9
$C_{20}H_{42}O$	1-Eicosanol	65.4	42
$C_{24}H_{12}$	Coronene	437.4	19.2

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PRESSURE AND TEMPERATURE DEPENDENCE OF LIQUID DENSITY

This table gives data on the variation of the density of some common liquids with pressure and temperature. The pressure dependence is described to first order by the isothermal compressibility coefficient κ defined as

$$\kappa = -(1/V)\,(\partial V/\partial P)_T$$

where V is the volume, and the temperature dependence by the cubic expansion coefficient α,

$$\alpha = (1/V)\,(\partial V/\partial T)_P$$

Substances are listed by molecular formula in the Hill order. More precise data on the variation of density with temperature over a wide temperature range can be found in Reference 1.

REFERENCES

1. Lide, D. R., and Kehiaian, H. V., *CRC Handbook of Thermophysical and Thermochemical Data*, CRC Press, Boca Raton, FL, 1994.
2. Le Neindre, B., *Effets des Hautes et Très Hautes Pressions*, in *Techniques de l'Ingénieur*, Paris, 1991.
3. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series*, IV/4, *High-pressure Properties of Matter*, Springer-Verlag, Heidelberg, 1980.
4. Riddick, J.A., Bunger, W.B., and Sakano, T.K., *Organic Solvents, Fourth Edition*, John Wiley & Sons, New York, 1986.
5. Isaacs, N. S., *Liquid Phase High Pressure Chemistry*, John Wiley, New York, 1981.

Molecular formula	Name	Isothermal Compressibility t/°C	$\kappa \times 10^4$/MPa^{-1}	Cubic Thermal Expansion t/°C	$\alpha \times 10^3$/°C^{-1}
Cl_3P	Phosphorus trichloride	20	9.45	20	1.9
H_2O	Water	20	4.591	20	0.206
		25	4.524	25	0.256
		30	4.475	30	0.302
Hg	Mercury	20	0.401	20	1.811
CCl_4	Tetrachloromethane	20	10.50	20	1.14
		40	12.20	40	1.21
		70	15.6	70	1.33
$CHBr_3$	Tribromomethane	50	8.76	25	0.91
$CHCl_3$	Trichloromethane	20	9.96	20	1.21
		50	12.9	50	1.33
CH_2Br_2	Dibromomethane	27	6.85		
CH_2Cl_2	Dichloromethane	25	10.3	25	1.39
CH_3I	Iodomethane	27	10.3	25	1.26
CH_4O	Methanol	20	12.14	20	1.49
		40	13.83	40	1.59
CS_2	Carbon disulfide	20	9.38	20	1.12
		40	10.6	35	1.16
C_2Cl_4	Tetrachloroethylene	25	7.56	25	1.02
C_2HCl_3	Trichloroethylene	25	8.57	25	1.17
$C_2H_2Cl_2$	trans-1,2-Dichloroethylene	25	11.2	25	1.36
$C_2H_4Cl_2$	1,1-Dichloroethane	20	7.97	25	0.93
$C_2H_4Cl_2$	1,2-Dichloroethane	30	8.46	20	1.14
$C_2H_4O_2$	Acetic acid	20	9.08	20	1.08
		80	13.7	80	1.38
C_2H_5Br	Bromoethane	20	11.53	20	1.31
C_2H_5I	Iodoethane	20	9.82	25	1.17
C_2H_6O	Ethanol	20	11.19	20	1.40
		70	15.93	70	1.67
$C_2H_6O_2$	Ethylene glycol	20	3.64	20	0.626
C_3H_6O	Acetone	20	12.62	20	1.46
		40	15.6	40	1.57
C_3H_7Br	1-Bromopropane	0	10.22	25	1.2
C_3H_7Cl	1-Chloropropane	0	12.09	20	1.4
C_3H_7I	1-Iodopropane	0	10.22	25	1.09
C_3H_8O	1-Propanol	0	8.43	0	1.22
C_3H_8O	2-Propanol	40	13.32	40	1.55
$C_3H_8O_2$	1,2-Propanediol	0	4.45	20	0.695

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PRESSURE AND TEMPERATURE DEPENDENCE OF LIQUID DENSITY (continued)

Molecular formula	Name	Isothermal Compressibility t/°C	$\kappa \times 10^4$/MPa^{-1}	Cubic Thermal Expansion t/°C	$\alpha \times 10^3$/°C^{-1}
$C_3H_8O_2$	1,3-Propanediol	0	4.09	20	0.61
$C_3H_8O_3$	Glycerol	0	2.54	20	0.520
$C_4H_8O_2$	Ethyl acetate	20	11.32	20	1.35
		60	16.2	60	1.54
C_4H_9Br	1-Bromobutane	25	10.26	20	1.13
C_4H_9I	1-Iodobutane	0	7.73	25	1.02
$C_4H_{10}O$	1-Butanol	0	8.10	0	1.12
$C_4H_{10}O$	Diethyl ether	20	18.65	20	1.65
		30	20.85	30	1.72
$C_4H_{10}O_3$	Diethylene glycol	0	3.34	20	0.635
C_5H_{10}	Cyclopentane	20	13.31	20	1.35
$C_5H_{11}Br$	1-Bromopentane	0	8.42	25	1.04
$C_5H_{11}I$	1-Iodopentane	0	7.56		
C_5H_{12}	Pentane	25	21.80	25	1.64
$C_5H_{12}O$	1-Pentanol	0	7.71	0	1.02
C_6H_5Br	Bromobenzene	20	6.46	20	0.86
C_6H_5Cl	Chlorobenzene	20	7.45	20	0.94
$C_6H_5NO_2$	Nitrobenzene	20	4.93	25	0.833
C_6H_6	Benzene	25	9.66	25	1.14
		45	11.28	45	1.21
C_6H_6O	Phenol	60	6.05	60	0.82
C_6H_7N	Aniline	20	4.53	20	0.81
		80	6.32	80	0.91
C_6H_{12}	Cyclohexane	20	11.30	20	1.15
		60	15.2	60	1.29
C_6H_{14}	Hexane	25	16.69	25	1.41
		45	20.27	45	1.52
C_6H_{14}	2-Methylpentane	0	13.97	25	1.43
C_6H_{14}	3-Methylpentane	0	14.57	25	1.40
C_6H_{14}	2,3-Dimethylbutane	20	17.97	25	1.39
$C_6H_{14}O$	1-Hexanol	25	8.24	25	1.03
$C_6H_{15}NO_3$	Triethanolamine	0	3.61	55	0.53
C_7H_8	Toluene	20	8.96	20	1.05
		50	11.0	50	1.13
C_7H_8O	Anisole	20	6.60	20	0.951
C_7H_{14}	Cycloheptane	20	9.22		
C_7H_{16}	Heptane	25	14.38	25	1.26
C_8H_{10}	*o*-Xylene	25	8.10	25	0.96
C_8H_{10}	*m*-Xylene	20	8.46	20	0.99
C_8H_{10}	*p*-Xylene	25	8.59	25	1.00
C_8H_{16}	Cyclooctane	20	8.03		
C_8H_{18}	Octane	25	12.82	25	1.16
		45	15.06	45	1.23
$C_8H_{18}O$	1-Octanol	25	7.64	25	0.827
C_9H_{12}	Mesitylene	25	8.14	25	0.94
$C_9H_{14}O_6$	Triacetin	0	4.49	25	0.94
C_9H_{20}	Nonane	25	11.75	25	1.08
$C_{10}H_{22}$	Decane	25	10.94	25	1.02
$C_{11}H_{24}$	Undecane	25	10.31	25	0.97
$C_{12}H_{26}$	Dodecane	25	9.88	25	0.93
$C_{13}H_{28}$	Tridecane	25	9.48	25	0.90
$C_{14}H_{30}$	Tetradecane	25	9.10	25	0.87
$C_{15}H_{32}$	Pentadecane	25	8.82		
$C_{16}H_{22}O_4$	Butyl phthalate	0	5.0	25	0.86
$C_{16}H_{34}$	Hexadecane	25	8.57		
		45	9.78		
$C_{19}H_{36}O_2$	Methyl oleate	0	6.18	60	0.85

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PROPERTIES OF CRYOGENIC FLUIDS

This table gives physical and thermodynamic properties of eight cryogenic fluids. The properties are:

M	Molar mass in grams per mole
T_t	Triple point temperature in kelvins
P_t	Triple point pressure in kilopascals
ρ_t (1)	Liquid density at the triple point in grams per milliliter
$\Delta_{fus}H$ @ T_t	Enthalpy of fusion at the triple point in joules per gram
T_b	Normal boiling point in kelvins at a pressure of 101325 pascals (760 mmHg)
$\Delta_{vap}H$ @ T_b	Enthalpy of vaporization at the normal boiling point in joules per gram
ρ (l) @ T_b	Liquid density at the normal boiling point in grams per milliliter
ρ (g) @ T_b	Vapor density at the normal boiling point in grams per liter
C_p (l) @ T_b	Liquid heat capacity at constant pressure at the normal boiling point in joules per gram kelvin
C_p (g) @ T_b	Vapor heat capacity at constant pressure at the normal boiling point in joules per gram kelvin
T_c	Critical temperature in kelvins
P_c	Critical pressure in megapascals
ρ_c	Critical density in grams per milliliter

In the case of air, the value given for the triple point temperature is the incipient solidification temperature, and the normal boiling point value is the incipient boiling (bubble) point. See Reference 3 for more details.

REFERENCES

1. Younglove, B. A., *J. Phys. Chem. Ref. Data,* 11, Suppl. 1, 1982.
2. Daubert, T. E., Danner, R. P., Sibul, H. M., and Stebbins, C. C., *Physical and Thermodynamic Properties of Pure Compounds: Data Compilation*, extant 1994 (core with 4 supplements), Taylor & Francis, Bristol, PA (also available as database).
3. Sytchev, V. V., et al., *Thermodynamic Properties of Air*, Hemisphere Publishing, New York, 1987.
4. Jacobsen, R. T., Stewart, R. B., and Jahangiri, M., *J. Phys. Chem. Ref. Data*, 15, 735, 1986. [Nitrogen]
5. Stewart, R. B., Jacobsen, R. T., and Wagner, W., *J. Phys. Chem. Ref. Data*, 20, 917, 1991. [Oxygen]
6. McCarty, R. D., *J. Phys. Chem. Ref. Data*, 2, 923, 1973. [Helium] Also, Donnelly, R. J., private communication.
7. Stewart, R. B. and Jacobsen, R. T., *J. Phys. Chem. Ref. Data*, 18, 639, 1989. [Argon]
8. Setzmann, U. and Wagner, W., *J. Phys. Chem. Ref. Data*, 20, 1061, 1991. [Methane]
9. Vargaftik, N. B., *Thermophysical Properties of Liquids and Gases*, 2nd ed., John Wiley, New York, 1975.

Property	Units	Air	N_2	O_2	H_2	He	Ne	Ar	Kr	Xe	CH_4
M	g/mol	28.96	28.014	31.999	2.0159	4.0026	20.180	39.948	83.800	131.290	16.043
T_t	K	59.75	63.15	54.3584	13.8		24.5561	83.8058	115.8	161.4	90.694
P_t	kPa		12.463	0.14633	7.042		50	68.95	72.92	81.59	11.696
ρ_t (l)	g/mL	0.959	0.870	1.306	0.0770		1.251	1.417	2.449	2.978	0.4515
$\Delta_{fus}H$ @ T_t	J/g		25.3	13.7	59.5		16.8	28.0	16.3	13.8	58.41
T_b	K	78.67	77.35	90.188	20.28	4.2221	27.07	87.293	119.92	165.10	111.668
$\Delta_{vap}H$ @ T_b	J/g	198.7	198.8	213.1	445	20.7	84.8	161.0	108.4	96.1	510.83
ρ (l) @ T_b	g/mL	0.8754	0.807	1.141	0.0708	0.124901	1.204	1.396	2.418	2.953	0.4224
ρ (g) @ T_b	g/L	3.199	4.622	4.467	1.3390	16.89	9.51	5.79	8.94		1.816
C_p (l) @ T_b	J/g K	1.865	2.042	1.699	9.668	4.545	1.877	1.078	0.533	0.340	3.481
C_p (g) @ T_b	J/g K		1.341	0.980	12.24	9.78		0.570	0.248	0.158	2.218
T_c	K	132.5	126.20	154.581	32.98	5.1953	44.40	150.663	209.40	289.73	190.56
P_c	MPa	3.766	3.390	5.043	1.293	0.227460	2.760	4.860	5.500	5.840	4.592
ρ_c	g/mL	0.316	0.313	0.436	0.031	0.06964	0.484	0.531	0.919	1.110	0.1627

HALOCARBON REFRIGERANTS

Halogen derivatives of the lower aliphatic hydrocarbons, especially fluorocarbons and chlorocarbons, are widely used as refrigerants, solvents, and cleaning agents. This table lists the most important halocarbons in current use or being considered as possible substitutes for those compounds that are potential environmental hazards. The code number for each compound appears in the first column; this number is frequently used in expressions like R 11 or CFC 11 or HFC 134.

In addition to name, molecular formula, CAS Registry Number, and molecular weight, the table lists the following properties:

t_m: normal melting point
t_b: normal boiling point (at 101.324 kPa)
t_c: critical temperature
TLV: Threshold Limit Value, which is the maximum safe concentration in air in the workplace, expressed as the time-weighted average (TWA) in parts per million by volume over an 8-hr workday and 40-hr workweek (see Reference 3). An * following the TLV indicates that the substance in a confirmed or suspected human carcinogen.

REFERENCES

1. *1989 ASHRAE Handbook: Fundamentals*, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, GA, 1989.
2. Platzer, B., Polt, A., and Mauer,G.,*Thermophysical Properties of Refrigerants*, Springer, Berlin, 1990.
3. 1991-1992 Threshold Limit Values and Biological Exposure Indexes, American Conference of Government Industrial Hygienists, Cincinnati, OH, 1991.

Code no.	Name	Molecular formula	CAS reg. no.	Molecular weight	t_m/°C	t_b/°C	t_c/°C	TLV ppm
10	Tetrachloromethane	CCl_4	56-23-5	153.822	-23	76.8	283.5	5*
11	Trichlorofluoromethane	CCl_3F	75-69-4	137.368	-111.11	23.75	198.1	1000
12	Dichlorodifluoromethane	CCl_2F_2	75-71-8	120.913	-158	-29.8	111.80	1000
12B1	Bromochlorodifluoromethane	$CBrClF_2$	353-59-3	165.365	-159.5	-3.72	153.73	
13	Chlorotrifluoromethane	$CClF_3$	75-72-9	104.459	-181	-81.4	29	
13B1	Bromotrifluoromethane	$CBrF_3$	75-63-8	148.910	-172	-57.89	67.1	
14	Tetrafluoromethane	CF_4	75-73-0	88.005	-183.59	-128.02	-45.5	
20	Trichloromethane	$CHCl_3$	67-66-3	119.377	-63.6	61.17	263.3	10*
21	Dichlorofluoromethane	$CHCl_2F$	75-43-4	102.923	-135	8.95	178.43	10
22	Chlorodifluoromethane	$CHClF_2$	75-45-6	86.468	-157.42	-40.75	96.2	1000
23	Trifluoromethane	CHF_3	75-46-7	70.014	-155.18	-82.1	26.2	
30	Dichloromethane	CH_2Cl_2	75-09-2	84.932	-95.14	40	237	50*
31	Chlorofluoromethane	CH_2ClF	593-70-4	68.478	-133	-9.1		
32	Difluoromethane	CH_2F_2	75-10-5	52.024	-136	-51.69	78.5	
40	Chloromethane	CH_3Cl	74-87-3	50.488	-97.7	-24.09	143.10	50*
41	Fluoromethane	CH_3F	593-53-3	34.033	-141.8	-78.41	44.7	
110	Hexachloroethane	C_2Cl_6	67-72-1	236.738	187	187		1*
111	Pentachlorofluoroethane	C_2Cl_5F	354-56-3	220.284				
112	Tetrachloro-1,2-difluoroethane	$C_2Cl_4F_2$	76-12-0	203.830	26	93	278	500
112a	1,1,1,2-Tetrachloro-2,2-difluoroethane	$C_2Cl_4F_2$	76-11-9	203.830	40.6	91.5		
113	1,1,2-Trichlorotrifluoroethane	$C_2Cl_3F_3$	76-13-1	187.375	-35	47.7	214.2	1000
113a	1,1,1-Trichlorotrifluoroethane	$C_2Cl_3F_3$	354-58-5	187.375	14.2	46.1		
114	1,2-Dichlorotetrafluoroethane	$C_2Cl_2F_4$	76-14-2	170.921	-94	3.8	145.63	1000
114a	1,1-Dichlorotetrafluoroethane	$C_2Cl_2F_4$	374-07-2	170.921	-56.6	4	145.5	

HALOCARBON REFRIGERANTS (continued)

Code no.	Name	Molecular formula	CAS reg. no.	Molecular weight	t_m/°C	t_b/°C	t_c/°C	TLV ppm
114B2	1,2-Dibromotetrafluoroethane	$C_2Br_2F_4$	124-73-2	259.824	-110.4	47.35	214.7	
115	Chloropentafluoroethane	C_2ClF_5	76-15-3	154.467	-99.44	-37.95	80.1	1000
116	Hexafluoroethane	C_2F_6	76-16-4	138.012	-100.7	-78.1	20	
120	Pentachloroethane	C_2HCl_5	76-01-7	202.293	-29	159.88		
121	1,1,2,2-Tetrachloro-1-fluoroethane	C_2HCl_4F	354-14-3	185.839	-82.6	116.6		
121a	1,1,1,2-Tetrachloro-2-fluoroethane	C_2HCl4_F	354-11-0	185.840	-95.35	116.5		
122	1,2,2-Trichloro-1,1-difluoroethane	$C_2HCl_3F_2$	354-21-2	169.385	-140	71.9		
122a	1,1,2-Trichloro-1,2-difluoroethane	$C_2HCl_3F_2$	354-15-4	169.385		72.5		
122b	1,1,1-Trichloro-2,2-difluoroethane	$C_2HCl_3F_2$	354-12-1	169.385		73		
123	2,2-Dichloro-1,1,1-trifluoroethane	$C_2HCl_2F_3$	306-83-2	152.931	-107	27.1		
123a	1,2-Dichloro-1,2,2-trifluoroethane	$C_2HCl_2F_3$	354-23-4	152.931		28.2		
124	2-Chloro-1,1,1,2-tetrafluoroethane	C_2HClF_4	2837-89-0	136.476		-12		
124a	1-Chloro-1,1,2,2-tetrafluoroethane	C_2HClF_4	354-25-6	136.476	-117	-10.2	126.8	
125	Pentafluoroethane	C_2HF_5	354-33-6	120.022	-103	-48.5		
130	1,1,2,2-Tetrachloroethane	$C_2H_2Cl_4$	79-34-5	167.849	-43.8	146.5	388.00	1*
131	1,1,2-Trichloro-2-fluoroethane	$C_2H_2Cl_3F$	359-28-4	151.394		102.5		
132	1,2-Dichloro-1,2-difluoroethane	$C_2H_2Cl_2F_2$	431-06-1	134.940	-155	59		
132b	1,2-Dichloro-1,1-difluoroethane	$C_2H_2Cl_2F_2$	1649-08-7	134.940				
133	1-Chloro-1,2,2-trifluoroethane	$C_2H_2ClF_3$	431-07-2	118.486		17		
133a	2-Chloro-1,1,1-trifluoroethane	$C_2H_2ClF_3$	75-88-7	118.486	-105.5	6.1		
133b	1-Chloro-1,1,2-trifluoroethane	$C_2H_2ClF_3$	421-04-5	118.486		12		
134	1,1,2,2-Tetrafluoroethane	$C_2H_2F_4$	359-35-3	102.032	-89	-19.9	119	
134a	1,1,1,2-Tetrafluoroethane	$C_2H_2F_4$	811-97-2	102.032	-101	-26.5	101.2	
140	1,1,2-Trichloroethane	$C_2H_3Cl_3$	79-00-5	133.404	-36.6	113.8		10
140a	1,1,1-Trichloroethane	$C_2H_3Cl_3$	71-55-6	133.404	-30.4	74.09	272	350
141	1,2-Dichloro-1-fluoroethane	$C_2H_3Cl_2F$	430-57-9	116.950		75.7		
141b	1,1-Dichloro-1-fluoroethane	$C_2H_3Cl_2F$	1717-00-6	116.950	-103.5	32.11		
142	2-Chloro-1,1-difluoroethane	$C_2H_3ClF_2$	338-65-8	100.495		35.1		
142b	1-Chloro-1,1-difluoroethane	$C_2H_3ClF_2$	75-68-3	100.495	-130.8	-9.75	137.14	
143	1,1,2-Trifluoroethane	$C_2H_3F_3$	430-66-0	84.041	-84	5		
143a	1,1,1-Trifluoroethane	$C_2H_3F_3$	420-46-2	84.041	-111.3	-47.55	73.2	
150	1,2-Dichloroethane	$C_2H_4Cl_2$	107-06-2	98.959	-35.5	83.5	288	10*
150a	1,1-Dichloroethane	$C_2H_4Cl_2$	75-34-3	98.959	-96.96	57.4	250	100
151	1-Chloro-2-fluoroethane	C_2H_4ClF	762-50-5	82.505		53.2		
151a	1-Chloro-1-fluoroethane	C_2H_4ClF	1615-75-4	82.505		16.1		
152	1,2-Difluoroethane	$C_2H_4F_2$	624-72-6	66.051		30.7		
152a	1,1-Difluoroethane	$C_2H_4F_2$	75-37-6	66.051	-117	-24.95	113.6	
160	Chloroethane	C_2H_5Cl	75-00-3	64.514	-138.7	13.1	187.3	1000
161	Fluoroethane	C_2H_5F	353-36-6	48.060	-143.2	-37.65	102.16	
218	Perfluoropropane	C_3F_8	76-19-7	188.020	-147.69	-36.65	72.0	
1112a	1,1-Dichloro-2,2-difluoroethylene	$C_2Cl_2F_2$	79-35-6	132.924				
1113	Chlorotrifluoroethylene	C_2ClF_3	79-38-9	116.470	-158	-27.85	106	

HALOCARBON REFRIGERANTS (continued)

Code no.	Name	Molecular formula	CAS reg. no.	Molecular weight	t_m/°C	t_b/°C	t_c/°C	TLV ppm
1114	Tetrafluoroethylene	C_2F_4	116-14-3	100.016	-142.5	-75.95	33.4	
1120	Trichloroethylene	C_2HCl_3	79-01-6	131.388	-84.75	87.21	271.1	50*
1130	*cis*-1,2-Dichloroethylene	$C_2H_2Cl_2$	156-59-2	96.943	-80	60.19	271.1	200
1130	*trans*-1,2-Dichloroethylene	$C_2H_2Cl_2$	156-60-5	96.943	-49.8	48.73	243.4	200
1132a	1,1-Difluoroethylene	$C_2H_2F_2$	75-38-7	64.035	-144	-85.7	29.8	
1140	Chloroethylene	C_2H_3Cl	75-01-4	62.499	-153.79	-13.37		5*
1141	Fluoroethylene	C_2H_3F	75-02-5	46.044	-160.5	-72	54.8	
C316	1,2-Dichlorohexafluorocyclobutane	$C_4Cl_2F_6$	356-18-3	232.940				
C317	Chloroheptafluorocyclobutane	C_4ClF_7	377-41-3	216.486				
C318	Perfluorocyclobutane	C_4F_8	115-25-3	200.031	-40.19	-5.99	115.31	

* Confirmed or suspected human carcinogen.

DENSITY AND SPECIFIC VOLUME OF MERCURY

The data in this table have been adjusted to the ITS-90 temperature scale. The uncertainty in density values is 0.0003 g/mL between –20 and –10°C; 0.0001 or less between –10 and 200°C; and 0.0002 between 200 and 300°C.

REFERENCE

Ambrose, D., *Metrologia*, 27, 245, 1990.

t/°C	ρ/(g/mL)	*v*/(mL/kg)	*t*/°C	ρ/(g/mL)	*v*/(mL/kg)	*t*/°C	ρ/(g/mL)	*v*/(mL/kg)
–20	13.64461	73.2890	27	13.52869	73.9170	74	13.41423	74.5477
–19	13.64212	73.3024	28	13.52624	73.9304	75	13.41181	74.5612
–18	13.63964	73.3157	29	13.52379	73.9438	76	13.40939	74.5746
–17	13.63716	73.3291	30	13.52134	73.9572	77	13.40697	74.5881
–16	13.63468	73.3424	31	13.51889	73.9705	78	13.40455	74.6016
–15	13.63220	73.3558	32	13.51645	73.9839	79	13.40213	74.6150
–14	13.62972	73.3691	33	13.51400	73.9973	80	13.39971	74.6285
–13	13.62724	73.3824	34	13.51156	74.0107	81	13.39729	74.6420
–12	13.62476	73.3958	35	13.50911	74.0241	82	13.39487	74.6554
–11	13.62228	73.4091	36	13.50667	74.0375	83	13.39245	74.6689
–10	13.61981	73.4225	37	13.50422	74.0509	84	13.39003	74.6824
–9	13.61733	73.4358	38	13.50178	74.0643	85	13.38762	74.6959
–8	13.61485	73.4492	39	13.49934	74.0777	86	13.38520	74.7094
–7	13.61238	73.4625	40	13.49690	74.0911	87	13.38278	74.7229
–6	13.60991	73.4759	41	13.49446	74.1045	88	13.38037	74.7364
–5	13.60743	73.4892	42	13.49202	74.1179	89	13.37795	74.7498
–4	13.60496	73.5026	43	13.48958	74.1313	90	13.37554	74.7633
–3	13.60249	73.5160	44	13.48714	74.1447	91	13.37313	74.7768
–2	13.60002	73.5293	45	13.48470	74.1581	92	13.37071	74.7903
–1	13.59755	73.5427	46	13.48226	74.1715	93	13.36830	74.8038
0	13.59508	73.5560	47	13.47982	74.1850	94	13.36589	74.8173
1	13.59261	73.5694	48	13.47739	74.1984	95	13.36347	74.8308
2	13.59014	73.5827	49	13.47495	74.2118	96	13.36106	74.8443
3	13.58768	73.5961	50	13.47251	74.2252	97	13.35865	74.8579
4	13.58521	73.6095	51	13.47008	74.2386	98	13.35624	74.8714
5	13.58275	73.6228	52	13.46765	74.2520	99	13.35383	74.8849
6	13.58028	73.6362	53	13.46521	74.2655	100	13.35142	74.8984
7	13.57782	73.6495	54	13.46278	74.2789	110	13.3273	75.0337
8	13.57535	73.6629	55	13.46035	74.2923	120	13.3033	75.1693
9	13.57289	73.6763	56	13.45791	74.3057	130	13.2793	75.3052
10	13.57043	73.6896	57	13.45548	74.3192	140	13.2553	75.4413
11	13.56797	73.7030	58	13.45305	74.3326	150	13.2314	75.5778
12	13.56551	73.7164	59	13.45062	74.3460	160	13.2075	75.7147
13	13.56305	73.7297	60	13.44819	74.3594	170	13.1836	75.8519
14	13.56059	73.7431	61	13.44576	74.3729	180	13.1597	75.9895
15	13.55813	73.7565	62	13.44333	74.3863	190	13.1359	76.1274
16	13.55567	73.7698	63	13.44090	74.3998	200	13.1120	76.2659
17	13.55322	73.7832	64	13.43848	74.4132	210	13.0882	76.4047
18	13.55076	73.7966	65	13.43605	74.4266	220	13.0644	76.5440
19	13.54831	73.8100	66	13.43362	74.4401	230	13.0406	76.6838
20	13.54585	73.8233	67	13.43120	74.4535	240	13.0167	76.8241
21	13.54340	73.8367	68	13.42877	74.4670	250	12.9929	76.9650
22	13.54094	73.8501	69	13.42635	74.4804	260	12.9691	77.1064
23	13.53849	73.8635	70	13.42392	74.4939	270	12.9453	77.2484
24	13.53604	73.8769	71	13.42150	74.5073	280	12.9214	77.3909
25	13.53359	73.8902	72	13.41908	74.5208	290	12.8975	77.5341
26	13.53114	73.9036	73	13.41665	74.5342	300	12.8736	77.6779

THERMAL PROPERTIES OF MERCURY

Lev R. Fokin

The first of these tables gives the molar heat capacity at constant pressure of liquid and gaseous mercury as a function of temperature. To convert to specific heat in units of J/g K, divide these values by 200.59, the atomic weight of mercury.

REFERENCE

Douglas, T. B., Ball, A. T., and Ginnings, D. C., *J. Res. Natl. Bur. Stands.*, 46, 334, 1951.

	C_p/(J/mol K)			C_p/(J/mol K)			C_p/(J/mol K)	
t/°C	**Liquid**	**Gas**	**t/°C**	**Liquid**	**Gas**	**t/°C**	**Liquid**	**Gas**
–38.84	28.2746	20.786	140	27.3675	20.786	340	27.1500	20.836
–20	28.1466	20.786	160	27.3090	20.786	356.73	27.1677	20.849
0	28.0190	20.786	180	27.2588	20.790	360	27.1709	20.853
20	27.9002	20.786	200	27.2169	20.790	380	27.1981	20.870
25	27.8717	20.786	220	27.1834	20.794	400	27.2324	20.891
40	27.7897	20.786	240	27.1583	20.794	420	27.2738	20.916
60	27.6880	20.786	260	27.1412	20.799	440	27.3207	20.941
80	27.5952	20.786	280	27.1320	20.807	460	27.3742	20.974
100	27.5106	20.786	300	27.1303	20.815	480	27.4332	21.008
120	27.4349	20.786	320	27.1366	20.824	500	27.4985	21.046

The second table gives the molar heat capacity of solid mercury in its rhombohedral (α-mercury) form.

REFERENCES

1. Busey and Giaque, *J. Am. Chem. Soc.*, 75, 806, 1953.
2. Amitin, Lebedeva, and Paukov, *Rus. J. Phys. Chem.*, 2666, 1979.

t/°C	C_p/J mol^{-1}	t/°C	C_p/J mol^{-1}	t/°C	C_p/J mol^{-1}	t/°C	C_p/J mol^{-1}
–268.99	0.99*	–248.15	12.74	–193.15	23.16	–113.15	26.15
–268.99	0.97**	–243.15	14.78	–183.15	23.76	–93.15	26.69
–268.15	1.6	–233.15	17.90	–173.15	24.24	–73.15	27.28
–263.15	4.6	–223.15	19.94	–153.15	25.00	–53.15	27.96
–258.15	7.6	–213.15	21.40	–133.15	25.61	–38.87	28.5
–253.15	10.33	–203.15	22.42				

* Superconducting state
** Normal state

The final table gives the cubic thermal expansion coefficient α, the isothermal compressibility coefficient κ_T, and the speed of sound *U* for liquid mercury as a function of temperature. These properties are defined as follows:

$$\alpha = \frac{1}{v}\left(\frac{\partial v}{\partial T}\right)_p \qquad \kappa_T = -\frac{1}{v}\left(\frac{\partial v}{\partial P}\right)_T \qquad U^2 = \left(\frac{\partial P}{\partial \rho}\right)_S \qquad \rho = v^{-1}$$

where *v* is the specific volume (given in the table on the preceding page).

REFERENCE

Vukalovich, M. P., et al., *Thermophysical Properties of Mercury*, Moscow Standard Press, 1971.

		$\kappa_T \times 10^6$/bar^{-1}					$\kappa_T \times 10^6$/bar^{-1}		
t/°C	**α × 10⁴/K⁻¹**	**At 1 bar**	**At 1000 bar**	**U/m s⁻¹**	**t/°C**	**α × 10⁴/K⁻¹**	**At 1 bar**	**At 1000 bar**	**U/m s⁻¹**
–20	1.818	3.83		1470	120	1.8058	4.513	4.33	1404.7
0	1.8144	3.918	3.78	1460.8	140	1.8074	4.622		1395.4
20	1.8110	4.013	3.87	1451.4	160	1.8100	4.731	4.53	1386.1
40	1.8083	4.109	3.96	1442.0	180	1.8136	4.844		1376.7
60	1.8064	4.207		1432.7	200	1.818	4.96		1367
80	1.8053	4.308	4.14	1423.4	250	1.834	5.26		1344
100	1.8051	4.410		1414.1	300	1.856	5.59		1321

SURFACE TENSION OF COMMON LIQUIDS

The surface tension γ of about 200 liquids is tabulated here as a function of temperature. Values of γ are given in units of millinewtons per meter (mN/m), which is equivalent to dyn/cm in cgs units. The values refer to a nominal pressure of one atmosphere (about 100 kPa) except in cases where the indicated temperature is above the normal boiling point of the substance; in those cases, the applicable pressure is the saturation vapor pressure at the temperature in question.

The uncertainty of the values is 0.1 to 0.2 mN/m or less in most cases. Values at temperatures between the points tabulated can be obtained by linear interpolation to a good approximation.

Substances are listed by molecular formula in the modified Hill order, with substances not containing carbon appearing before those that do contain carbon. A more extensive compilation of surface tension may be found in the Reference.

REFERENCE

Jasper, J. J., *J. Phys. Chem. Ref. Data*, 1, 841, 1972.

		γ in mN/m				
Mol. form.	**Name**	**10°C**	**25°C**	**50°C**	**75°C**	**100°C**
Br_2	Bromine	43.68	40.95	36.40		
Cl_2O_2S	Sulfuryl chloride		28.78			
Cl_3OP	Phosphoryl chloride		32.03	28.85	25.66	
Cl_3P	Phosphorus trichloride		27.98	24.81		
Cl_4Si	Silicon tetrachloride	19.78	18.29	15.80		
H_2O	Water	74.23	71.99	67.94	63.57	58.91
H_4N_2	Hydrazine		66.39			
Hg	Mercury	488.55	485.48	480.36	475.23	470.11
CCl_4	Tetrachloromethane		26.43	23.37	20.31	17.25
CS_2	Carbon disulfide	33.81	31.58	27.87		
$CHBr_3$	Tribromomethane		44.87	41.60	38.33	
$CHCl_3$	Trichloromethane		26.67	23.44	20.20	
CH_2Br_2	Dibromomethane		39.05	35.33	31.61	
CH_2Cl_2	Dichloromethane		27.20			
CH_2O_2	Formic acid		37.13	34.38	31.64	
CH_3I	Iodomethane	32.19	30.34			
CH_3NO	Formamide		57.03	54.92	52.82	50.71
CH_3NO_2	Nitromethane	39.04	36.53	32.33		
CH_4O	Methanol	23.23	22.07	20.14		
CH_5N	Methylamine		19.15			
C_2HCl_5	Pentachloroethane		34.15	31.20	28.26	
$C_2HF_3O_2$	Trifluoroacetic acid		13.53	11.42		
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane		35.58	32.41	29.24	26.07
$C_2H_3Cl_3$	1,1,1-Trichloroethane		25.18	22.07		
$C_2H_3Cl_3$	1,1,2-Trichloroethane		34.02	30.65	27.27	23.89
C_2H_3N	Acetonitrile		28.66	25.51		
$C_2H_4Br_2$	1,2-Dibromoethane		39.55	36.25	32.95	
$C_2H_4Cl_2$	1,1-Dichloroethane		24.07			
$C_2H_4Cl_2$	1,2-Dichloroethane		31.86	28.29	24.72	
C_2H_4O	Acetaldehyde	22.54	20.50	17.10		
$C_2H_4O_2$	Acetic acid		27.10	24.61	22.13	
$C_2H_4O_2$	Methyl formate	26.72	24.36	20.43	16.50	12.57
C_2H_5Br	Bromoethane	25.36	23.62			
C_2H_5I	Iodoethane	30.38	28.46	25.24		
$C_2H_5NO_2$	Nitroethane	34.02	32.13	29.00		
C_2H_6O	Ethanol	23.22	21.97	19.89		
C_2H_6OS	Dimethyl sulfoxide		42.92	40.06		
$C_2H_6O_2$	Ethylene glycol		47.99	45.76	43.54	41.31
C_2H_6S	Dimethyl sulfide	25.27	24.06			
C_2H_6S	Ethanethiol		23.08			
$C_2H_6S_2$	Dimethyl disulfide		33.39	30.04		
C_2H_7N	Dimethylamine		26.34			
C_2H_7N	Ethylamine		19.20			

SURFACE TENSION OF COMMON LIQUIDS (continued)

Mol. form.	Name	γ in mN/m 10°C	25°C	50°C	75°C	100°C
C_2H_7NO	Ethanolamine		48.32	45.53	42.73	
C_3H_5Br	3-Bromopropene		26.31	23.17		
C_3H_5Cl	3-Chloropropene		23.14			
C_3H_5ClO	Epichlorohydrin	38.40	36.36	32.96	29.56	26.16
C_3H_5N	Propanenitrile		26.75	23.87		
$C_3H_6Cl_2$	1,2-Dichloropropane		28.32	25.22	22.12	
C_3H_6O	Acetone		23.46	20.66		
C_3H_6O	Allyl alcohol	26.63	25.28	23.02	20.77	
$C_3H_6O_2$	Ethyl formate	25.16	23.18			
$C_3H_6O_2$	Methyl acetate	26.66	24.73	21.51		
$C_3H_6O_2$	Propanoic acid		26.20	23.72	21.23	
C_3H_7Br	1-Bromopropane	27.08	25.26	22.21		
C_3H_7Br	2-Bromopropane	25.03	23.25	20.30		
C_3H_7Cl	1-Chloropropane	23.16	21.30			
C_3H_7Cl	2-Chloropropane	20.49	19.16			
$C_3H_7NO_2$	2-Nitropropane	31.02	29.29	26.39		
C_3H_8O	1-Propanol	24.48	23.32	21.38	19.43	
C_3H_8O	2-Propanol	22.11	20.93	18.96	16.98	
$C_3H_8O_2$	2-Methoxyethanol	32.32	30.84	28.38	25.92	23.46
C_3H_8S	1-Propanethiol		24.20	21.02		
C_3H_8S	2-Propanethiol		21.33	18.39		
C_3H_9N	Propylamine		21.75			
C_3H_9N	Trimethylamine		13.41			
$C_4H_4N_2$	Pyridazine	49.51	47.96	45.37	42.78	40.19
$C_4H_4N_2$	Pyrimidine		30.33	27.80	25.28	22.75
C_4H_4S	Thiophene		30.68	27.36		
C_4H_5N	Pyrrole	38.71	37.06	34.31		
$C_4H_6O_3$	Acetic anhydride	34.08	31.93	28.34	24.75	21.16
C_4H_7N	Butanenitrile		26.92	24.33	21.73	
C_4H_8O	2-Butanone		23.97	21.16		
$C_4H_8O_2$	1,4-Dioxane		32.75	29.28	25.80	22.32
$C_4H_8O_2$	Ethyl acetate	25.13	23.39	20.49	17.58	14.68
$C_4H_8O_2$	Methyl propanoate	26.32	24.44	21.29		
$C_4H_8O_2$	Butanoic acid		26.05	23.75	21.45	
C_4H_9Br	1-Bromobutane	27.58	25.90	23.08	20.27	17.45
C_4H_9Cl	1-Chlorobutane	24.85	23.18	20.39		
C_4H_9I	1-Iodobutane	29.79	28.24	25.67	23.09	20.51
C_4H_9N	Pyrrolidine	30.58	29.23	26.98		
$C_4H_{10}O$	1-Butanol	26.28	24.93	22.69	20.44	18.20
$C_4H_{10}O$	2-Butanol	23.74	22.54	20.56	18.57	16.58
$C_4H_{10}O$	2-Methyl-2-propanol		19.96	17.71		
$C_4H_{10}O$	Diethyl ether		16.65			
$C_4H_{10}O_2$	2-Ethoxyethanol		28.35	26.11	23.86	21.62
$C_4H_{10}O_3$	Diethylene glycol		44.77	42.57	40.37	38.17
$C_4H_{10}S$	Diethyl sulfide	26.22	24.57	21.80		
$C_4H_{11}N$	Butylamine		23.44	20.63		
$C_4H_{11}N$	Isobutylamine		21.75	19.02		
$C_4H_{11}N$	*tert*-Butylamine		16.87			
$C_4H_{11}N$	Diethylamine		19.85			
$C_5H_4O_2$	Furfural	45.08	43.09	39.78	36.46	33.14
C_5H_5N	Pyridine		36.56	33.29	30.03	
C_5H_8	Cyclopentene	24.45	22.20			
C_5H_8O	Cyclopentanone	34.45	32.80	30.05	27.30	24.55
C_5H_{10}	1-Pentene	17.10	15.45			
C_5H_{10}	2-Methyl-2-butene	18.61	17.15			
C_5H_{10}	Cyclopentane	24.07	21.88	18.22		
$C_5H_{10}O$	2-Pentanone		23.25	21.62		

SURFACE TENSION OF COMMON LIQUIDS (continued)

Mol. form.	Name	γ in mN/m 10°C	25°C	50°C	75°C	100°C
$C_5H_{10}O$	3-Pentanone		24.74	22.13		
$C_5H_{10}O$	Pentanal	26.95	25.44	22.91		
$C_5H_{10}O_2$	Butyl formate	26.05	24.52	21.95	19.39	16.82
$C_5H_{10}O_2$	Propyl acetate	25.48	23.80	21.00	18.20	15.40
$C_5H_{10}O_2$	Isopropyl acetate	23.37	21.76	19.08	16.40	
$C_5H_{10}O_2$	Ethyl propanoate	25.55	23.80	20.88	17.96	
$C_5H_{10}O_2$	Methyl butanoate	26.34	24.62	21.76	18.89	16.03
$C_5H_{11}Cl$	1-Chloropentane	26.01	24.40	21.71	19.02	16.33
$C_5H_{11}N$	Piperidine	30.64	28.91	26.03	23.14	20.26
C_5H_{12}	Pentane	17.15	15.49			
$C_5H_{12}O$	1-Pentanol	26.67	25.36	23.17	20.99	18.80
$C_5H_{12}O$	2-Pentanol	24.96	23.45	20.94	18.43	15.92
$C_5H_{12}O$	3-Methyl-1-butanol	24.94	23.71	21.66	19.61	17.56
$C_5H_{13}N$	Pentylamine		24.69	22.14	19.58	
$C_6H_4Cl_2$	*m*-Dichlorobenzene	37.15	35.43	32.57	29.70	26.83
C_6H_5Br	Bromobenzene	36.98	35.24	32.34	29.44	26.54
C_6H_5Cl	Chlorobenzene	34.78	32.99	30.02	27.04	24.06
C_6H_5ClO	*o*-Chlorophenol		39.70	36.89	34.09	31.28
C_6H_5ClO	*m*-Chlorophenol		41.18	38.66	36.13	33.61
C_6H_5F	Fluorobenzene	28.47	26.66	23.65	20.64	
C_6H_5I	Iodobenzene	40.40	38.71	35.91	33.10	30.29
$C_6H_5NO_2$	Nitrobenzene			40.56	37.66	34.77
C_6H_6	Benzene		28.22	25.00	21.77	
C_6H_6O	Phenol			38.20	35.53	32.86
C_6H_7N	Aniline		42.12	39.41	36.69	
C_6H_7N	2-Methylpyridine		33.00	29.90	26.79	
$C_6H_8N_2$	Adiponitrile		45.45	43.02	40.58	
C_6H_{10}	Cyclohexene	28.01	26.17	23.12		
$C_6H_{10}O$	Cyclohexanone	36.43	34.57	31.46	28.36	25.25
$C_6H_{11}N$	Hexanenitrile		27.37	25.11	22.84	
C_6H_{12}	Cyclohexane	26.43	24.65	21.68		
C_6H_{12}	Methylcyclopentane	23.47	21.72	18.82		
C_6H_{12}	1-Hexene	19.44	17.90	15.33		
$C_6H_{12}O$	Cyclohexanol		32.92	30.50	28.09	25.67
$C_6H_{12}O$	2-Hexanone		25.45	22.72		
$C_6H_{12}O_2$	Butyl acetate	26.48	24.88	22.21	19.54	16.87
$C_6H_{12}O_2$	Isobutyl acetate	24.58	23.06	20.53	17.99	15.46
$C_6H_{12}O_2$	Ethyl butanoate	25.51	23.94	21.33	18.71	16.10
$C_6H_{12}O_3$	Paraldehyde	27.22	25.63	22.97	20.32	17.66
$C_6H_{13}Cl$	1-Chlorohexane	27.28	25.73	23.13	20.54	17.94
$C_6H_{13}N$	Cyclohexylamine		31.22	28.25	25.28	
C_6H_{14}	Hexane	19.42	17.89	15.33		
C_6H_{14}	2-Methylpentane	18.37	16.88	14.39		
C_6H_{14}	3-Methylpentane	19.20	17.61	14.96		
$C_6H_{14}O$	Diisopropyl ether		17.27	14.65		
$C_6H_{14}O$	1-Hexanol		25.81	23.81	21.80	19.80
$C_6H_{14}O_2$	1,1-Diethoxyethane		20.89	18.31	15.74	
$C_6H_{14}O_2$	2-Butoxyethanol	27.36	26.14	24.10	22.06	20.02
$C_6H_{15}N$	Triethylamine		20.22	17.74		
$C_6H_{15}N$	Dipropylamine		22.31	19.75	17.20	
$C_6H_{15}N$	Diisopropylamine		19.14	16.45		
C_7H_5N	Benzonitrile		38.79	35.90	33.00	
C_7H_6O	Benzaldehyde	39.63	38.00	35.27	32.55	29.82
C_7H_8	Toluene	29.71	27.93	24.96	21.98	19.01
C_7H_8O	*o*-Cresol		36.90	34.38	31.85	29.32
C_7H_8O	*m*-Cresol		35.69	33.38	31.07	28.76
C_7H_8O	Benzyl alcohol				27.89	24.44

SURFACE TENSION OF COMMON LIQUIDS (continued)

Mol. form.	Name	γ in mN/m 10°C	25°C	50°C	75°C	100°C
C_7H_8O	Anisole		35.10	32.09	29.08	
C_7H_9N	*N*-Methylaniline		36.90	34.47	32.05	
C_7H_9N	2,3-Dimethylpyridine		32.71	30.04	27.36	
C_7H_9N	Benzylamine		39.30	36.27	33.23	
C_7H_{14}	Methylcyclohexane	24.98	23.29	20.46		
C_7H_{14}	1-Heptene	21.29	19.80	17.33	14.85	
$C_7H_{14}O$	2-Heptanone		26.12	23.48		
$C_7H_{14}O_2$	Pentyl acetate	26.67	25.17	22.69	20.20	17.72
$C_7H_{14}O_2$	Heptanoic acid		27.76	25.64		
C_7H_{16}	Heptane	21.12	19.65	17.20	14.75	
C_7H_{16}	3-Methylhexane	20.76	19.31	16.88	14.46	
C_8H_8O	Acetophenone		39.04	36.15	33.27	
$C_8H_8O_2$	Methyl benzoate		37.17	34.25	31.32	
$C_8H_8O_3$	Methyl salicylate	40.98	39.22	36.28	33.35	30.41
C_8H_{10}	Ethylbenzene	30.39	28.75	26.01	23.28	20.54
C_8H_{10}	*o*-Xylene	31.41	29.76	27.01	24.25	21.50
C_8H_{10}	*m*-Xylene	30.13	28.47	25.71	22.95	20.19
C_8H_{10}	*p*-Xylene		28.01	25.32	22.64	19.95
$C_8H_{10}O$	Phenetole		32.41	29.65	26.89	
$C_8H_{11}N$	*N,N*-Dimethylaniline		35.52	32.90	30.27	
$C_8H_{11}N$	*N*-Ethylaniline		36.33	33.65	30.98	
C_8H_{16}	Ethylcyclohexane	26.73	25.15	22.51		
C_8H_{18}	Octane	22.57	21.14	18.77	16.39	14.01
C_8H_{18}	2,5-Dimethylhexane	20.77	19.40	17.12	14.84	12.56
$C_8H_{18}O$	1-Octanol	28.30	27.10	25.12		
$C_8H_{19}N$	Dibutylamine		24.12	21.74	19.36	
$C_8H_{19}N$	Diisobutylamine		21.72	19.44	17.16	
C_9H_7N	Quinoline	44.19	42.59	39.94	37.28	34.62
C_9H_{12}	Cumene	29.27	27.69	25.05	22.42	19.78
C_9H_{12}	1,2,4-Trimethylbenzene	30.74	29.20	26.64	24.07	21.51
C_9H_{12}	Mesitylene	28.89	27.55	25.31	23.07	20.82
$C_9H_{18}O$	5-Nonanone		26.28	23.85		
C_9H_{20}	Nonane	23.79	22.38	20.05	17.71	15.37
$C_9H_{20}O$	1-Nonanol	29.03	27.89	26.00	24.10	22.20
$C_{10}H_{12}$	1,2,3,4-Tetrahydronaphthalene		33.17	30.78	28.40	
$C_{10}H_{22}$	Decane	24.75	23.37	21.07	18.77	16.47
$C_{10}H_{22}O$	1-Decanol	29.61	28.51	26.68	24.85	23.02
$C_{11}H_{24}$	Undecane	25.56	24.21	21.96	19.70	17.45
$C_{12}H_{10}O$	Diphenyl ether		26.75	24.80		
$C_{12}H_{27}N$	Tributylamine		24.39	22.32	20.24	
$C_{13}H_{28}$	Tridecane	26.86	25.55	23.37	21.19	19.01
$C_{14}H_{12}O_2$	Benzyl benzoate	44.47	42.82	40.06	37.31	34.55
$C_{14}H_{30}$	Tetradecane	27.43	26.13	23.96	21.78	19.61
$C_{16}H_{34}$	Hexadecane		27.05	24.91	22.78	20.64
$C_{18}H_{38}$	Octadecane		27.87	25.77	23.66	21.55

PERMITTIVITY (DIELECTRIC CONSTANT) OF LIQUIDS

Christian Wohlfarth

The permittivity of a substance (often called the dielectric constant) is the ratio of the electric displacement *D* to the electric field strength *E* when an external field is applied to the substance. The quantity tabulated here is the relative permittivity, which is the ratio of the actual permittivity to the permittivity of a vacuum; it is a dimensionless number.

The table gives the static relative permittivity ε_r, i.e., the relative permittivity measured in static fields or at low frequencies where no relaxation effects occur. The fourth column of the table lists the value of ε_r at the temperature specified in the third column, usually 293.15 or 298.15 K. Otherwise, the temperature closest to 293.15 K was chosen, or (as it is the case for many of the substances included here) ε_r is given at the only temperature for which data are available.

The static permittivity refers to nominal atmospheric pressure as long as the corresponding temperature is below the normal boiling point. Otherwise, at temperatures above the normal boiling point, the pressure is understood to be the saturated vapor pressure of the substance considered.

For substances where information on the temperature dependence of the permittivity is available, the table gives the coefficients of a simple polynomial fitting of permittivity to temperature with an equation of the form

$$\varepsilon_r(T) = a + bT + cT^2 + dT^3$$

where *T* is the absolute temperature in K. Since the parameter *d* was used in only a few cases where the quadratic fit was not satisfactory, only *a*, *b*, and *c* are listed as columns in the table, while the *d* values are given at the end of this introduction. For all other substances, *d* = 0. The temperature range of the fit is given in the last column. The coefficients of the fitting equation can be used to calculate dielectric constants within the fitted temperature range but should not be used for extrapolation outside this range. The user who needs dielectric constant data with more accuracy than can be provided by this equation is referred to Reference 1, which gives the original data together with their literature source.

Substances are listed by molecular formula in modified Hill order, with substances not containing carbon preceding those that do contain carbon.

* Indicates that the isomer was not specified in the original reference.
** Indicates a compound for which the cubic term is needed:

Ethanol	*d* = -0.15512E-05
N-Methylacetamide	*d* = -0.12998E-04
1,2-Propylene glycol	*d* = -0.32544E-05
1-Butanol	*d* = -0.48841E-06
2-Butanol	*d* = -0.89512E-06
2-Methyl-1-propanol	*d* = -0.45229E-06
2-Methyl-2-propanol	*d* = -0.25968E-05
N-Butylacetamide	*d* = -0.48716E-05

REFERENCES

1. Wohlfarth, Ch., "Static Dielectric Constants of Pure Liquids and Binary Liquid Mixtures", *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology*, New Series, Editor in Chief, O. Madelung, Group IV, Macroscopic and Technical Properties of Matter, Volume 6, Springer-Verlag, Berlin, Heidelberg, New York, 1991.
2. Marsh, K. N., Ed., *Recommended Reference Materials for the Realization of Physicochemical Properties*, Blackwell Scientific Publications, Oxford, 1987.

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$AlBr_3$	Aluminum tribromide	373.2	3.38				
Ar	Argon	140.00	1.3247	0.12408E+01	0.68755E-02	-0.45344E-04	87-149
AsH_3	Arsine	200.9	2.40	0.37674E+01	-0.97454E-02	0.14537E-04	157-201
BBr_3	Boron tribromide	273.2	2.58				
B_2H_6	Diborane	180.66	1.8725	0.23848E+01	-0.29501E-02	0.64189E-06	108-181
B_5H_9	Pentaborane(9)	298.2	21.1	0.40952E+03	-0.24414E+01	0.38225E-02	226-298
BrF_3	Bromine trifluoride	298.2	106.8				
BrF_5	Bromine pentafluoride	297.7	7.91	0.11428E+02	-0.11822E-01		262-298
BrH	Hydrogen bromide	186.8	8.23				
BrNO	Nitrosyl bromide	288.4	13.4				
Br_2	Bromine	297.9	3.1484	0.32701E+01	-0.12535E-03		273-327
Br_2OS	Thionyl bromide	293.2	9.06				
Br_3OV	Vanadyl tribromide	298.2	3.6	0.61112E+01	-0.84211E-02		203-298
Br_4Ge	Germanium(IV) bromide	299.9	2.955	0.34450E+01	-0.16083E-02		300-316
Br_4Sn	Tin(IV) bromide	303.45	3.169	0.50001E+01	-0.60383E-02		304-316
$ClFO_3$	Perchloryl fluoride	150.2	2.194	0.23808E+01	-0.38629E-03	-0.57143E-05	125-150
ClF_3	Chlorine trifluoride	293.2	4.394	0.96716E+01	-0.18000E-01		273-313

PERMITTIVITY (DIELECTRIC CONSTANT) OF LIQUIDS (continued)

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
ClF_5	Chlorine pentafluoride	193.2	4.28	0.78192E+01	-0.20860E-01	0.13132E-04	193-256
ClH	Hydrogen chloride	158.9	14.3	0.47316E+02	-0.28455E+00	0.48650E-03	159-258
ClNO	Nitrosyl chloride	285.2	18.2				
Cl_2	Chlorine	208.0	2.147	0.29440E+01	-0.44649E-02	0.30388E-05	208-240
Cl_2F_3P	Phosphorus(V) dichloride trifluoride	228.63	2.8129	0.46501E+01	-0.80358E-02		172-229
Cl_2OS	Thionyl chloride	298.2	8.675				
Cl_2OSe	Selenium oxychloride	293.2	46.2				
Cl_2O_2S	Sulfuryl chloride	293.2	9.1				
Cl_2S	Sulfur dichloride	298.2	2.915				
Cl_2S_2	Sulfur chloride	288.2	4.79				
Cl_3F_2P	Phosphorus(V) trichloride difluoride	268.0	2.3752	0.28905E+01	-0.19228E-02		215-268
Cl_3OP	Phosphorus(V) oxychloride	293.2	14.1				
Cl_3OV	Vanadyl trichloride	298.2	3.4				
Cl_3P	Phosphorus(III) chloride	290.2	3.498	0.59098E+01	-0.83322E-02		290-333
Cl_3PS	Phosphorus(V) sulfide trichloride	298.2	4.94				
Cl_4FP	Phosphorus(V) tetrachloride fluoride	272.64	2.6499	0.33503E+01	-0.29651E-02		244-273
Cl_4Ge	Germanium(IV) chloride	273.2	2.463	-0.55078E+01	0.64881E-01	-0.13091E-03	246-273
Cl_4Pb	Lead(IV) chloride	293.2	2.78				
Cl_4Si	Tetrachlorosilane	273.2	2.248	0.58041E+01	-0.27129E-01	0.51678E-04	207-273
Cl_4Sn	Tin(IV) chloride	273.2	3.014	0.43951E+01	-0.48805E-02		234-273
Cl_4Ti	Titanium(IV) chloride	257.4	2.843	0.33668E+01	-0.19675E-02		237-257
Cl_4V	Vanadium(IV) chloride	298.2	3.05				
Cl_5P	Phosphorus(V) chloride	433.2	2.85				
Cl_5Sb	Antimony(V) chloride	293.0	3.222	0.45413E+01	-0.45078E-02		276-320
FH	Hydrogen fluoride	273.2	83.6	0.50352E+03	-0.19297E+01	0.14372E-02	200-273
F_2	Fluorine	53.48	1.4913	0.14144E+01	0.26387E-02	-0.28356E-04	54-144
F_5I	Iodine pentafluoride	293.2	37.13	0.95184E+02	-0.19800E+00		273-313
F_6S	Sulfur hexafluoride	223.2	1.81				
F_6Xe	Xenon hexafluoride	398.2	4.10				
F_7I	Iodine heptafluoride	298.2	1.75				
$F_{10}S_2$	Sulfur decafluoride	293.2	2.0202				
HI	Hydrogen iodide	220.2	3.87	0.51557E+03	-0.44552E+01	0.96795E-02	220-236
H_2	Hydrogen	13.52	1.2792	0.13327E+01	-0.51946E-02		14-19
H_2O	Water	293.2	80.100	0.24921E+03	-0.79069E+00	0.72997E-03	273-372
H_2O_2	Hydrogen peroxide	290.2	74.6	0.48511E+03	-0.23145E+01	0.31020E-02	233-303
H_2S	Hydrogen sulfide	283.2	5.93	0.14736E+02	-0.33675E-01	0.96740E-05	212-363
H_3N	Ammonia	293.2	16.61	0.66756E+02	-0.24696E+00	0.25913E-03	238-323
H_4N_2	Hydrazine	298.2	51.7	0.22061E+03	-0.89633E+00	0.11066E-02	278-323
He	Helium	2.055	1.0555	0.10640E+01	-0.35584E-02		2-4
I_2	Iodine	391.25	11.08	0.64730E+02	-0.29266E+00	0.39759E-03	391-441
Kr	Krypton	119.80	1.664				
Mn_2O_7	Manganese(VII) oxide	293.2	3.28	0.37655E+01	-0.16463E-02		283-312
NO	Nitric oxide	1.997					
N_2	Nitrogen	63.15	1.4680	0.12550E+01	0.67949E-02	-0.56704E-04	63-126
N_2O_3	Nitrogen trioxide	203.2	31.13	0.92287E+02	-0.43306E+00	0.65000E-03	203-243
N_2O_4	Nitrogen tetroxide	293.2	2.44	0.28212E+01	-0.13000E-02		253-293
Ne	Neon	26.11	1.1907	0.12667E+01	-0.29064E-02		26-29
O_2	Oxygen	54.478	1.5684	0.15434E+01	0.14615E-02	-0.21964E-04	55-154
O_2S	Sulfur dioxide	298.2	16.3	0.52045E+02	-0.16125E+00	0.11042E-03	213-449
O_3	Ozone	90.2	4.75	0.86344E+01	-0.54807E-01	0.12596E-03	90-185
O_3S	Sulfur trioxide	291.2	3.11				
P	Phosphorus	307.2	4.096	0.79018E+00	0.23911E-01	-0.42826E-04	307-358
S	Sulfur	407.2	3.4991	0.51651E+01	-0.77381E-02	0.89120E-05	407-479
Se	Selenium	510.65	5.44	0.67569E+01	-0.25829E-02		511-575
Xe	Xenon	161.35	1.880				
$CBrClF_2$	Bromochlorodifluoromethane	123.2	3.920	0.52442E+01	-0.11000E-01		123-223
$CBrCl_3$	Bromotrichloromethane	293.2	2.405	0.29249E+01	-0.17650E-02		273-333
$CBrF_3$	Bromotrifluoromethane	123.2	3.730	0.54154E+01	-0.13680E-01		123-173
CBr_2Cl_2	Dibromodichloromethane	298.2	2.542	0.32330E+01	-0.23162E-02		298-333

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
CBr_2F_2	Dibromodifluoromethane	273.2	2.939	0.67296E+01	-0.22133E-01	0.30213E-04	139-273
CBr_3Cl	Tribromochloromethane	333.2	2.601				
CBr_3F	Tribromofluoromethane	293.2	3.00	0.53203E+01	-0.11061E-01	0.10688E-04	206-323
CBr_3NO_2	Tribromonitromethane	298.2	9.034	0.16079E+02	-0.23630E-01		298-328
$CClF_3$	Chlorotrifluoromethane	123.2	3.010	0.43677E+01	-0.11020E-01		123-173
CCl_2F_2	Dichlorodifluoromethane	123.2	3.500	0.46984E+01	-0.97600E-02		123-223
CCl_2O	Carbonyl chloride	295.2	4.30				
CCl_3D	Trichloromethane-*d*	298.2	4.67				
CCl_3F	Trichlorofluoromethane	293.2	3.00	0.53203E+01	-0.11061E-01	0.10688E-04	206-323
CCl_3NO_2	Trichloronitromethane	293.2	7.319	0.14403E+02	-0.24178E-01		276-333
CCl_4	Tetrachloromethane	293.2	2.2379	0.28280E+01	-0.20339E-02	0.71795E-07	283-333
CF_4	Tetrafluoromethane	126.3	1.685	0.20350E+01	-0.27616E-02		126-142
$CHBr_3$	Tribromomethane	283.2	4.404	0.71707E+01	-0.98000E-02		283-343
$CHCl_3$	Trichloromethane	293.2	4.8069	0.15115E+02	-0.51830E-01	0.56803E-04	218-323
CHF_3	Trifluoromethane	294.0	5.2	0.11442E+03	-0.75600E+00	0.13562E-02	130-263
CHN	Hydrogen cyanide	293.2	114.9	0.37331E+04	-0.23180E+02	0.36963E-01	258-299
CH_2Br_2	Dibromomethane	283.2	7.77	0.18060E+02	-0.36333E-01		283-313
CH_2Cl_2	Dichloromethane	298.0	8.93	0.40452E+02	-0.17748E+00	0.23942E-03	184-306
CH_2F_2	Difluoromethane	152.2	53.74	0.19428E+03	-0.12939E+01	0.24280E-02	152-224
CH_2I_2	Diiodomethane	298.2	5.32				
CH_2O_2	Formic acid	298.2	51.1	0.14040E+03	-0.24673E+00	-0.17151E-03	287-358
CH_3Br	Bromomethane	275.7	9.71	0.40580E+02	-0.18418E+00	0.26219E-03	195-276
CH_3Cl	Chloromethane	295.2	10.0	0.42775E+02	-0.16175E+00	0.17108E-03	190-392
CH_3ClO_2S	Methanesulfonyl chloride	293.2	34.0	0.10384E+03	-0.33838E+00	0.34156E-03	293-373
CH_3DO	Methan-d_1-ol	297.5	31.68	0.20839E+03	-0.10318E+01	0.14740E-02	176-298
CH_3F	Fluoromethane	131.0	51.0	0.11338E+03	-0.63979E+00	0.96983E-03	150-299
CH_3I	Iodomethane	293.2	6.97	0.24264E+02	-0.93914E-01	0.11926E-03	223-303
CH_3NO	Formamide	293.2	111.0	0.26076E+03	-0.61145E+00	0.34296E-03	278-333
CH_3NO_2	Nitromethane	293.2	37.27	0.11227E+03	-0.35591E+00	0.34206E-03	288-343
CH_3NO_2	Methyl nitrite	200.0	20.77	0.11071E+03	-0.73428E+00	0.14054E-02	110-260
CH_3NO_3	Methyl nitrate	293.2	23.9				
CH_4	Methane	91.0	1.6761	0.15996E+01	0.27434E-02	-0.22086E-04	91-184
CH_4O	Methanol	293.2	33.0	0.19341E+03	-0.92211E+00	0.12839E-02	177-293
CH_5N	Methylamine	215.2	16.7	0.34398E+02	-0.73630E-01	-0.41279E-04	198-258
CN_4O_8	Tetranitromethane	293.2	2.317				
COS	Carbon oxysulfide	185.0	4.47	0.84702E+01	-0.21488E-01		143-185
$COSe$	Carbon oxyselenide	283.2	3.47	0.48740E+01	-0.49425E-02		219-283
CO_2	Carbon dioxide	295.0	1.4492	0.79062E+00	0.10639E-01	-0.28510E-04	220-300
CS_2	Carbon disulfide	293.2	2.6320	0.45024E+01	-0.12054E-01	0.19147E-04	154-319
$C_2Br_2F_4$	1,2-Dibromotetrafluoroethane	298.2	2.34				
$C_2Cl_2F_4$	1,2-Dichlorotetrafluoroethane	273.2	2.4842	0.36663E+01	-0.42271E-02	-0.36255E-06	193-273
$C_2Cl_2O_2$	Oxalyl chloride	294.35	3.470				
C_2Cl_3N	Trichloroacetonitrile	292.2	7.85				
C_2Cl_4	Tetrachloroethylene	303.2	2.268				
$C_2Cl_4F_2$	1,1,2,2-Tetrachloro-1,2-difluoroethane	308.2	2.52				
C_2HBr_3O	Tribromoacetaldehyde	293.2	7.6				
C_2HCl_3	Trichloroethylene	301.5	3.390	0.58319E+01	-0.80828E-02		302-338
$C_2HCl_3F_2$	1,2,2-Trichloro-1,1-difluoroethane	303.2	4.01	0.75423E+01	-0.11667E-01		303-333
C_2HCl_3O	Trichloroacetaldehyde	298.2	6.8				
$C_2HCl_3O_2$	Trichloroacetic acid	333.2	4.34	0.13412E+01	0.90000E-02	-0.24130E-14	333-393
C_2HCl_5	Pentachloroethane	298.2	3.716	0.65972E+01	-0.96800E-02		298-338
$C_2HF_3O_2$	Trifluoroacetic acid	293.2	8.42	0.21652E+02	-0.68146E-01	0.78571E-04	263-323
C_2H_2	Acetylene	195.0	2.4841				
$C_2H_2Br_2$	*cis*-1,2-Dibromoethylene	298.2	7.08				
$C_2H_2Br_2$	*trans*-1,2-Dibromoethylene	298.2	2.88				
$C_2H_2Br_4$	1,1,2,2-Tetrabromoethane	303.2	6.72	0.16246E+02	-0.31500E-01		303-333
$C_2H_2Cl_2$	1,1-Dichloroethylene	293.2	4.60				
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethylene	298.2	9.20				
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethylene	293.2	2.14				

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_2H_2Cl_2O_2$	Dichloroacetic acid	293.2	8.33	0.11014E+02	-0.10859E-01	0.49242E-05	284-363
$C_2H_2Cl_4$	1,1,1,2-Tetrachloroethane	207.2	9.22	0.19606E+02	-0.49847E-01		207-233
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane	293.2	8.50				
$C_2H_2I_2$	*cis*-1,2-Diiodoethylene	345.65	4.46				
C_2H_3ClO	Acetyl chloride	295.2	15.8				
$C_2H_3ClO_2$	Chloroacetic acid	338.2	12.35	0.17310E+02	-0.14674E-01		338-393
$C_2H_3Cl_2NO_2$	1,1-Dichloro-1-nitroethane	303.2	16.3	0.37576E+02	-0.70400E-01		303-333
$C_2H_3Cl_3$	1,1,1-Trichloroethane	293.2	7.243	0.27705E+02	-0.10621E+00	0.12424E-03	258-318
$C_2H_3Cl_3$	1,1,2-Trichloroethane	298.2	7.1937	0.17147E+02	-0.33371E-01		288-318
$C_2H_3F_3O$	2,2,2-Trifluoroethanol	293.2	27.68	0.90593E+02	-0.21421E+00		293-318
C_2H_3N	Acetonitrile	293.2	36.64	0.29724E+03	-0.15508E+01	0.22591E-02	288-333
C_2H_3NO	Methyl isocyanate	288.7	21.75				
C_2H_4	Ethylene	270.0	1.4833	0.13546E+01	0.62614E-02	-0.21374E-04	200-270
C_2H_4BrCl	1-Bromo-2-chloroethane	283.2	7.41	0.19493E+02	-0.59054E-01	0.58036E-04	263-363
$C_2H_4Br_2$	1,2-Dibromoethane	293.2	4.9612	0.67142E+01	-0.59800E-02		293-313
$C_2H_4Cl_2$	1,1-Dichloroethane	298.2	10.10	0.24429E+02	-0.48000E-01		288-318
$C_2H_4Cl_2$	1,2-Dichloroethane	293.2	10.42	0.24404E+02	-0.47892E-01		293-343
$C_2H_4Cl_2O$	Bis(chloromethyl) ether	293.2	3.51				
$C_2H_4N_2O_6$	Ethylene glycol dinitrate	293.2	28.26				
C_2H_4O	Acetaldehyde	291.2	21.0				
C_2H_4O	Ethylene oxide	293.2	12.42	0.52661E+02	-0.21337E+00	0.25947E-03	293-243
C_2H_4OS	Thioacetic acid	298.2	14.30				
$C_2H_4O_2$	Acetic acid	293.2	6.20	-0.15731E+02	0.12662E+00	-0.17738E-03	293-363
$C_2H_4O_2$	Methyl formate	288.2	9.20	0.19699E+02	-0.36429E-01		288-302
$C_2H_4O_3S$	Ethylene glycol sulfite	298.2	39.6	0.85483E+02	-0.15400E+00		298-328
C_2H_5Br	Bromoethane	298.2	9.01	0.28473E+02	-0.85495E-01	0.67971E-04	243-308
C_2H_5Cl	Chloroethane	293.2	9.45	0.60693E+02	-0.31290E+00	0.47154E-03	237-293
C_2H_5ClO	2-Chloroethanol	293.2	25.80	0.11155E+03	-0.30149E+00		140-175
C_2H_5I	Iodoethane	293.2	7.82	0.25598E+02	-0.94367E-01	0.11424E-03	183-343
C_2H_5N	Ethyleneimine	298.2	18.3	0.61405E+02	-0.14474E+00		273-298
C_2H_5NO	Acetamide	363.7	67.6	-0.20055E+03	0.15515E+01	-0.22392E-02	364-448
C_2H_5NO	*N*-Methylformamide	293.2	189.0	0.10383E+04	-0.43165E+01	0.48398E-02	276-353
C_2H_5NO	Acetaldoxime	298.2	4.70				
$C_2H_5NO_2$	Nitroethane	288.2	29.11	0.57406E+02	-0.97657E-01		276-333
$C_2H_5NO_2$	Methyl carbamate	328.2	18.48	0.36773E+02	-0.55700E-01		328-368
$C_2H_5NO_3$	Ethyl nitrate	293.2	19.7				
C_2H_6	Ethane	95.0	1.9356	0.20185E+01	-0.51493E-03	-0.48148E-05	95-295
C_2H_6O	Ethanol	293.2	25.3	0.15145E+03	-0.87020E+00	0.19570E-02	163-523
C_2H_6O	Dimethyl ether	258.0	6.18	0.22389E+02	-0.86524E-01	0.91291E-04	155-258
C_2H_6OS	Dimethyl sulfoxide	293.2	47.24	0.38478E+02	0.16939E+00	-0.47423E-03	288-343
$C_2H_6O_2$	Ethylene glycol	293.2	41.4	0.14355E+03	-0.48573E+00	0.46703E-03	293-423
$C_2H_6O_2S$	Dimethyl sulfone	383.2	47.39	0.10830E+03	-0.15900E+00		383-398
$C_2H_6O_4S$	Dimethyl sulfate	298.2	55.0				
C_2H_6S	Ethanethiol	298.2	6.667				
C_2H_6S	Dimethyl sulfide	294.2	6.70				
$C_2H_6S_2$	1,2-Ethanedithiol	293.2	7.26	0.11228E+02	-0.13500E-01		293-333
$C_2H_6S_2$	Dimethyl disulfide	298.2	9.6	0.19109E+02	-0.32000E-01		298-323
C_2H_7N	Ethylamine	273.2	8.7	0.30163E+02	-0.79000E-01		233-273
C_2H_7NO	Ethanolamine	293.2	31.94	0.14890E+03	-0.62491E+00	0.77143E-03	253-293
$C_2H_8N_2$	1,2-Ethanediamine	293.2	13.82	0.48922E+02	-0.17021E+00	0.17262E-03	273-333
C_3Cl_6O	Hexachloroacetone	291.9	3.925	0.76423E+01	-0.15838E-01	0.10618E-04	269-303
C_3F_6O	Perfluoroacetone	202.2	2.104	0.34809E+01	-0.92883E-02	0.12282E-04	151-238
C_3HN	Cyanoacetylene	291.9	72.3	0.91803E+03	-0.49149E+01	0.69104E-02	281-314
$C_3H_2F_6O$	1,1,1,3,3,3-Hexafluoro-2-propanol	293.2	16.70				
$C_3H_3ClO_3$	4-Chloro-1,3-dioxolan-2-one	313.2	62.0				
C_3H_3N	Acrylonitrile	293.2	33.0	0.11109E+03	-0.36806E+00	0.34879E-03	233-413
$C_3H_3NO_2$	Cyanoacetic acid	277.2	33.4				
C_3H_4	Allene	269.0	2.025	0.26049E+01	-0.44147E-03	-0.63420E-05	156-269
C_3H_4	Propyne	246.0	3.218	0.60871E+01	-0.11730E-01		185-246

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_3H_4ClF_3$	3-Chloro-1,1,1-trifluoropropane	295.2	7.32	0.22361E+02	-0.68840E-01	0.60594E-04	275-313
C_3H_4ClNO	2-Chloroethyl isocyanate	288.2	29.1	0.64311E+02	-0.12217E+00		288-403
$C_3H_4Cl_2O$	1,1-Dichloroacetone	293.2	14.6				
$C_3H_4F_4O$	2,2,3,3-Tetrafluoro-1-propanol	298.2	21.03				
C_3H_4O	Propargyl alcohol	293.2	20.8	0.99895E+02	-0.38911E+00	0.40776E-03	213-293
$C_3H_4O_3$	Ethylene carbonate	313.2	89.78	0.20746E+03	-0.37610E+00		313-343
C_3H_5Br	3-Bromopropene	293.2	7.0				
$C_3H_5BrO_2$	2-Bromopropanoic acid	294.2	11.0				
$C_3H_5Br_3$	1,2,3-Tribromopropane	303.2	6.00	0.11024E+02	-0.16596E-01		303-358
C_3H_5Cl	2-Chloropropene	299.25	8.92				
C_3H_5Cl	3-Chloropropene	293.2	8.2				
$C_3H_5ClN_2O_6$	3-Chloro-1,2-propanediol dinitrate	293.2	17.50				
C_3H_5ClO	Epichlorohydrin	293.2	22.6				
$C_3H_5ClO_2$	Ethyl chloroformate	308.7	9.736	0.15356E+02	-0.18250E-01		309-349
$C_3H_5ClO_2$	Methyl chloroacetate	293.2	12.0				
$C_3H_5Cl_3$	1,2,3-Trichloropropane	293.2	7.5				
C_3H_5I	3-Iodopropene	292.2	6.1				
C_3H_5N	Propanenitrile	293.2	29.7	0.82222E+02	-0.22937E+00	0.17424E-03	213-473
C_3H_5NO	Ethyl isocyanate	293.2	19.7				
C_3H_5NS	Ethyl isothiocyanate	293.2	19.6				
$C_3H_5N_3O_9$	Trinitroglycerol	293.2	19.25				
C_3H_6	Propene	220.0	2.1365	0.29623E+01	-0.37564E-02		220-250
$C_3H_6Br_2$	1,2-Dibromopropane	283.2	4.60	0.54973E+01	-0.31695E-02		283-333
$C_3H_6Br_2$	1,3-Dibromopropane	293.2	9.482	0.29193E+02	-0.94450E-01	0.92800E-04	293-368
$C_3H_6ClNO_2$	2-Chloro-2-nitropropane	250.4	31.90				
$C_3H_6Cl_2$	1,2-Dichloropropane	293.2	8.37	0.18915E+02	-0.35907E-01		281-323
$C_3H_6Cl_2$	1,3-Dichloropropane	303.2	10.27	0.21609E+02	-0.37333E-01		303-333
$C_3H_6Cl_2$	2,2-Dichloropropane	293.2	11.37	0.32421E+02	-0.72188E-01		245-293
$C_3H_6N_2O_4$	2,2-Dinitropropane	325.1	42.4				
C_3H_6O	Allyl alcohol	293.2	19.7	0.62714E+02	-0.14771E+00	0.37879E-05	213-303
C_3H_6O	Propanal	290.2	18.5				
C_3H_6O	Acetone	293.2	21.01	0.88157E+02	-0.34300E+00	0.38925E-03	273-323
$C_3H_6O_2$	Propanoic acid	298.2	3.44	0.18793E+01	0.46841E-02	0.19983E-05	289-408
$C_3H_6O_2$	Ethyl formate	288.2	8.57	0.15884E+02	-0.25333E-01		288-318
$C_3H_6O_2$	Methyl acetate	288.2	7.07	0.13190E+02	-0.21226E-01		276-318
$C_3H_6O_3$	3-Hydroxypropanoic acid	296.2	30.0				
$C_3H_6O_3$	Dimethyl carbonate	298.2	3.087				
$C_3H_6O_3$	1,3,5-Trioxane	338.2	15.55				
C_3H_7Br	1-Bromopropane	293.2	8.09	0.17769E+02	-0.32599E-01		274-328
C_3H_7Br	2-Bromopropane	293.2	9.46	0.26195E+02	-0.72995E-01	0.55454E-04	186-328
C_3H_7Cl	1-Chloropropane	293.2	8.588	0.21214E+02	-0.43130E-01		273-313
C_3H_7ClO	3-Chloro-1-propanol	215.2	36.0	0.12436E+03	-0.60841E+00	0.92060E-03	145-215
C_3H_7ClO	1-Chloro-2-propanol	153.2	59.0	-0.19169E+02	0.13605E+01	-0.55567E-02	153-177
$C_3H_7ClO_2$	3-Chloro-1,2-propanediol	293.2	31.0				
C_3H_7I	1-Iodopropane	293.2	7.07	0.13744E+02	-0.22745E-01		293-323
C_3H_7I	2-Iodopropane	298.2	8.19				
C_3H_7NO	*N*-Ethylformamide	298.2	102.7	0.64764E+03	-0.28499E+01	0.34286E-02	298-338
C_3H_7NO	*N,N*-Dimethylformamide	293.2	38.25	0.15364E+03	-0.60367E+00	0.71505E-03	213-353
C_3H_7NO	*N*-Methylacetamide	303.2	179.0	0.15975E+04	-0.90451E+01	0.18345E-01	303-473
$C_3H_7NO_2$	1-Nitropropane	288.2	24.70	0.94999E+02	-0.38358E+00	0.48480E-03	276-333
$C_3H_7NO_2$	2-Nitropropane	288.2	26.74	0.60138E+02	-0.11566E+00		276-303
$C_3H_7NO_2$	Propyl nitrite	250.0	12.35	0.70552E+02	-0.40362E+00	0.66687E-03	110-310
$C_3H_7NO_2$	Isopropyl nitrite	260.0	13.92	0.74578E+02	-0.38283E+00	0.57071E-03	150-300
$C_3H_7NO_2$	Ethyl carbamate	328.2	14.14	0.32431E+02	-0.65097E-01	0.28571E-04	328-368
C_3H_8	Propane	293.19	1.6678	0.22883E+01	-0.23276E-02	0.84710E-06	90-300
C_3H_8O	1-Propanol	293.2	20.8	0.98045E+02	-0.36860E+00	0.36422E-03	193-493
C_3H_8O	2-Propanol	293.2	20.18	0.10416E+03	-0.41011E+00	0.42049E-03	193-493
$C_3H_8O_2$	1,2-Propylene glycol	303.2	27.5	0.24546E+03	-0.15738E+01	0.38068E-02	193-403
$C_3H_8O_2$	1,3-Propylene glycol	293.2	35.1	0.11365E+03	-0.36680E+00	0.33766E-03	288-328

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_3H_8O_2$	Ethylene glycol monomethyl ether	298.2	17.2	0.11803E+03	-0.58000E+00	0.81001E-03	254-318
$C_3H_8O_2$	Dimethoxymethane	293.2	2.644	0.25877E+01	-0.93019E-03	0.38472E-05	171-293
$C_3H_8O_3$	Glycerol	293.2	46.53	0.77503E+02	-0.37984E-01	-0.23107E-03	288-343
C_3H_8S	1-Propanethiol	288.2	5.937	0.11602E+02	-0.19580E-01		273-318
C_3H_8S	2-Propanethiol	298.2	5.952				
$C_3H_8S_2$	1,2-Propanedithiol	293.2	7.24	0.14667E+02	-0.32660E-01	0.25000E-04	293-333
$C_3H_8S_2$	1,3-Propanedithiol	303.2	8.11	0.66607E+01	0.31310E-01	-0.87500E-04	303-343
$C_3H_9BO_3$	Trimethyl borate	293.2	2.2762				
C_3H_9ClSi	Trimethylchlorosilane	273.2	10.21	-0.19492E+02	0.29806E+00	-0.69284E-03	223-273
C_3H_9N	Propylamine	296.2	5.08	0.17719E+02	-0.59022E-01	0.54780E-04	204-296
C_3H_9N	Isopropylamine	293.2	5.6268	0.40429E+02	-0.21441E+00	0.32634E-03	213-298
C_3H_9N	Trimethylamine	298.2	2.440	0.39745E+01	-0.51331E-02		273-298
$C_3H_9O_4P$	Trimethyl phosphate	293.2	20.6				
C_4Cl_6	Hexachloro-1,3-butadiene	293.2	2.55				
$C_4Cl_6O_3$	Trichloroacetic anhydride	298.2	5.0				
$C_4F_6O_3$	Trifluoroacetic acid anhydride	298.2	2.7				
$C_4H_2Cl_4O_3$	Dichloroacetic anhydride	298.2	15.8				
$C_4H_2O_3$	Maleic anhydride	326.2	52.75				
$C_4H_3F_7O$	2,2,3,3,4,4,4-Heptafluoro-1-butanol	298.2	14.4				
$C_4H_4N_2$	Succinonitrile	298.2	62.6	0.17724E+03	-0.54654E+00	0.54046E-03	236-351
$C_4H_4N_2$	Pyrazine	323.2	2.80				
C_4H_4O	Furan	277.1	2.88	0.13636E+01	0.12864E-01	-0.22701E-04	188-277
C_4H_4S	Thiophene	293.2	2.739	0.32941E+01	-0.19019E-02		253-293
C_4H_5Cl	2-Chloro-1,3-butadiene	293.2	4.914				
$C_4H_5Cl_3O_2$	Ethyl trichloroacetate	293.2	8.428				
C_4H_5N	Pyrrole	293.0	8.00	0.12672E+02	-0.14075E-01	-0.62671E-05	293-357
C_4H_5NO	Allyl isocynate	288.2	15.15	0.34299E+02	-0.66444E-01		288-333
C_4H_6	1,3-Butadiene	265.0	2.050	0.27674E+01	-0.26738E-02		185-265
C_4H_6O	Divinyl ether	288.2	3.94				
C_4H_6O	Ethoxyacetylene	298.2	8.05				
C_4H_6O	Cyclobutanone	298.2	14.27	0.43974E+02	-0.15712E+00	0.19264E-03	220-317
$C_4H_6O_2$	Methyl acrylate	303.2	7.03	0.11968E+02	-0.16500E-01		303-333
$C_4H_6O_2$	2,3-Butanedione	298.2	4.04	0.46907E+01	-0.22302E-02		278-348
$C_4H_6O_2$	γ-Butyrolactone	293.2	39.0				
$C_4H_6O_3$	Acetic anhydride	293.2	22.45				
$C_4H_6O_3$	Propylene carbonate	293.0	66.14	0.15940E+03	-0.39530E+00	0.26284E-03	273-333
C_4H_7Br	*cis*-2-Bromo-2-butene	293.2	5.38				
C_4H_7Br	*trans*-2-Bromo-2-butene	293.2	6.76				
$C_4H_7BrO_2$	2-Bromobutanoic acid	293.2	7.2				
$C_4H_7BrO_2$	Ethyl bromoacetate	303.2	9.75	0.15627E+02	-0.19600E-01		303-333
$C_4H_7BrO_2$	Methyl 3-bromopropanoate	303.2	5.81	0.36001E+01	0.72500E-02		303-343
$C_4H_7ClO_2$	Propyl chlorocarbonate	293.2	11.2				
$C_4H_7ClO_2$	Methyl 2-chloropropanoate	303.2	11.45	0.22449E+02	-0.36250E-01		303-343
C_4H_7N	Butanenitrile	293.2	24.83	0.53884E+02	-0.99257E-01		293-333
C_4H_7N	2-Methylpropanenitrile	293.2	24.42	0.52554E+02	-0.96000E-01		293-313
C_4H_7NO	2-Pyrrolidone	298.2	28.18	0.11054E+03	-0.47945E+00	0.68182E-03	
298-338							
C_4H_8	1-Butene	220.0	2.2195	0.29354E+01	-0.32580E-02		220-250
C_4H_8	*cis*-2-Butene	296.0	1.960	0.28802E+01	-0.31064E-02		197-296
C_4H_8	Isobutene	288.7	2.1225	0.33701E+01	-0.43295E-02		220-289
$C_4H_8Br_2$	1,2-Dibromobutane	293.2	4.74	0.11199E+03	-0.63334E+00	0.91250E-03	293-333
$C_4H_8Br_2$	1,3-Dibromobutane	293.2	9.14	0.34031E+02	-0.13254E+00	0.16250E-03	293-333
$C_4H_8Br_2$	1,4-Dibromobutane	303.2	8.68	0.20944E+02	-0.55620E-01	0.50000E-04	303-333
$C_4H_8Br_2$	2,3-Dibromobutane	298.2	6.245	0.23849E+02	-0.96300E-01	0.12500E-03	293-333
$C_4H_8Br_2$	1,2-Dibromo-2-methylpropane	293.2	4.1				
$C_4H_8Cl_2$	1,2-Dichlorobutane	293.2	7.74	0.31925E+02	-0.13232E+00	0.17007E-03	293-356
$C_4H_8Cl_2$	1,4-Dichlorobutane	308.2	9.30	0.59766E+01	0.49300E-01	-0.12500E-03	308-338
$C_4H_8Cl_2$	1,2-Dichloro-2-methylpropane	296.0	7.15	0.39429E+02	-0.20028E+00	0.30917E-03	165-296
$C_4H_8Cl_2O$	Bis(2-chloroethyl) ether	293.2	21.20				
C_4H_8O	Butanal	298.2	13.45				

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
C_4H_8O	2-Butanone	293.2	18.56	0.15457E+02	0.90152E-01	-0.27100E-03	293-333
C_4H_8O	Tetrahydrofuran	295.2	7.52	0.30739E+02	-0.12946E+00	0.17195E-03	224-295
$C_4H_8O_2$	Butanoic acid	287.2	2.98	0.15010E+01	0.50046E-02		287-403
$C_4H_8O_2$	2-Methylpropanoic acid	293.2	2.58				
$C_4H_8O_2$	Propyl formate	303.2	6.92				
$C_4H_8O_2$	Ethyl acetate	293.2	6.0814	0.15646E+02	-0.44066E-01	0.39137E-04	293-433
$C_4H_8O_2$	Methyl propanoate	293.2	6.200	0.12798E+02	-0.22540E-01		293-333
$C_4H_8O_2$	1,4-Dioxane	293.2	2.2189	0.27299E+01	-0.17440E-02		293-313
$C_4H_8O_3$	2-Hydroxybutanoic acid	296.2	37.7				
$C_4H_8O_3$	3-Hydroxybutanoic acid	296.2	31.5				
$C_4H_8O_3$	Ethyl methyl carbonate	293.2	2.985				
$C_4H_8O_3$	Ethylene glycol monoacetate	303.2	12.95				
C_4H_9Br	1-Bromobutane	283.2	7.315	0.22542E+02	-0.79306E-01	0.89867E-04	183-363
C_4H_9Br	2-Bromobutane	298.2	8.64	0.18461E+02	-0.32933E-01		274-328
C_4H_9Br	1-Bromo-2-methylpropane	273.2	7.70	0.37558E+02	-0.20571E+00	0.35496E-03	112-273
C_4H_9Br	2-Bromo-2-methylpropane	293.0	10.98	0.35085E+02	-0.14075E+00	0.19960E-03	258-293
C_4H_9Cl	1-Chlorobutane	293.2	7.276	0.13565E+02	-0.10161E-01	-0.38750E-04	273-323
C_4H_9Cl	2-Chlorobutane	293.2	8.564	0.30376E+02	-0.11377E+00	0.13429E-03	273-323
C_4H_9Cl	1-Chloro-2-methylpropane	293.2	7.027	0.14945E+02	-0.33747E-01	0.23036E-04	273-323
C_4H_9Cl	2-Chloro-2-methylpropane	293.2	9.663	0.35077E+02	-0.12867E+00	0.14304E-03	273-323
C_4H_9I	1-Iodobutane	293.2	6.27	0.16493E+02	-0.50262E-01	0.52485E-04	293-323
C_4H_9I	2-Iodobutane	293.2	7.873	0.10883E+02	-0.14680E-02	-0.30000E-04	293-323
C_4H_9I	2-Iodo-2-methylpropane	283.2	6.65	0.76780E+01	0.69900E-02	-0.37500E-04	283-323
C_4H_9N	Pyrrolidine	293.0	8.30	0.38191E+02	-0.15462E+00	0.17941E-03	274-333
C_4H_9NO	*N*-Methylpropanamide	293.2	170.0				
C_4H_9NO	*N*-Ethylacetamide	293.2	135.0	0.74494E+03	-0.31400E+01	0.36131E-02	213-353
C_4H_9NO	*N*,*N*-Dimethylacetamide	294.2	38.85	0.15420E+03	-0.57506E+00	0.61911E-03	294-433
C_4H_9NO	2-Butanone oxime	293.2	3.4				
C_4H_9NO	Morpholine	298.2	7.42				
$C_4H_9NO_2$	*tert*-Butyl nitrite	298.2	11.47				
$C_4H_9NO_2$	Propyl carbamate	338.2	12.06	0.24356E+02	-0.36400E-01		338-378
$C_4H_9NO_2$	Ethyl-*N*-methyl carbamate	298.2	21.10	0.11477E+03	-0.47568E+00	0.54127E-03	298-373
$C_4H_9NO_2$	*N*-Acetylethanolamine	298.2	96.6	0.37016E+03	-0.13113E+01	0.13214E-02	298-348
$C_4H_9NO_3$	Butyl nitrate	293.2	13.10				
C_4H_{10}	Butane	295.0	1.7697	0.22379E+01	-0.13884E-02	-0.66711E-06	135-303
C_4H_{10}	Isobutane	295.0	1.7518	0.23295E+01	-0.19953E-02	0.14197E-06	115-303
$C_4H_{10}O$	1-Butanol	293.2	17.84	0.10578E+03	-0.50587E+00	0.84733E-03	193-553
$C_4H_{10}O$	2-Butanol	293.2	17.26	0.13850E+03	-0.75146E+00	0.14086E-02	172-533
$C_4H_{10}O$	2-Methyl-1-propanol	293.2	17.93	0.10762E+03	-0.51398E+00	0.83702E-03	173-533
$C_4H_{10}O$	2-Methyl-2-propanol	298.2	12.47	0.22541E+03	-0.14990E+01	0.34050E-02	298-503
$C_4H_{10}O$	Diethyl ether	293.2	4.2666	0.79725E+01	-0.12519E-01		283-301
$C_4H_{10}O_2$	1,2-Butanediol	298.2	22.4	0.63702E+02	-0.13807E+00		278-323
$C_4H_{10}O_2$	1,3-Butanediol	298.2	28.8	0.72883E+02	-0.14770E+00		278-323
$C_4H_{10}O_2$	1,4-Butanediol	298.2	31.9	0.13079E+03	-0.46985E+00	0.46320E-03	288-328
$C_4H_{10}O_2$	Ethylene glycol monoethyl ether	298.2	13.38				
$C_4H_{10}O_2$	Ethylene glycol dimethyl ether	296.7	7.30	0.48832E+02	-0.24218E+00	0.34413E-03	256-318
$C_4H_{10}O_2S$	Bis(2-hydroxyethyl) sulfide	293.2	28.61	0.13128E+03	-0.52719E+00	0.60465E-03	253-333
$C_4H_{10}O_3$	Diethylene glycol	293.2	31.82	0.13973E+03	-0.54725E+00	0.61149E-03	288-343
$C_4H_{10}O_3S$	Diethyl sulfite	293.2	15.6				
$C_4H_{10}O_4$	1,2,3,4-Butanetetrol	393.2	28.2				
$C_4H_{10}O_4S$	Diethyl sulfate	293.2	29.2				
$C_4H_{10}S$	1-Butanethiol	288.2	5.204	0.11201E+02	-0.20767E-01		273-318
$C_4H_{10}S$	2-Butanethiol	288.2	5.645	0.10866E+02	-0.17993E-01		273-318
$C_4H_{10}S$	2-Methyl-1-propanethiol	298.2	4.961				
$C_4H_{10}S$	2-Methyl-2-propanethiol	293.2	5.475	0.10597E+02	-0.17500E-01		283-313
$C_4H_{10}S$	Diethyl sulfide	298.2	5.723				
$C_4H_{11}N$	Butylamine	293.2	4.71	0.13322E+02	-0.44176E-01	0.50250E-04	223-333
$C_4H_{11}N$	Diethylamine	293.2	3.680	0.26462E+02	-0.13750E+00	0.20373E-03	243-323
$C_4H_{11}NO_2$	Diethanolamine	293.2	25.75	0.73435E+02	-0.21377E+00	0.17500E-03	273-323

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_4H_{12}O_2Si$	Dimethoxydimethylsilane	298.2	3.663				
$C_4H_{12}O_3Si$	Trimethoxymethylsilane	298.2	4.9				
$C_4H_{12}O_4Si$	Tetramethyl silicate	293.2	6.0				
$C_4H_{12}Si$	Diethylsilane	293.2	2.544				
$C_4H_{12}Si$	Tetramethylsilane	293.2	1.921				
$C_4H_{13}N_3$	Diethylenetriamine	293.2	12.62	0.57840E+02	-0.23873E+00	0.28841E-03	213-333
C_5FeO_5	Iron pentacarbonyl	293.2	2.602				
C_5H_4BrN	2-Bromopyridine	298.2	23.18	0.73391E+02	-0.23678E+00	0.22930E-03	298-398
C_5H_4ClN	2-Chloropyridine	298.2	27.32	0.98702E+02	-0.34237E+00	0.34502E-03	298-398
$C_5H_4F_8O$	2,2,3,3,4,4,5,5-Octafluoro-1-pentanol	298.2	15.30				
$C_5H_4O_2$	Furfural	293.2	42.1				
C_5H_5N	Pyridine	293.2	13.260	0.43991E+02	-0.15150E+00	0.15925E-03	293-323
C_5H_5NO	Pyridine-1-oxide	343.0	35.94	0.20878E+02	0.16450E+00	-0.35269E-03	343-398
C_5H_6O	2-Methylfuran	293.2	2.76				
$C_5H_6O_2$	Furfuryl alcohol	298.2	16.85				
$C_5H_7Cl_3O_2$	Propyl trichloroacetate	298.2	8.32				
$C_5H_7NO_2$	Ethyl cyanoacetate	263.2	31.62				
C_5H_8	1,3-Pentadiene*	298.2	2.319				
C_5H_8	1,4-Pentadiene	294.0	2.054	0.29994E+01	-0.34578E-02	0.85300E-06	178-294
C_5H_8	2-Methyl-1,3-butadiene	293.2	2.098	0.28170E+01	-0.23147E-02	-0.43975E-06	198-293
C_5H_8	Cyclopentene	295.0	2.083	0.28177E+01	-0.27597E-02	0.89346E-06	171-319
C_5H_8O	Cyclopentanone	298.2	13.58	0.24083E+02	-0.30286E-01	-0.16802E-04	219-298
$C_5H_8O_2$	Ethyl acrylate	303.2	6.05	0.47827E+02	-0.24394E+00	0.35000E-03	303-343
$C_5H_8O_2$	Methyl *trans*-2-butenoate	293.2	6.6645				
$C_5H_8O_2$	Methyl methacrylate	303.2	6.32	0.32098E+02	-0.14568E+00	0.20000E-03	303-343
$C_5H_8O_2$	2,4-Pentanedione	303.2	26.524				
$C_5H_8O_4$	Dimethyl malonate	293.2	9.82	0.26470E+02	-0.76656E-01	0.67888E-04	293-433
$C_5H_9BrO_2$	Ethyl 2-bromopropanoate	293.2	9.4				
$C_5H_9ClO_2$	Isobutyl chlorocarbonate	293.2	9.1				
$C_5H_9ClO_2$	Ethyl 2-chloropropanoate	303.2	11.95	0.25965E+02	-0.46250E-01		303-343
$C_5H_9ClO_2$	Ethyl 3-chloropropanoate	303.2	10.19	0.21951E+02	-0.38750E-01		303-343
$C_5H_9ClO_2$	Methyl 4-chlorobutanoate	303.2	9.51	0.17127E+02	-0.25000E-01		303-343
C_5H_9N	Pentanenitrile	293.2	20.04	0.55793E+02	-0.15750E+00	0.12432E-03	183-333
C_5H_9N	2,2-Dimethylpropanenitrile	293.2	21.1	0.58418E+02	-0.16884E+00	0.14131E-03	293-453
C_5H_9NO	Isobutyl isocyanate	293.2	11.638	0.38026E+02	-0.12714E+00	0.12679E-03	293-353
C_5H_9NO	*N*-Methyl-2-pyrrolidone	293.2	32.55				
C_5H_{10}	1-Pentene	293.2	2.011	-0.11438E+01	0.25420E-01	-0.50000E-04	273-293
C_5H_{10}	2-Methyl-1-butene	293.2	2.180				
C_5H_{10}	2-Methyl-2-butene	296.0	1.979	0.26064E+01	-0.19578E-02	-0.53908E-06	225-296
C_5H_{10}	Cyclopentane	293.2	1.9687	0.24287E+01	-0.15304E-02	-0.13095E-06	278-313
C_5H_{10}	Ethylcyclopropane	293.2	1.933				
$C_5H_{10}Br_2$	1,2-Dibromopentane	298.2	4.39				
$C_5H_{10}Br_2$	1,4-Dibromopentane	293.2	9.05	0.26443E+02	-0.88640E-01	0.10000E-03	293-333
$C_5H_{10}Br_2$	1,5-Dibromopentane	303.2	9.14	0.38192E+02	-0.15648E+00	0.20000E-03	303-333
$C_5H_{10}Cl_2$	1,2-Dichloropentane	293.2	6.89	0.19016E+02	-0.57954E-01	0.56801E-04	293-356
$C_5H_{10}Cl_2$	1,5-Dichloropentane	298.2	9.92				
$C_5H_{10}O$	Cyclopentanol	288.2	18.5	0.10565E+03	-0.44244E+00	0.48657E-03	258-323
$C_5H_{10}O$	Pentanal	293.2	10.00				
$C_5H_{10}O$	2,2-Dimethylpropanal	293.2	9.051	0.18645E+02	-0.32395E-01	-0.16157E-05	280-333
$C_5H_{10}O$	2-Pentanone	293.2	15.45	0.40893E+02	-0.10423E+00	0.60557E-04	204-353
$C_5H_{10}O$	3-Pentanone	293.2	17.00	0.12690E+02	0.95177E-01	-0.27321E-03	233-353
$C_5H_{10}O$	3-Methyl-2-butanone	293.2	10.37	0.30695E+02	-0.10962E+00	0.13810E-03	293-328
$C_5H_{10}O$	Tetrahydropyran	293.2	5.66	0.19793E+02	-0.76071E-01	0.94852E-04	234-333
$C_5H_{10}O$	2-Methyltetrahydrofuran	298.2	6.97				
$C_5H_{10}O_2$	Pentanoic acid	294.4	2.661	0.33491E+01	-0.75156E-02	0.17820E-04	250-344
$C_5H_{10}O_2$	Butyl formate	303.2	6.10	0.21532E+02	-0.84106E-01	0.10952E-03	288-323
$C_5H_{10}O_2$	Isobutyl formate	293.2	6.41				
$C_5H_{10}O_2$	Propyl acetate	293.2	5.62	0.17677E+02	-0.61404E-01	0.69196E-04	253-353
$C_5H_{10}O_2$	Ethyl propanoate	293.2	5.76				

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_5H_{10}O_2$	Methyl butanoate	301.2	5.48	0.38604E+02	-0.19171E+00	0.27128E-03	301-343
$C_5H_{10}O_2$	Tetrahydrofurfuryl alcohol	303.2	13.48				
$C_5H_{10}O_2S$	3-Methyl sulfolane	298.2	29.4	0.53158E+02	-0.93730E-01	0.47275E-04	298-398
$C_5H_{10}O_3$	Diethyl carbonate	297.2	2.820				
$C_5H_{10}O_3$	Ethyl lactate	303.2	15.4	0.31225E+02	-0.43531E-01	-0.28571E-04	273-373
$C_5H_{10}O_4$	1,2,3-Propanetriol-1-acetate	242.2	38.57	0.10653E+03	-0.26439E+00	-0.62371E-04	215-242
$C_5H_{11}Br$	2-Bromo-2-methylbutane	298.2	9.21				
$C_5H_{11}Br$	1-Bromopentane	299.2	6.31	0.20954E+02	-0.78743E-01	0.98908E-04	183-328
$C_5H_{11}Br$	3-Bromopentane	298.2	8.37				
$C_5H_{11}Br$	1-Bromo-3-methylbutane	291.5	6.33	0.27743E+02	-0.13927E+00	0.22627E-03	123-292
$C_5H_{11}Cl$	1-Chloropentane	293.2	6.654	0.18626E+02	-0.54719E-01	0.47143E-04	273-323
$C_5H_{11}Cl$	1-Chloro-3-methylbutane	292.0	6.10	0.22228E+02	-0.93189E-01	0.12991E-03	171-297
$C_5H_{11}Cl$	2-Chloro-2-methylbutane	222.75	12.31	0.55104E+02	-0.29866E+00	0.47840E-03	201-223
$C_5H_{11}F$	1-Fluoropentane	293.2	3.931				
$C_5H_{11}I$	1-Iodopentane	293.2	5.78	0.15753E+02	-0.50543E-01	0.56401E-04	293-323
$C_5H_{11}I$	3-Iodopentane	293.2	7.432				
$C_5H_{11}I$	1-Iodo-3-methylbutane	292.2	5.6				
$C_5H_{11}I$	2-Iodo-2-methylbutane	293.2	8.192				
$C_5H_{11}N$	Piperidine	293.0	4.33	0.82317E+01	-0.11229E-01	-0.71429E-05	293-333
$C_5H_{11}N$	*N*-Methylpyrrolidine	298.2	32.2				
$C_5H_{11}NO$	2,2-Dimethylpropanamide	298.2	20.13	0.10400E+03	-0.46017E+00	0.60000E-03	298-328
$C_5H_{11}NO$	*N*,*N*-Diethylformamide	293.2	29.6				
$C_5H_{11}NO$	2-Pentanone oxime	293.2	3.3				
$C_5H_{11}NO_2$	Pentyl nitrite	298.2	7.21				
C_5H_{12}	Pentane	293.2	1.8371				
C_5H_{12}	Isopentane	293.2	1.845	0.22384E+01	-0.12985E-02	-0.16182E-06	143-293
C_5H_{12}	Neopentane	296.0	1.769	0.10949E+02	-0.63057E-01	0.10835E-03	251-296
$C_5H_{12}N_2O$	Tetramethylurea	293.2	23.10				
$C_5H_{12}O$	1-Pentanol	298.2	15.13	0.73397E+02	-0.28165E+00	0.28427E-03	213-513
$C_5H_{12}O$	2-Pentanol	298.2	13.71	0.16437E+03	-0.86506E+00	0.11955E-02	273-323
$C_5H_{12}O$	3-Pentanol	298.2	13.35	0.12838E+03	-0.60980E+00	0.75000E-03	288-318
$C_5H_{12}O$	2-Methyl-1-butanol	298.2	15.63	0.14020E+02	0.13948E+00	-0.45000E-03	288-318
$C_5H_{12}O$	3-Methyl-1-butanol	293.2	15.63	0.79733E+02	-0.31272E+00	0.32014E-03	173-513
$C_5H_{12}O$	2-Methyl-2-butanol	298.2	5.78	0.11662E+03	-0.69756E+00	0.10920E-02	268-318
$C_5H_{12}O$	3-Methyl-2-butanol	298.2	12.1				
$C_5H_{12}O$	2,2-Dimethyl-1-propanol	333.2	8.35	0.92350E+02	-0.41870E+00	0.50000E-03	333-373
$C_5H_{12}O_2$	1,2-Pentanediol	296.8	17.31	0.18436E+03	-0.10682E+01	0.17037E-02	197-297
$C_5H_{12}O_2$	1,4-Pentanediol	295.7	26.74	0.13568E+03	-0.59198E+00	0.75398E-03	193-318
$C_5H_{12}O_2$	1,5-Pentanediol	293.2	26.2	0.11858E+03	-0.45920E+00	0.49341E-03	243-343
$C_5H_{12}O_2$	2,3-Pentanediol	296.9	17.37	0.95876E+02	-0.46463E+00	0.67434E-03	238-297
$C_5H_{12}O_2$	2,4-Pentanediol	294.2	24.69	0.11914E+03	-0.52569E+00	0.69607E-03	224-294
$C_5H_{12}O_2$	Diethoxymethane	293.2	2.527	0.25294E+01	0.73988E-04	-0.28331E-06	227-293
$C_5H_{12}O_4$	Tetramethoxymethane	293.2	2.40				
$C_5H_{12}O_5$	Xylitol	293.2	40.0				
$C_5H_{12}S$	1-Pentanethiol	293.2	4.847	0.71131E+01	-0.30228E-02	-0.16414E-04	273-333
$C_5H_{12}S$	2-Methyl-2-butanethiol	293.2	5.087	0.15116E+02	-0.50700E-01	0.56250E-04	273-333
$C_5H_{12}S_4$	Tetrakis(methylthio)methane	343.2	2.818				
$C_5H_{13}N$	Pentylamine	293.2	4.27	0.11274E+02	-0.34965E-01	0.37706E-04	223-353
$C_5H_{13}N_3$	1,1,3,3-Tetramethylguanidine	298.2	11.5				
$C_5H_{14}OSi$	Ethoxytrimethylsilane	298.2	3.013				
C_6F_6	Hexafluorobenzene	298.2	2.029	0.24041E+01	-0.83086E-03	-0.14286E-05	298-338
C_6F_{14}	Perfluorohexane	298.2	1.76				
$C_6H_3N_3O_7$	2,4,6-Trinitrophenol	294.2	4.0				
C_6H_4BrF	1-Bromo-2-fluorobenzene	298.2	4.72				
C_6H_4BrF	1-Bromo-3-fluorobenzene	298.2	4.85				
C_6H_4BrF	1-Bromo-4-fluorobenzene	298.2	2.60				
$C_6H_4BrNO_2$	1-Bromo-3-nitrobenzene	328.2	20.2	0.81413E+02	-0.27645E+00	0.27367E-03	328-413
$C_6H_4Br_2$	*o*-Dibromobenzene	293.2	7.86	-0.81849E-02	0.62671E-01	-0.12222E-03	293-353
$C_6H_4Br_2$	*m*-Dibromobenzene	293.2	4.81	0.93214E+01	-0.20273E-01	0.16667E-04	293-353

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_6H_4Br_2$	*p*-Dibromobenzene	368.2	2.57				
C_6H_4ClF	1-Chloro-2-fluorobenzene	298.2	6.10				
C_6H_4ClF	1-Chloro-3-fluorobenzene	298.2	4.96				
C_6H_4ClF	1-Chloro-4-fluorobenzene	298.2	3.34				
$C_6H_4ClNO_2$	1-Chloro-2-nitrobenzene	323.2	37.7	0.16800E+03	-0.59708E+00	0.59957E-03	323-436
$C_6H_4ClNO_2$	1-Chloro-3-nitrobenzene	323.2	20.9	0.77193E+02	-0.25118E+00	0.23798E-03	323-433
$C_6H_4ClNO_2$	1-Chloro-4-nitrobenzene	393.2	8.09				
$C_6H_4Cl_2$	*o*-Dichlorobenzene	293.2	10.12	0.13629E+02	0.10622E-02	-0.44444E-04	293-353
$C_6H_4Cl_2$	*m*-Dichlorobenzene	293.2	5.02	0.77565E+01	-0.93333E-02	-0.26880E-14	293-353
$C_6H_4Cl_2$	*p*-Dichlorobenzene	328.2	2.3943	0.26999E+01	-0.35325E-03	-0.17619E-05	328-363
C_6H_4FI	1-Fluoro-2-iodobenzene	298.2	8.22				
C_6H_4FI	1-Fluoro-4-iodobenzene	298.2	3.12				
$C_6H_4F_2$	*o*-Difluorobenzene	301.2	13.38	0.59107E+02	-0.23611E+00	0.27987E-03	273-323
$C_6H_4F_2$	*m*-Difluorobenzene	301.2	5.01	0.14448E+02	-0.46982E-01	0.51948E-04	273-323
$C_6H_4I_2$	*o*-Diiodobenzene	323.2	5.41	0.31150E+02	-0.14428E+00	0.20000E-03	323-353
$C_6H_4I_2$	*m*-Diiodobenzene	323.2	4.11				
$C_6H_4I_2$	*p*-Diiodobenzene	393.2	2.88				
$C_6H_4N_2$	2-Pyridinecarbonitrile	303.2	93.77	0.45596E+03	-0.17746E+01	0.19105E-02	303-398
$C_6H_4N_2$	3-Pyridinecarbonitrile	323.2	20.54	0.60484E+02	-0.17280E+00	0.15218E-03	323-398
$C_6H_4N_2$	4-Pyridinecarbonitrile	353.2	5.23	0.12533E+02	-0.30115E-01	0.26674E-04	353-398
$C_6H_4N_2O_4$	1,3-Dinitrobenzene	365.2	22.9	0.10406E+03	-0.34133E+00	0.32609E-03	365-413
C_6H_5Br	Bromobenzene	293.2	5.45	0.94100E+01	-0.12537E-01	-0.31127E-05	234-333
C_6H_5Cl	Chlorobenzene	293.2	5.6895	0.19471E+02	-0.70786E-01	0.82466E-04	293-430
C_6H_5ClO	*o*-Chlorophenol	296.2	7.40	0.29755E+02	-0.11256E+00	0.12390E-03	296-448
C_6H_5ClO	*m*-Chlorophenol	293.2	6.255				
C_6H_5ClO	*p*-Chlorophenol	314.2	11.18	0.31997E+02	-0.94241E-01	0.88392E-04	314-453
$C_6H_5ClO_2S$	Benzenesulfonyl chloride	323.2	28.90	0.83886E+02	-0.23405E+00	0.19713E-03	323-473
C_6H_5ClS	4-Chlorobenzenethiol	338.2	3.59				
C_6H_5F	Fluorobenzene	293.2	5.465				
C_6H_5I	Iodobenzene	293.2	4.59	0.89442E+01	-0.20008E-01	0.17641E-04	243-323
C_6H_5NOS	*N*-Sulfinylaniline	298.2	6.97				
$C_6H_5NO_2$	Nitrobenzene	293.0	35.6	0.11212E+03	-0.35211E+00	0.31128E-03	279-533
$C_6H_5NO_3$	*o*-Nitrophenol	323.2	16.50	0.33827E+02	-0.62123E-01	0.26774E-04	323-453
$C_6H_5NO_3$	*m*-Nitrophenol	373.2	35.45	0.18967E+03	-0.66144E+00	0.66532E-03	373-458
$C_6H_5NO_3$	*p*-Nitrophenol	393.2	42.20	0.22901E+03	-0.74264E+00	0.68006E-03	393-463
C_6H_6	Benzene	293.2	2.2825	0.26706E+01	-0.91648E-03	-0.14257E-05	293-513
C_6H_6BrN	*m*-Bromoaniline	293.2	13.0				
C_6H_6ClN	*o*-Chloroaniline	293.2	13.40				
C_6H_6ClN	*m*-Chloroaniline	293.2	13.3				
$C_6H_6N_2O_2$	*o*-Nitroaniline	353.0	47.3	0.18900E+03	-0.56977E+00	0.47484E-03	353-468
$C_6H_6N_2O_2$	*m*-Nitroaniline	398.0	35.6	0.20352E+03	-0.66582E+00	0.61310E-03	398-468
$C_6H_6N_2O_2$	*p*-Nitroaniline	428.0	78.5	0.48673E+03	-0.15040E+01	0.12857E-02	428-468
C_6H_6O	Phenol	303.2	12.40	0.63391E+02	-0.24988E+00	0.26930E-03	303-433
$C_6H_6O_2$	Pyrocatechol	388.2	17.57	0.74930E+02	-0.22142E+00	0.18919E-03	388-463
$C_6H_6O_2$	Resorcinol	393.2	13.55	0.30252E+02	-0.56443E-01	0.35578E-04	393-463
C_6H_6S	Benzenethiol	303.2	4.26	0.57155E+01	-0.70336E-02	0.73617E-05	303-358
C_6H_7N	Aniline	293.2	7.06	0.89534E+01	0.38990E-02	-0.36310E-04	293-413
C_6H_7N	2-Methylpyridine	293.2	10.18	0.34560E+02	-0.11980E+00	0.12500E-03	293-333
C_6H_7N	3-Methylpyridine	303.0	11.10	0.19643E+03	-0.11167E+01	0.16667E-02	303-333
C_6H_7N	4-Methylpyridine	293.0	12.2	0.33765E+02	-0.10113E+00	0.93860E-04	274-333
C_6H_7NO	2-Methylpyridine-1-oxide	323.2	36.4	0.11705E+03	-0.35301E+00	0.32000E-03	323-398
C_6H_7NO	3-Methylpyridine-1-oxide	318.2	28.26	0.59851E+02	-0.12682E+00	0.86622E-04	318-398
C_6H_8	1,3-Cyclohexadiene	184.2	2.68				
C_6H_8	1,4-Cyclohexadiene	296.0	2.211	0.27459E+01	-0.16975E-02	-0.36461E-06	232-356
$C_6H_8N_2$	Phenylhydrazine	293.2	7.15				
$C_6H_8N_2$	2,5-Dimethylpyrazine	293.2	2.436				
$C_6H_8N_2$	2,6-Dimethylpyrazine	308.2	2.653				
$C_6H_8O_2$	1,4-Cyclohexanedione	351.2	4.40				
$C_6H_9Cl_3O_2$	Butyl trichloroacetate	293.2	7.480				

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_6H_9Cl_3O_2$	Isobutyl trichloroacetate	293.2	7.667				
C_6H_9N	Cyclopentanecarbonitrile	293.2	22.68	0.69830E+02	-0.25303E+00	0.31491E-03	201-293
C_6H_{10}	1,5-Hexadiene	294.0	2.125	0.30014E+01	-0.28668E-02	-0.31026E-06	151-294
C_6H_{10}	*cis,cis*-2,4-Hexadiene	297.0	2.163	0.27284E+01	-0.17178E-02	-0.62926E-06	234-351
C_6H_{10}	*trans,trans*-2,4-Hexadiene	297.0	2.123	0.26774E+01	-0.16977E-02	-0.55637E-06	232-353
C_6H_{10}	2-Methyl-1,3-pentadiene*	298.2	2.422				
C_6H_{10}	3-Methyl-1,3-pentadiene	298.2	2.426				
C_6H_{10}	4-Methyl-1,3-pentadiene	293.2	2.599	0.51328E+01	-0.12774E-01	0.14215E-04	198-323
C_6H_{10}	2,3-Dimethyl-1,3-butadiene	293.2	2.102	0.26258E+01	-0.17990E-02	0.12035E-06	223-323
C_6H_{10}	1-Hexyne	296.0	2.621	0.58591E+01	-0.17099E-01	0.20856E-04	184-296
C_6H_{10}	Cyclohexene	293.2	2.2176	0.30598E+01	-0.39841E-02	0.37554E-05	141-313
$C_6H_{10}O$	Butoxyacetylene	298.2	6.62				
$C_6H_{10}O$	Cyclohexanone	293.0	16.1	0.41577E+02	-0.11463E+00	0.92454E-04	253-423
$C_6H_{10}O$	Mesityl oxide	273.2	15.6				
$C_6H_{10}O_2$	Ethyl 2-butenoate	293.2	5.4				
$C_6H_{10}O_2$	Ethyl methacrylate	303.2	5.68	0.40962E+02	-0.20520E+00	0.29286E-03	303-343
$C_6H_{10}O_3$	Ethyl acetoacetate	293.2	14.0				
$C_6H_{10}O_3$	Propanoic anhydride	293.2	18.30				
$C_6H_{10}O_4$	Monomethyl glutarate	293.2	8.37	0.16779E+02	-0.39839E-01	0.38095E-04	293-363
$C_6H_{10}O_4$	Diethyl oxalate	293.2	8.266	0.21938E+02	-0.66226E-01	0.66800E-04	293-368
$C_6H_{10}O_4$	Dimethyl succinate	293.2	7.19	0.13551E+02	-0.23109E-01	0.55440E-05	293-433
$C_6H_{10}O_4$	Ethylene glycol diacetate	290.2	7.7	0.25093E+02	-0.95171E-01	0.12224E-03	223-290
$C_6H_{11}Br$	Bromocyclohexane	303.2	8.0026				
$C_6H_{11}BrO_2$	Ethyl 2-bromobutanoate	303.2	8.57	0.49005E+02	-0.23193E+00	0.32500E-03	303-333
$C_6H_{11}BrO_2$	Ethyl 2-bromo-2-methylpropanoate	303.2	8.55	0.77044E+02	-0.40784E+00	0.60000E-03	303-333
$C_6H_{11}Cl$	Chlorocyclohexane	303.2	7.9505				
$C_6H_{11}N$	Hexanenitrile	298.2	17.26				
$C_6H_{11}N$	4-Methylpentanenitrile	295.2	17.5				
$C_6H_{11}NO$	Cyclohexanone oxime	362.2	3.04				
C_6H_{12}	1-Hexene	294.0	2.077	0.31476E+01	-0.50003E-02	0.46673E-05	149-294
C_6H_{12}	*trans*-2-Hexene	295.0	1.978	0.24338E+01	-0.11323E-02	-0.13720E-05	157-295
C_6H_{12}	*cis*-3-Hexene	296.0	2.069	0.30691E+01	-0.45458E-02	0.39898E-05	155-296
C_6H_{12}	*trans*-3-Hexene	293.2	1.954				
C_6H_{12}	Cyclohexane	293.2	2.0243	0.24293E+01	-0.12095E-02	-0.58741E-06	283-333
C_6H_{12}	Methylcyclopentane	293.2	1.9853	0.21587E+01	-0.22450E-03	-0.12500E-05	293-323
C_6H_{12}	Ethylcyclobutane	293.2	1.965				
$C_6H_{12}Br_2$	1,6-Dibromohexane	298.2	8.52	-0.55185E+01	0.11746E+00	-0.23658E-03	274-328
$C_6H_{12}Br_2$	3,4-Dibromohexane	298.2	6.732				
$C_6H_{12}Cl_2$	1,6-Dichlorohexane	308.2	8.60	0.11277E+02	0.67200E-02	-0.50000E-04	308-338
$C_6H_{12}O$	1-Methylcyclopentanol	310.1	7.11	0.75444E+02	-0.36617E+00	0.47021E-03	310-333
$C_6H_{12}O$	Isobutyl vinyl ether	293.2	3.34	0.48060E+01	-0.50000E-02	-0.41495E-14	293-323
$C_6H_{12}O$	2-Hexanone	293.2	14.56	0.70378E+02	-0.29385E+00	0.35289E-03	243-293
$C_6H_{12}O$	4-Methyl-2-pentanone	293.2	13.11	0.36341E+02	-0.97119E-01	0.61896E-04	204-373
$C_6H_{12}O$	3,3-Dimethyl-2-butanone	293.2	12.73	0.66857E+02	-0.28552E+00	0.34422E-03	243-293
$C_6H_{12}O$	Cyclohexanol	293.2	16.40	0.10173E+03	-0.43072E+00	0.47926E-03	293-423
$C_6H_{12}O_2$	Hexanoic acid	298.2	2.600	0.21730E+01	0.14840E-02	-0.16526E-06	298-433
$C_6H_{12}O_2$	2-Ethylbutanoic acid	296.2	2.72				
$C_6H_{12}O_2$	*tert*-Butylacetic acid	296.2	2.85				
$C_6H_{12}O_2$	Pentyl formate	292.2	5.7				
$C_6H_{12}O_2$	Isopentyl formate	288.2	5.44	0.29257E+02	-0.14028E+00	0.20000E-03	288-323
$C_6H_{12}O_2$	Butyl acetate	293.2	5.07	0.13825E+02	-0.43994E-01	0.48214E-04	253-353
$C_6H_{12}O_2$	*sec*-Butyl acetate	293.2	5.135	0.12427E+02	-0.32035E-01	0.24286E-04	273-323
$C_6H_{12}O_2$	*tert*-Butyl acetate	293.2	5.672	0.55435E+02	-0.30494E+00	0.46107E-03	273-323
$C_6H_{12}O_2$	Isobutyl acetate	293.2	5.068	0.14323E+02	-0.46048E-01	0.49286E-04	273-323
$C_6H_{12}O_2$	Propyl propanoate	293.2	5.249				
$C_6H_{12}O_2$	Ethyl butanoate	301.2	5.18	0.48698E+02	-0.25660E+00	0.37237E-03	301-343
$C_6H_{12}O_2$	Methyl pentanoate	293.2	4.992				
$C_6H_{12}O_2$	Diacetone alcohol	298.2	18.2				
$C_6H_{12}O_3$	Ethylene glycol monoethyl ether acetate	303.2	7.567	0.23290E+02	-0.71566E-01	0.65000E-04	303-323

PERMITTIVITY (DIELECTRIC CONSTANT) OF LIQUIDS (continued)

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_6H_{12}S$	Cyclohexanethiol	298.2	5.420				
$C_6H_{13}Br$	1-Bromohexane	298.2	5.82	0.15233E+02	-0.44385E-01	0.43039E-04	274-328
$C_6H_{13}Cl$	1-Chlorohexane	293.2	6.104	0.15994E+02	-0.43647E-01	0.33393E-04	273-323
$C_6H_{13}ClO$	6-Chloro-1-hexanol	242.2	21.6	-0.73364E+01	0.46377E+00	-0.14202E-02	195-242
$C_6H_{13}I$	1-Iodohexane	293.3	5.35	0.16685E+02	-0.61309E-01	0.77262E-04	293-323
$C_6H_{13}N$	Cyclohexylamine	293.2	4.547				
$C_6H_{13}NO$	*N*-Propylpropanamide	298.2	118.1	0.58846E+03	-0.22012E+01	0.20870E-02	298-328
$C_6H_{13}NO$	*N*-Butylacetamide	293.2	104.0	0.70739E+03	-0.37369E+01	0.71585E-02	253-493
$C_6H_{13}NO$	*N*,*N*-Diethylacetamide	293.2	32.1				
C_6H_{14}	Hexane	293.2	1.8865	0.19768E+01	0.70933E-03	-0.34470E-05	293-473
C_6H_{14}	2-Methylpentane	293.2	1.886	0.20745E+01	0.50871E-03	-0.39286E-05	273-323
C_6H_{14}	3-Methylpentane	293.2	1.886	0.24739E+01	-0.23190E-02	0.10714E-05	273-323
C_6H_{14}	2,2-Dimethylbutane	293.2	1.869	0.22740E+01	-0.96229E-03	-0.14286E-05	273-313
C_6H_{14}	2,3-Dimethylbutane	293.2	1.889	0.24305E+01	-0.20081E-02	0.53571E-06	273-323
$C_6H_{14}O$	1-Hexanol	293.2	13.03	0.62744E+02	-0.24214E+00	0.24704E-03	233-513
$C_6H_{14}O$	2-Hexanol	298.2	11.06				
$C_6H_{14}O$	3-Hexanol	298.2	9.66				
$C_6H_{14}O$	3-Methyl-1-pentanol	298.2	15.2				
$C_6H_{14}O$	3-Methyl-3-pentanol	293.2	4.322				
$C_6H_{14}O$	2-Ethyl-1-butanol	362.2	6.19				
$C_6H_{14}O$	2,2-Dimethyl-1-butanol	293.2	10.5	0.14054E+03	-0.72925E+00	0.97821E-03	243-393
$C_6H_{14}O$	Dipropyl ether	297.0	3.38	0.14600E+02	-0.72670E-01	0.11742E-03	161-297
$C_6H_{14}O$	Diisopropyl ether	303.2	3.805				
$C_6H_{14}OS$	Dipropyl sulfoxide	303.2	30.37	0.84868E+02	-0.23486E+00	0.18198E-03	303-373
$C_6H_{14}O_2$	2-Methyl-2,4-pentanediol	293.2	25.86	0.14531E+03	-0.65285E+00	0.83503E-03	203-333
$C_6H_{14}O_2$	Ethylene glycol diethyl ether	293.2	3.90	0.99099E+01	-0.33403E-01	0.44048E-04	223-303
$C_6H_{14}O_2S$	Dipropyl sulfone	303.2	32.62	0.70195E+02	-0.15008E+00	0.86506E-04	303-398
$C_6H_{14}O_3$	1,2,6-Hexanetriol	285.3	31.5	0.26127E+03	-0.14552E+01	0.22765E-02	261-285
$C_6H_{14}O_3$	Diethylene glycol dimethyl ether	298.2	7.23	0.28291E+02	-0.11236E+00	0.14000E-03	298-333
$C_6H_{14}O_4$	Triethylene glycol	293.2	23.69	0.91845E+02	-0.33827E+00	0.36062E-03	253-333
$C_6H_{14}O_6$	*D*-Glucitol	353.2	35.5				
$C_6H_{14}O_6$	*D*-Mannitol	443.2	24.6				
$C_6H_{14}S$	1-Hexanethiol	293.2	4.436	0.11774E+02	-0.37298E-01	0.41875E-04	273-333
$C_6H_{15}B$	Triethylborane	293.2	1.974				
$C_6H_{15}N$	Hexylamine	293.2	4.08	0.80244E+01	-0.16627E-01	0.10874E-04	253-373
$C_6H_{15}N$	Dipropylamine	293.2	2.923	0.11376E+02	-0.49796E-01	0.71792E-04	243-323
$C_6H_{15}N$	Triethylamine	293.2	2.418	0.29205E+01	-0.14007E-02	-0.13469E-05	233-323
$C_6H_{15}OP$	Triethylphosphine oxide	323.2	35.5				
$C_6H_{15}O_4P$	Triethyl phosphate	298.2	13.20	0.61230E+02	-0.26047E+00	0.33333E-03	298-333
$C_6H_{15}PS$	Triethylphosphine sulfide	371.2	39.0				
$C_6H_{16}O_2Si$	Diethoxydimethylsilane	298.2	3.216				
$C_6H_{16}Si$	Triethylsilane	293.2	2.323				
$C_6H_{18}N_3OP$	Hexamethylphosphoric triamide	293.2	31.3	0.95666E+02	-0.29769E+00	0.26407E-03	283-363
$C_6H_{18}N_4$	*N*,*N'*-Bis(2-aminoethyl)-1,2-ethanediamine	293.2	10.76	0.50699E+02	-0.21730E+00	0.27582E-03	213-333
$C_6H_{18}OSi_2$	Hexamethyldisiloxane	293.2	2.179	0.34537E+01	-0.61530E-02	0.61544E-05	213-313
$C_6H_{18}O_3Si_3$	Hexamethylcyclotrisiloxane	343.2	2.139				
$C_6H_{19}NSi_2$	Hexamethyldisilazane	294.2	2.273	0.23358E+01	0.16127E-02	-0.62078E-05	294-333
C_7F_{14}	Perfluoromethylcyclohexane	298.2	1.82				
C_7F_{16}	Perfluoroheptane	289.2	1.847				
$C_7H_3Cl_5$	2,3,4,5,6-Pentachlorotoluene	293.2	4.8				
C_7H_4ClNO	4-Chlorophenyl isocyanate	288.2	3.177	0.40896E+01	-0.31667E-02		288-348
C_7H_5BrO	Benzoyl bromide	293.2	21.33	0.84231E+02	-0.31089E+00	0.32857E-03	283-313
C_7H_5ClO	Benzoyl chloride	293.2	23.0				
C_7H_5FO	Benzoyl fluoride	293.2	22.7				
$C_7H_5F_3$	(Trifluoromethyl)benzene	298.2	9.22				
C_7H_5N	Benzonitrile	293.2	25.9	0.57605E+02	-0.13354E+00	0.87767E-04	273-453
C_7H_5NO	Phenyl isocyanate	293.2	8.940	0.17541E+02	-0.29790E-01	0.15476E-05	293-353
$C_7H_6ClNO_2$	4-Chloro-3-nitrotoluene	301.2	28.07				

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_7H_6Cl_2$	2,4-Dichlorotoluene	301.2	5.68				
$C_7H_6Cl_2$	2,6-Dichlorotoluene	301.2	3.36				
$C_7H_6Cl_2$	3,4-Dichlorotoluene	301.2	9.39				
$C_7H_6Cl_2$	(Dichloromethyl)benzene	293.2	6.9				
C_7H_6O	Benzaldehyde	293.2	17.85	0.35046E+02	-0.61271E-01	0.16222E-04	301-346
$C_7H_6O_2$	Salicylaldehyde	293.2	18.35	0.51315E+02	-0.15379E+00	0.14111E-03	289-453
C_7H_7Br	*o*-Bromotoluene	293.2	4.641	0.10229E+02	-0.25050E-01	0.20357E-04	273-323
C_7H_7Br	*m*-Bromotoluene	293.2	5.566	0.11522E+02	-0.24946E-01	0.15714E-04	273-323
C_7H_7Br	*p*-Bromotoluene	293.2	5.503	0.10014E+02	-0.13918E-01	-0.50000E-05	273-293
C_7H_7Br	(Bromomethyl)benzene	293.2	6.658	0.18482E+02	-0.57207E-01	0.57321E-04	273-323
C_7H_7BrO	*o*-Bromoanisole	303.2	8.96	0.12023E+02	-0.59116E-02	-0.13787E-04	303-358
C_7H_7BrO	*p*-Bromoanisole	303.2	7.40	0.74367E+01	0.12648E-01	-0.42128E-04	303-358
C_7H_7Cl	*o*-Chlorotoluene	293.2	4.721	0.11507E+02	-0.31148E-01	0.27143E-04	273-323
C_7H_7Cl	*m*-Chlorotoluene	293.2	5.763	0.13921E+02	-0.37186E-01	0.31786E-04	273-323
C_7H_7Cl	*p*-Chlorotoluene	293.2	6.25	0.20265E+01	0.40060E-01	-0.87500E-04	293-333
C_7H_7Cl	(Chloromethyl)benzene	293.2	6.854	0.17108E+02	-0.45285E-01	0.35000E-04	273-323
C_7H_7ClO	*p*-Chloroanisole	293.2	7.84	0.64019E+01	0.30560E-01	-0.87500E-04	293-333
$C_7H_7ClO_2S$	*p*-Toluenesulfonyl chloride	343.2	22.6				
$C_7H_7ClO_3S$	4-Methoxybenzenesulfonyl chloride	314.2	27.2				
C_7H_7F	*o*-Fluorotoluene	298.2	4.23				
C_7H_7F	*m*-Fluorotoluene	298.2	5.41				
C_7H_7F	*p*-Fluorotoluene	298.2	5.88				
C_7H_7I	*p*-Iodotoluene	308.2	4.4				
C_7H_7N	2-Vinylpyridine	293.2	9.126				
C_7H_7N	4-Vinylpyridine	293.2	10.50				
$C_7H_7NO_2$	Benzyl nitrite	298.2	7.78				
$C_7H_7NO_2$	*o*-Nitrotoluene	293.0	26.26	0.10420E+03	-0.41726E+00	0.51607E-03	273-323
$C_7H_7NO_2$	*m*-Nitrotoluene	303.2	24.95	0.62492E+02	-0.16235E+00	0.12844E-03	303-403
$C_7H_7NO_2$	*p*-Nitrotoluene	331.2	22.2				
$C_7H_7NO_2S$	4-Nitrothioanisole	346.0	21.7				
$C_7H_7NO_3$	2-Nitroanisole	293.2	45.75	0.16684E+03	-0.58196E+00	0.57382E-03	293-423
$C_7H_7NO_3$	3-Nitroanisole	318.2	25.7	0.65402E+02	-0.16460E+00	0.12560E-03	318-443
$C_7H_7NO_3$	4-Nitroanisole	338.2	26.95	0.59811E+02	-0.10955E+00	0.36042E-04	338-443
C_7H_8	Toluene	296.35	2.379	0.32584E+01	-0.34410E-02	0.15937E-05	207-316
C_7H_8O	*o*-Cresol	298.2	6.76	0.21633E+02	-0.71069E-01	0.70590E-04	298-453
C_7H_8O	*m*-Cresol	298.2	12.44	0.81716E+02	-0.35039E+00	0.39878E-03	274-463
C_7H_8O	*p*-Cresol	298.2	13.05	0.70253E+02	-0.28870E+00	0.31979E-03	298-453
C_7H_8O	Benzyl alcohol	303.2	11.916	0.13661E+03	-0.72127E+00	0.10225E-02	303-333
C_7H_8O	Anisole	294.2	4.30	0.10887E+02	-0.32372E-01	0.33629E-04	294-413
$C_7H_8O_2$	2-Methoxyphenol	298.2	11.95	0.31751E+02	-0.88173E-01	0.72953E-04	291-448
$C_7H_8O_2$	3-Methoxyphenol	298.2	11.59	0.37279E+02	-0.12113E+00	0.11698E-03	298-433
$C_7H_8O_2$	4-Methoxyphenol	333.7	11.05	0.39483E+02	-0.12142E+00	0.10841E-03	334-453
$C_7H_8O_2S$	Ethyl thiophene-2-carboxylate	293.2	6.18				
$C_7H_8O_2S$	Methyl phenyl sulfone	373.2	37.9				
C_7H_8S	Benzenemethanethiol	298.2	4.705	0.16628E+02	-0.68276E-01	0.94636E-04	298-358
C_7H_8S	4-Methylbenzenethiol	323.2	4.74	0.87052E+01	-0.15347E-01	0.95238E-05	323-358
C_7H_8S	(Methylthio)benzene	303.2	4.88	0.21841E+02	-0.97630E-01	0.13750E-03	303-343
C_7H_9N	Benzylamine	293.2	5.18				
C_7H_9N	*o*-Methylaniline	298.2	6.138	0.10988E+02	-0.18976E-01	0.91958E-05	298-398
C_7H_9N	*m*-Methylaniline	298.2	5.816	0.13477E+02	-0.35551E-01	0.33135E-04	298-398
C_7H_9N	*p*-Methylaniline	333.2	5.058	0.78897E+01	-0.10196E-01	0.51190E-05	333-403
C_7H_9N	*N*-Methylaniline	293.2	5.96				
C_7H_9N	2-Ethylpyridine	293.2	8.33	0.36397E+02	-0.15070E+00	0.18750E-03	293-333
C_7H_9N	4-Ethylpyridine	293.2	10.98	-0.73831E+01	0.14326E+00	-0.27500E-03	293-333
C_7H_9N	2,4-Dimethylpyridine	293.2	9.60	0.25895E+02	-0.73900E-01	0.62500E-04	293-333
C_7H_9N	2,6-Dimethylpyridine	293.2	7.33	0.17714E+02	-0.39080E-01	0.12500E-04	293-333
C_7H_9NO	2,6-Dimethylpyridine-1-oxide	298.2	46.11	0.22765E+03	-0.90760E+00	0.10011E-02	298-398
C_7H_9NO	*o*-Methoxyaniline	303.2	5.230	0.79911E+01	-0.92183E-02	0.37879E-06	303-393
C_7H_9NO	*m*-Methoxyaniline	298.2	8.76	0.28179E+02	-0.97840E-01	0.11027E-03	289-393

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
C_7H_9NO	*p*-Methoxyaniline	333.2	7.85	0.30149E+02	-0.10523E+00	0.11467E-03	333-453
$C_7H_{10}N_2$	1-Methyl-1-phenylhydrazine	292.2	7.3				
$C_7H_{11}Cl_3O_2$	Isopentyl trichloroacetate	293.2	7.287				
C_7H_{12}	1,6-Heptadiene	293.0	2.161	0.30815E+01	-0.36095E-02	0.16354E-05	184-293
C_7H_{12}	Cycloheptene	295.0	2.265	0.32309E+01	-0.42373E-02	0.32572E-05	227-363
$C_7H_{12}O$	Cycloheptanone	298.2	13.16	0.17511E+03	-0.11221E+01	0.19417E-02	258-298
$C_7H_{12}O$	2-Methylcyclohexanone	293.2	14.0				
$C_7H_{12}O$	3-Methylcyclohexanone	293.2	12.4				
$C_7H_{12}O$	4-Methylcyclohexanone	293.2	12.35				
$C_7H_{12}O_2$	Cyclohexanecarboxylic acid	304.2	2.67				
$C_7H_{12}O_2$	Cyclohexyl formate	293.2	6.47				
$C_7H_{12}O_2$	Butyl acrylate	301.2	5.25	0.38296E+02	-0.19109E+00	0.27006E-03	301-343
$C_7H_{12}O_4$	Monomethyl adipate	293.2	6.69	0.11962E+02	-0.23973E-01	0.20608E-04	293-433
$C_7H_{12}O_4$	Diethyl malonate	304.2	7.550	0.14809E+02	-0.31207E-01	0.24066E-04	304-393
$C_7H_{12}O_4$	Dimethyl glutarate	293.2	7.87	0.20697E+02	-0.57794E-01	0.48405E-04	293-433
$C_7H_{12}O_5$	1,2,3-Propanetriol-1,3-diacetate	288.2	9.80	0.28321E+02	-0.89073E-01	0.86891E-04	258-374
C_7H_{14}	1-Heptene	293.2	2.092	0.21755E+01	0.13896E-02	-0.57049E-05	273-323
C_7H_{14}	2-Methyl-2-hexene	293.2	2.962				
C_7H_{14}	3-Ethyl-2-pentene	293.2	2.051				
C_7H_{14}	Cycloheptane	293.2	2.0784	0.25136E+01	-0.15089E-02	0.84915E-07	278-333
C_7H_{14}	Methylcyclohexane	293.2	2.024				
$C_7H_{14}Br_2$	1,2-Dibromoheptane	298.2	3.77				
$C_7H_{14}Br_2$	2,3-Dibromoheptane	298.2	5.08				
$C_7H_{14}Br_2$	3,4-Dibromoheptane	298.2	4.70				
$C_7H_{14}Cl_2$	1,7-Dichloroheptane	298.2	8.34				
$C_7H_{14}O$	1-Heptanal	295.2	9.07				
$C_7H_{14}O$	2-Heptanone	293.2	11.95	0.38348E+02	-0.12531E+00	0.12005E-03	253-413
$C_7H_{14}O$	3-Heptanone	293.2	12.7				
$C_7H_{14}O$	4-Heptanone	293.2	12.60	0.41520E+02	-0.13839E+00	0.13497E-03	253-393
$C_7H_{14}O$	5-Methyl-2-hexanone	293.2	13.53	0.52353E+02	-0.17695E+00	0.15195E-03	293-333
$C_7H_{14}O$	Cyclohexanemethanol	333.2	9.70	0.10164E+03	-0.45839E+00	0.54762E-03	333-368
$C_7H_{14}O$	2-Methylcyclohexanol*	293.2	9.375	0.17315E+03	-0.98794E+00	0.14634E-02	273-323
$C_7H_{14}O$	3-Methylcyclohexanol*	293.2	13.79	0.65896E+02	-0.21954E+00	0.14107E-03	273-323
$C_7H_{14}O$	4-Methylcyclohexanol*	293.2	13.45	0.65021E+02	-0.22896E+00	0.17946E-03	273-323
$C_7H_{14}O_2$	Heptanoic acid	288.2	3.04	0.36423E+01	-0.31996E-02	0.39362E-05	288-423
$C_7H_{14}O_2$	Pentyl acetate	293.2	4.79	0.12091E+02	-0.36536E-01	0.39732E-04	253-353
$C_7H_{14}O_2$	Isopentyl acetate	293.2	4.72				
$C_7H_{14}O_2$	Butyl propanoate	293.2	4.838				
$C_7H_{14}O_2$	Propyl butanoate	293.2	4.3				
$C_7H_{14}O_2$	Ethyl pentanoate	291.2	4.71				
$C_7H_{14}O_2$	Ethyl 3-methylbutanoate	293.2	4.71				
$C_7H_{14}O_2$	Methyl hexanoate	293.2	4.615				
$C_7H_{15}Br$	1-Bromoheptane	303.2	5.255	0.15289E+02	-0.50621E-01	0.57753E-04	203-343
$C_7H_{15}Br$	2-Bromoheptane	295.2	6.46				
$C_7H_{15}Br$	4-Bromoheptane	295.2	6.81				
$C_7H_{15}Cl$	1-Chloroheptane	293.2	5.521	0.14279E+02	-0.39431E-01	0.32321E-04	273-323
$C_7H_{15}Cl$	2-Chloroheptane	295.2	6.52				
$C_7H_{15}Cl$	3-Chloroheptane	295.2	6.70				
$C_7H_{15}Cl$	4-Chloroheptane	295.2	6.54				
$C_7H_{15}I$	1-Iodoheptane	298.2	4.92	0.11856E+02	-0.33493E-01	0.34368E-04	294-323
$C_7H_{15}I$	3-Iodoheptane	295.2	6.39				
C_7H_{16}	Heptane	293.2	1.9209	0.24740E+01	-0.22577E-02	0.12428E-05	273-373
C_7H_{16}	2-Methylhexane	293.2	1.9221	0.24759E+01	-0.22535E-02	0.12500E-05	293-323
C_7H_{16}	3-Methylhexane	293.2	1.920	0.27089E+01	-0.37908E-02	0.37500E-05	273-323
C_7H_{16}	3-Ethylpentane	293.2	1.942	0.23771E+01	-0.15140E-02	0.10093E-06	163-363
C_7H_{16}	2,2-Dimethylpentane	293.2	1.915	0.23414E+01	-0.14362E-02	-0.51322E-07	153-353
C_7H_{16}	2,3-Dimethylpentane	293.2	1.929	0.25637E+01	-0.26328E-02	0.16071E-05	273-323
C_7H_{16}	2,4-Dimethylpentane	293.2	1.902	0.23979E+01	-0.17436E-02	0.17857E-06	273-323
C_7H_{16}	3,3-Dimethylpentane	291.3	1.9419	0.24007E+01	-0.16802E-02	0.36069E-06	291-322

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
C_7H_{16}	2,2,3-Trimethylbutane	293.2	1.930				
$C_7H_{16}O$	1-Heptanol	293.2	11.75	0.60662E+02	-0.24049E+00	0.25155E-03	239-513
$C_7H_{16}O$	2-Heptanol	293.7	9.72	0.10050E+03	-0.49793E+00	0.64504E-03	207-365
$C_7H_{16}O$	3-Heptanol	296.1	7.07	0.19586E+03	-0.11465E+01	0.17175E-02	248-349
$C_7H_{16}O$	4-Heptanol	296.2	6.18	0.28995E+03	-0.18499E+01	0.30109E-02	270-301
$C_7H_{16}O$	2-Methyl-2-hexanol	297.0	3.257				
$C_7H_{16}O$	3-Methyl-2-hexanol	297.2	4.990	0.59724E+02	-0.32417E+00	0.47058E-03	244-372
$C_7H_{16}O$	3-Methyl-3-hexanol	298.2	3.248				
$C_7H_{16}O$	3-Ethyl-3-pentanol	293.2	3.158				
$C_7H_{16}O$	2,2-Dimethyl-1-pentanol	293.2	6.020	0.37318E+02	-0.17095E+00	0.22022E-03	283-393
$C_7H_{16}O$	Ethyl pentyl ether	296.2	3.6				
$C_7H_{16}O$	Ethyl isopentyl ether	293.2	3.955	0.66541E+01	-0.55450E-02	-0.12500E-04	293-323
$C_7H_{16}O_3$	Triethoxymethane	293.2	4.779				
$C_7H_{16}S$	1-Heptanethiol	293.2	4.194	0.71333E+01	-0.97320E-02	-0.12500E-05	273-333
$C_7H_{17}N$	Heptylamine	293.2	3.81	0.87794E+01	-0.24363E-01	0.25325E-04	253-373
$C_7H_{18}O_3Si$	Triethoxymethylsilane	298.2	3.845				
$C_8H_4F_6$	1,3-Bis(trifluoromethyl)benzene	303.2	5.98				
C_8H_6	Phenylacetylene	298.2	2.98				
$C_8H_6Cl_2$	2,5-Dichlorostyrene	298.2	2.58				
$C_8H_6Cl_4$	1,2,3,4-Tetrachloro-5,6-dimethylbenzene	293.2	8.0				
$C_8H_6Cl_4$	1,2,3,5-Tetrachloro-4,6-dimethylbenzene	293.2	5.4				
C_8H_6O	Phenoxyacetylene	298.2	4.76				
C_8H_7N	Benzeneacetonitrile	299.2	17.87	0.82175E+02	-0.37416E+00	0.53220E-03	299-343
$C_8H_7NO_2$	4-Methoxyphenyl isocyanate	333.2	10.26	0.20780E+02	-0.31571E-01		333-403
$C_8H_7NO_4$	Methyl 2-nitrobenzoate	300.1	27.76				
C_8H_8	Styrene	293.2	2.4737	0.44473E+01	-0.11422E-01	0.16000E-04	293-313
C_8H_8O	Acetophenone	298.2	17.44	0.26099E+02	0.64048E-02	-0.11905E-03	298-333
$C_8H_8O_2$	Benzeneacetic acid	353.2	3.47	0.24104E+01	0.30000E-02		353-393
$C_8H_8O_2$	Benzyl formate	303.2	6.34	0.26162E+02	-0.11026E+00	0.14787E-03	303-358
$C_8H_8O_2$	Phenyl acetate	298.2	5.403	0.11327E+02	-0.26707E-01	0.22938E-04	298-404
$C_8H_8O_2$	Methyl benzoate	302.7	6.642	0.17486E+02	-0.51027E-01	0.50222E-04	303-393
$C_8H_8O_2$	(Hydroxyacetyl)benzene	298.2	21.33	0.42286E+02	-0.69215E-01	-0.35714E-05	298-368
$C_8H_8O_2$	4-Methoxybenzaldehyde	303.2	22.0				
$C_8H_8O_3$	Methyl salicylate	314.4	8.80	0.20501E+02	-0.39045E-01	0.68298E-05	223-398
C_8H_9Br	1-Bromo-2-ethylbenzene	298.2	5.55				
C_8H_9Br	1-Bromo-3-ethylbenzene	298.2	5.56				
C_8H_9Br	1-Bromo-4-ethylbenzene	298.2	5.42				
C_8H_9BrO	1-Bromo-2-ethoxybenzene	313.2	7.04	0.23146E+02	-0.75753E-01	0.77778E-04	313-358
C_8H_9Cl	1-Chloro-2-ethylbenzene	298.2	4.36				
C_8H_9Cl	1-Chloro-3-ethylbenzene	298.2	5.18				
C_8H_9Cl	1-Chloro-4-ethylbenzene	298.2	5.16				
$C_8H_9NO_2$	1-Ethyl-2-nitrobenzene	273.4	21.9				
$C_8H_9NO_2$	Methyl 2-aminobenzoate	298.2	21.9				
$C_8H_9NO_2$	Ethyl 4-pyridinecarboxylate	293.2	8.95				
C_8H_{10}	Ethylbenzene	293.2	2.4463	0.35969E+01	-0.53169E-02	0.47500E-05	293-323
C_8H_{10}	*o*-Xylene	293.2	2.562	0.36163E+01	-0.40177E-02	0.14286E-05	273-323
C_8H_{10}	*m*-Xylene	293.2	2.359	0.28421E+01	-0.10191E-02	-0.21429E-05	273-323
C_8H_{10}	*p*-Xylene	293.2	2.2735	0.23140E+01	0.97221E-03	-0.37500E-05	293-363
$C_8H_{10}O$	2,3-Xylenol	343.2	4.81	0.14399E+02	-0.41438E-01	0.39244E-04	343-433
$C_8H_{10}O$	2,4-Xylenol	303.2	5.060	0.22125E+02	-0.85543E-01	0.96548E-04	303-363
$C_8H_{10}O$	2,5-Xylenol	338.2	5.36	0.18049E+02	-0.54991E-01	0.51656E-04	338-455
$C_8H_{10}O$	2,6-Xylenol	313.2	4.90	0.12284E+02	-0.32996E-01	0.29867E-04	313-453
$C_8H_{10}O$	3,4-Xylenol	333.2	9.02	0.54423E+02	-0.21153E+00	0.22508E-03	333-453
$C_8H_{10}O$	3,5-Xylenol	323.2	9.06	0.54251E+02	-0.21647E+00	0.23542E-03	323-453
$C_8H_{10}O$	Benzeneethanol	293.2	12.31	0.12170E+03	-0.63124E+00	0.87776E-03	278-333
$C_8H_{10}O$	1-Phenylethanol	293.2	8.77	0.32971E+02	-0.12042E+00	0.12809E-03	293-423
$C_8H_{10}O$	Phenetole	293.2	4.216	-0.15043E+02	0.13752E+00	-0.24500E-03	293-313

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_8H_{10}O$	2-Methylanisole	293.2	3.502	0.50825E+01	-0.62297E-02	0.28571E-05	293-333
$C_8H_{10}O$	3-Methylanisole	293.2	3.967	0.12830E+02	-0.49701E-01	0.66429E-04	293-333
$C_8H_{10}O$	4-Methylanisole	293.2	3.914	0.86608E+01	-0.23510E-01	0.25000E-04	293-333
$C_8H_{10}O_2$	1,2-Dimethoxybenzene	293.2	4.45	0.74604E+01	-0.13445E-01	0.10737E-04	293-443
$C_8H_{10}O_2$	1,3-Dimethoxybenzene	298.2	5.363	0.11911E+02	-0.30804E-01	0.29643E-04	298-358
$C_8H_{10}O_2$	1,4-Dimethoxybenzene	333.7	5.60	0.11289E+02	-0.20765E-01	0.11987E-04	334-463
$C_8H_{10}O_2S$	Ethyl phenyl sulfone	348.2	39.0				
$C_8H_{10}S$	(Ethylthio)benzene	298.2	4.95				
$C_8H_{11}N$	*p*-Ethylaniline	298.2	4.84				
$C_8H_{11}N$	*N*-Ethylaniline	293.2	5.87				
$C_8H_{11}N$	*N,N*-Dimethylaniline	298.2	4.90	0.84052E+01	-0.13549E-01	0.62835E-05	289-453
$C_8H_{11}N$	2,4,6-Trimethylpyridine	298.2	7.807	0.20990E+02	-0.57419E-01	0.44286E-04	298-358
$C_8H_{11}NO$	4-Ethoxyaniline	298.2	7.43				
$C_8H_{12}N_2O_2$	Hexamethylene diisocyanate	288.2	14.41	0.26715E+02	-0.42696E-01		288-403
$C_8H_{12}O_4$	Diethyl maleate	298.2	7.560	0.13953E+02	-0.21969E-01	0.17817E-05	298-343
$C_8H_{12}O_4$	Diethyl fumarate	296.2	6.56				
C_8H_{14}	1,7-Octadiene	293.0	2.186	0.28376E+01	-0.17442E-02	-0.16141E-05	214-293
C_8H_{14}	*cis*-Cyclooctene	296.0	2.306	0.31115E+01	-0.32058E-02	0.16713E-05	269-406
C_8H_{14}	1,2-Dimethylcyclohexene	296.0	2.144	0.26443E+01	-0.17973E-02	0.35815E-06	211-374
C_8H_{14}	1,3-Dimethylcyclohexene	296.0	2.182	0.29951E+01	-0.34615E-02	0.24026E-05	213-373
$C_8H_{14}O_2$	Methyl cyclohexanecarboxylate	293.2	4.87				
$C_8H_{14}O_2$	Cyclohexyl acetate	293.2	5.08				
$C_8H_{14}O_3$	Butanoic anhydride	293.2	12.8				
$C_8H_{14}O_3$	2-Methylpropanoic anhydride	292.2	13.6				
$C_8H_{14}O_4$	Diisopropyl oxalate	293.2	6.403	0.10709E+02	-0.16328E-01	0.56000E-05	293-368
$C_8H_{14}O_4$	Diethyl succinate	293.2	6.098	0.80213E+01	0.11810E-02	-0.26400E-04	293-343
$C_8H_{14}O_4$	Dimethyl adipate	293.2	6.84	0.11739E+02	-0.17281E-01	0.11447E-05	293-433
$C_8H_{15}N$	Octanenitrile	293.2	13.90				
C_8H_{16}	1-Octene	293.2	2.113	0.24348E+01	0.34200E-03	-0.50000E-05	273-323
C_8H_{16}	*cis*-3-Octene	298.2	2.062				
C_8H_{16}	*trans*-3-Octene	298.2	2.002				
C_8H_{16}	*cis*-4-Octene	298.2	2.053				
C_8H_{16}	*trans*-4-Octene	298.2	2.004				
C_8H_{16}	3-Methyl-2-heptene*	293.2	2.436				
C_8H_{16}	2,5-Dimethyl-2-hexene	293.2	2.431				
C_8H_{16}	2,4,4-Trimethyl-1-pentene	298.2	2.0908				
C_8H_{16}	Cyclooctane	295.0	2.116	0.25036E+01	-0.12460E-02	-0.23175E-06	295-411
$C_8H_{16}Br_2$	1,8-Dibromooctane	298.2	7.43	0.94117E+00	0.61520E-01	-0.13333E-03	298-328
$C_8H_{16}Cl_2$	1,8-Dichlorooctane	298.2	7.64				
$C_8H_{16}O$	2-Octanone	293.2	9.51	-0.16219E+02	0.18799E+00	-0.34156E-03	293-333
$C_8H_{16}O$	3-Octanone	303.2	10.50				
$C_8H_{16}O_2$	Octanoic acid	288.2	2.85	0.29391E+01	-0.38721E-03		288-423
$C_8H_{16}O_2$	2-Ethylhexanoic acid	296.2	2.64				
$C_8H_{16}O_2$	Hexyl acetate	293.2	4.42				
$C_8H_{16}O_2$	Pentyl propanoate	293.2	4.552				
$C_8H_{16}O_2$	Isopentyl propanoate	273.2	5.21	0.17665E+02	-0.71718E-01	0.95635E-04	273-373
$C_8H_{16}O_2$	Butyl butanoate	298.2	4.39	0.79684E+01	-0.12000E-01	0.15266E-13	298-318
$C_8H_{16}O_2$	Propyl pentanoate	292.2	4.0				
$C_8H_{16}O_2$	Ethyl hexanoate	293.2	4.45	0.11007E+02	-0.32800E-01	0.35714E-04	253-353
$C_8H_{16}O_2$	Methyl heptanoate	293.2	4.355				
$C_8H_{16}O_3$	Isopentyl lactate	273.2	11.2	0.48649E+02	-0.21253E+00	0.27619E-03	273-373
$C_8H_{17}Br$	1-Bromooctane	293.2	5.0957	0.12404E+02	-0.35050E-01	0.34542E-04	283-353
$C_8H_{17}Br$	2-Bromooctane	293.2	5.44				
$C_8H_{17}Cl$	1-Chlorooctane	298.2	5.05	0.11346E+02	-0.25120E-01	0.13450E-04	274-328
$C_8H_{17}Cl$	2-Chlorooctane	293.2	5.42				
$C_8H_{17}F$	1-Fluorooctane	293.2	3.89				
$C_8H_{17}I$	1-Iodooctane	293.2	4.67	0.12452E+02	-0.41229E-01	0.50108E-04	233-313
$C_8H_{17}NO_2$	1-Nitrooctane	293.2	11.46				
C_8H_{18}	Octane	293.2	1.948	0.22590E+01	-0.84212E-03	-0.75758E-06	233-393

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
C_8H_{18}	2-Methylheptane	293.2	1.9519				
C_8H_{18}	3-Ethylhexane	293.2	1.9617				
C_8H_{18}	2,2-Dimethylhexane	293.2	1.9498				
C_8H_{18}	2,5-Dimethylhexane	293.95	1.9619	0.25821E+01	-0.26804E-02	0.19404E-05	294-324
C_8H_{18}	3,3-Dimethylhexane	293.2	1.9645				
C_8H_{18}	3,4-Dimethylhexane	292.1	1.9814	0.26849E+01	-0.33712E-02	0.32949E-05	292-324
C_8H_{18}	3-Ethyl-3-methylpentane	291.49	1.9869	0.25983E+01	-0.28027E-02	0.24195E-05	292-324
C_8H_{18}	2,2,3-Trimethylpentane	293.2	1.960				
C_8H_{18}	2,2,4-Trimethylpentane	293.2	1.943	0.23677E+01	-0.14768E-02	0.94261E-07	173-373
C_8H_{18}	2,3,3-Trimethylpentane	293.2	1.9780				
C_8H_{18}	2,3,4-Trimethylpentane	293.2	1.9738				
$C_8H_{18}O$	1-Octanol	293.2	10.30	0.51647E+02	-0.20371E+00	0.21320E-03	258-513
$C_8H_{18}O$	2-Octanol	293.2	8.13	0.63760E+02	-0.27643E+00	0.31075E-03	213-513
$C_8H_{18}O$	3-Octanol	293.2	5.55	0.12505E+03	-0.70646E+00	0.10245E-02	223-383
$C_8H_{18}O$	4-Octanol	293.2	4.48	0.51049E+02	-0.26664E+00	0.37280E-03	243-403
$C_8H_{18}O$	2-Methyl-1-heptanol	293.1	5.16	0.61698E+02	-0.33647E+00	0.49066E-03	236-328
$C_8H_{18}O$	3-Methyl-1-heptanol	290.3	2.884	0.84687E+01	-0.33712E-01	0.49793E-04	241-316
$C_8H_{18}O$	4-Methyl-1-heptanol	290.6	4.63	0.48612E+02	-0.26773E+00	0.39972E-03	237-332
$C_8H_{18}O$	5-Methyl-1-heptanol	290.4	7.68	0.54581E+02	-0.24772E+00	0.29734E-03	235-328
$C_8H_{18}O$	6-Methyl-1-heptanol	290.3	10.54	0.57997E+02	-0.23517E+00	0.24663E-03	265-328
$C_8H_{18}O$	2-Methyl-2-heptanol	292.2	3.43				
$C_8H_{18}O$	3-Methyl-2-heptanol	289.6	7.47	0.39178E+02	-0.17976E+00	0.24218E-03	229-329
$C_8H_{18}O$	4-Methyl-2-heptanol	290.0	3.59	0.39715E+02	-0.23115E+00	0.36771E-03	240-333
$C_8H_{18}O$	5-Methyl-2-heptanol	278.5	7.5	0.68568E+02	-0.40706E+00	0.67433E-03	230-279
$C_8H_{18}O$	6-Methyl-2-heptanol	290.1	6.41	0.77520E+02	-0.41724E+00	0.59448E-03	239-329
$C_8H_{18}O$	2-Methyl-3-heptanol	293.2	3.260	-0.59739E+01	0.56700E-01	-0.83125E-04	343-403
$C_8H_{18}O$	3-Methyl-3-heptanol	293.2	3.013	-0.38440E+01	0.42327E-01	-0.61250E-04	343-403
$C_8H_{18}O$	4-Methyl-3-heptanol	293.2	3.312	-0.48003E+01	0.50740E-01	-0.75000E-04	343-403
$C_8H_{18}O$	5-Methyl-3-heptanol	293.2	3.832	0.61967E+01	-0.63750E-02		343-383
$C_8H_{18}O$	6-Methyl-3-heptanol	293.2	4.992	0.23037E+02	-0.98029E-01	0.12479E-03	283-383
$C_8H_{18}O$	2-Methyl-4-heptanol	296.3	3.338	0.42102E+00	0.10427E-01	-0.20438E-05	230-333
$C_8H_{18}O$	3-Methyl-4-heptanol	290.0	7.46	0.33354E+02	-0.14077E+00	0.17750E-03	230-330
$C_8H_{18}O$	4-Methyl-4-heptanol	296.2	2.902				
$C_8H_{18}O$	2-Ethyl-1-hexanol	298.2	7.58	0.86074E+02	-0.42636E+00	0.55078E-03	208-318
$C_8H_{18}O$	2,2-Dimethyl-1-hexanol	293.2	4.50	0.91244E+01	-0.21785E-01	0.21018E-04	283-393
$C_8H_{18}O$	Dibutyl ether	293.2	3.0830	0.65383E+01	-0.16172E-01	0.14969E-04	293-314
$C_8H_{18}OS$	Dibutyl sulfoxide	313.2	24.73	0.67156E+02	-0.16448E+00	0.92275E-04	313-393
$C_8H_{18}O_2$	2-Ethyl-1,3-hexanediol	293.2	18.73	0.57919E+02	-0.17128E+00	0.12949E-03	233-333
$C_8H_{18}O_2S$	Dibutyl sulfone	323.2	25.72	0.66248E+02	-0.16417E+00	0.12001E-03	323-398
$C_8H_{18}O_4$	Triethylene glycol dimethyl ether	298.2	7.62				
$C_8H_{18}O_5$	Tetraethylene glycol	293.2	20.44	0.83547E+02	-0.31691E+00	0.34689E-03	253-333
$C_8H_{18}S$	1-Octanethiol	293.2	3.949	0.63667E+01	-0.87920E-02	0.18750E-05	273-333
$C_8H_{18}S$	Dibutyl sulfide	298.2	4.29				
$C_8H_{19}N$	Octylamine	293.2	3.58	0.77931E+01	-0.20015E-01	0.19347E-04	273-373
$C_8H_{19}N$	Dibutylamine	293.2	2.765	0.52504E+01	-0.10538E-01	0.71485E-05	243-323
$C_8H_{20}O_4Si$	Ethyl silicate	293.2	2.50				
$C_8H_{20}Si$	Tetraethylsilane	293.2	2.090				
$C_8H_{20}Sn$	Tetraethylstannane	293.2	2.241				
$C_8H_{23}N_5$	Tetraethylenepentamine	293.2	9.40	0.40553E+02	-0.16681E+00	0.20659E-03	213-333
$C_8H_{24}O_4Si_4$	Octamethylcyclotetrasiloxane	296.2	2.390	0.36286E+01	-0.56885E-02	0.50874E-05	296-333
$C_9H_6N_2O_2$	Toluene-2,4-diisocyanate	293.2	8.433	0.22174E+02	-0.66982E-01	0.68571E-04	293-353
$C_9H_6O_2$	2*H*-1-Benzopyran-2-one	343.2	34.04	0.11311E+03	-0.33804E+00	0.31324E-03	343-423
C_9H_7N	Quinoline	293.2	9.16	0.33432E+02	-0.13497E+00	0.17788E-03	258-323
C_9H_7N	Isoquinoline	298.2	11.0	0.14412E+03	-0.79935E+00	0.11839E-02	298-323
C_9H_8O	Cinnamaldehyde	305.8	17.72	0.41837E+02	-0.11060E+00	0.10401E-03	306-354
$C_9H_8O_4$	2-(Acetyloxy)benzoic acid	333.2	6.55	0.69994E+01	-0.14553E-02		333-416
C_9H_{10}	1-Propenylbenzene	293.2	2.73				
C_9H_{10}	Allylbenzene	293.2	2.63				
C_9H_{10}	Isopropenylbenzene	293.2	2.28				

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_9H_{10}OS$	4-Acetylthioanisole	355.2	11.34				
$C_9H_{10}O_2$	Ethyl benzoate	293.2	6.20	0.18216E+02	-0.62361E-01	0.72884E-04	288-343
$C_9H_{10}O_2$	Methyl 4-methylbenzoate	306.2	4.3				
$C_9H_{10}O_2$	Benzyl acetate	303.2	5.34	0.11727E+02	-0.30869E-01	0.32340E-04	303-358
$C_9H_{10}O_2$	Phenyl propanoate	293.2	4.77				
$C_9H_{10}O_2$	4-Acetylanisole	313.2	17.3				
$C_9H_{10}O_3$	Ethyl salicylate	308.2	8.48	0.18910E+02	-0.35623E-01	0.46529E-05	225-321
$C_9H_{10}O_3$	Methyl 2-methoxybenzoate	294.2	7.7				
$C_9H_{11}Br$	(3-Bromopropyl)benzene	302.2	5.41	0.11360E+02	-0.27471E-01	0.25775E-04	302-358
$C_9H_{11}NO$	*N*-Ethylbenzamide	352.7	42.6	-0.20109E+03	0.17866E+01	-0.31065E-02	353-389
$C_9H_{11}NO$	*N*,*N*-Dimethylbenzamide	318.2	20.77	0.76725E+02	-0.26908E+00	0.29409E-03	318-443
$C_9H_{11}NO_2$	Ethyl 2-aminobenzoate	298.2	4.14				
C_9H_{12}	Propylbenzene	293.2	2.370	0.26933E+01	0.21679E-03	-0.44643E-05	273-323
C_9H_{12}	Isopropylbenzene	293.2	2.381	0.31149E+01	-0.30801E-02	0.19643E-05	273-323
C_9H_{12}	*o*-Ethyltoluene	293.2	2.595				
C_9H_{12}	*m*-Ethyltoluene	293.2	2.365				
C_9H_{12}	*p*-Ethyltoluene	293.2	2.265				
C_9H_{12}	1,2,3-Trimethylbenzene	293.2	2.656	0.76006E+01	-0.29118E-01	0.41786E-04	273-323
C_9H_{12}	1,2,4-Trimethylbenzene	293.2	2.377	0.31517E+01	-0.30634E-02	0.14286E-05	273-323
C_9H_{12}	1,3,5-Trimethylbenzene	293.2	2.279	0.38998E+01	-0.88072E-02	0.11149E-04	288-358
$C_9H_{12}O$	Benzenepropanol	293.2	11.97	0.94482E+02	-0.45540E+00	0.59307E-03	213-303
$C_9H_{12}O$	α-Ethylbenzenemethanol	293.2	6.68	0.44520E+02	-0.21505E+00	0.29443E-03	233-373
$C_9H_{12}O$	α,α-Dimethylbenzenemethanol	303.2	5.61	0.57072E+01	0.86568E-02	-0.29580E-04	303-373
$C_9H_{12}O$	1-Phenyl-2-propanol	293.2	9.35	0.10762E+03	-0.56026E+00	0.76915E-03	233-373
$C_9H_{12}O$	Benzyl ethyl ether	298.2	3.90				
$C_9H_{12}O$	2,6-Dimethylanisole	293.2	3.780	0.76700E+01	-0.18298E-01	0.17143E-04	293-333
$C_9H_{12}O$	3,5-Dimethylanisole	293.2	3.711	0.54981E+01	-0.56651E-02	-0.14286E-05	293-333
$C_9H_{12}O_2S$	Butyl thiophene-2-carboxylate	293.2	6.40				
$C_9H_{12}S$	Benzenepropanethiol	303.2	4.36	0.82411E+01	-0.15034E-01	0.73617E-05	303-358
$C_9H_{13}N$	Benzylethylamine	293.2	4.3				
$C_9H_{13}N$	*N*-Propylaniline	293.2	5.48				
$C_9H_{13}N$	2-Methyl-*N*,*N*-dimethylaniline	293.2	3.4				
$C_9H_{13}N$	4-Methyl-*N*,*N*-dimethylaniline	293.2	3.9				
$C_9H_{14}OSi$	Trimethylphenoxysilane	298.2	3.3953				
$C_9H_{14}O_6$	Triacetin	293.6	7.11	0.17819E+02	-0.53656E-01	0.57759E-04	219-304
$C_9H_{14}Si$	Trimethylphenylsilane	298.2	2.3533	0.21463E+01	0.32711E-02	-0.86264E-05	288-323
$C_9H_{16}O_2$	2-Nonenoic acid	296.2	2.5				
$C_9H_{16}O_2$	Cyclohexyl propanoate	293.2	4.82				
$C_9H_{16}O_2$	Ethyl cyclohexanecarboxylate	293.2	4.64				
$C_9H_{16}O_4$	Diethyl glutarate	303.2	6.659				
$C_9H_{17}N$	Nonanenitrile	293.2	12.08				
C_9H_{18}	1-Nonene	293.2	2.180	0.22710E+01	0.15797E-02	-0.64286E-05	273-323
$C_9H_{18}Br_2$	1,9-Dibromononane	293.2	7.153	0.18931E+02	-0.57764E-01	0.60000E-04	293-343
$C_9H_{18}O$	2-Nonanone	295.2	9.14				
$C_9H_{18}O$	5-Nonanone	293.2	10.6				
$C_9H_{18}O$	Di-*tert*-butyl ketone	287.65	10.0				
$C_9H_{18}O$	2,6-Dimethyl-4-heptanone	293.2	9.91	0.33178E+02	-0.11290E+00	0.11454E-03	273-393
$C_9H_{18}O_2$	Nonanoic acid	294.9	2.475	0.25039E+01	0.67274E-03	-0.24180E-05	295-365
$C_9H_{18}O_2$	2-Methyloctanoic acid	293.2	2.39				
$C_9H_{18}O_2$	2-Ethylheptanoic acid	293.2	1.98				
$C_9H_{18}O_2$	Heptyl acetate	293.2	4.2				
$C_9H_{18}O_2$	Pentyl butanoate	301.2	4.08	0.59029E+01	-0.49905E-02	-0.34292E-05	301-343
$C_9H_{18}O_2$	Isopentyl butanoate	293.2	4.0				
$C_9H_{18}O_2$	Isobutyl pentanoate	292.2	3.8				
$C_9H_{18}O_2$	Methyl octanoate	293.2	4.101				
$C_9H_{19}Br$	1-Bromononane	298.2	4.74	0.79870E+01	-0.10488E-01	-0.13450E-05	274-328
$C_9H_{19}Cl$	1-Chlorononane	293.2	4.803	0.95528E+01	-0.16200E-01	-0.16365E-13	293-323
$C_9H_{19}NO$	*N*,*N*-Dibutylformamide	293.2	18.4				
C_9H_{20}	Nonane	293.2	1.9722	0.23894E+01	-0.14830E-02	0.14881E-06	253-393

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
C_9H_{20}	2-Methyloctane	293.2	1.967				
C_9H_{20}	4-Methyloctane	293.2	1.967				
C_9H_{20}	2,4-Dimethylheptane	293.2	1.89				
C_9H_{20}	2,5-Dimethylheptane	293.2	1.89				
C_9H_{20}	2,6-Dimethylheptane	293.2	1.987				
$C_9H_{20}N_2O$	Tetraethylurea	296.8	14.29	0.52820E+02	-0.18790E+00	0.19580E-03	205-411
$C_9H_{20}O$	1-Nonanol	293.2	8.83	0.97467E+02	-0.51103E+00	0.71429E-03	288-343
$C_9H_{20}O$	2-Nonanol	298.2	6.66	0.10136E+03	-0.55612E+00	0.80000E-03	288-308
$C_9H_{20}O$	3-Nonanol	298.2	4.49	0.55214E+02	-0.31920E+00	0.50000E-03	288-308
$C_9H_{20}O$	4-Nonanol	298.2	3.69	0.27954E+01	0.30000E-02	-0.52375E-13	288-308
$C_9H_{20}O$	5-Nonanol	298.2	3.54	-0.25463E+01	0.35320E-01	-0.50000E-04	288-308
$C_9H_{21}B$	Tripropylborane	293.2	2.026				
$C_9H_{21}N$	Nonylamine	293.2	3.42	0.53575E+01	-0.71982E-02	0.19481E-05	293-373
$C_9H_{21}N$	Tripropylamine	293.2	2.380	0.33380E+01	-0.86332E-02	0.18322E-04	243-293
$C_9H_{21}O_4P$	Tripropyl phosphate	293.2	10.93	0.33166E+02	-0.10514E+00	0.10000E-03	293-373
$C_{10}H_7Br$	1-Bromonaphthalene	298.2	4.768	0.10561E+02	-0.27671E-01	0.27655E-04	293-323
$C_{10}H_7Cl$	1-Chloronaphthalene	298.2	5.04	0.84861E+01	-0.12357E-01	0.26899E-05	274-328
$C_{10}H_7NO_2$	1-Nitronaphthalene	333.2	19.68	0.36267E+02	-0.41283E-01	-0.25595E-04	333-403
$C_{10}H_8$	Naphthalene	363.2	2.54				
$C_{10}H_8O$	1-Naphthol	373.0	5.03	0.16489E+02	-0.46700E-01	0.42857E-04	373-453
$C_{10}H_8O$	2-Naphthol	413.0	4.95	0.92865E+01	-0.10500E-01	0.42501E-15	413-453
$C_{10}H_9N$	1-Naphthylamine	333.2	5.20	0.10577E+02	-0.22114E-01	0.17857E-04	333-453
$C_{10}H_9N$	2-Naphthylamine	393.0	5.26	0.19722E+02	-0.60679E-01	0.60714E-04	393-473
$C_{10}H_9N$	2-Methylquinoline	293.2	7.24	0.11688E+02	-0.78400E-02	-0.25000E-04	293-333
$C_{10}H_9N$	4-Methylquinoline	293.2	9.31	0.17788E+02	-0.32580E-01	0.12500E-04	293-333
$C_{10}H_9N$	6-Methylquinoline	293.2	8.48	0.21696E+02	-0.63400E-01	0.62500E-04	293-333
$C_{10}H_9N$	8-Methylquinoline	293.2	6.58	0.19356E+02	-0.61900E-01	0.62500E-04	293-333
$C_{10}H_{10}O_4$	Methyl 2-(acetyloxy)benzoate	328.9	5.31	0.19579E+02	-0.69970E-01	0.80889E-04	329-371
$C_{10}H_{10}O_4$	Dimethyl phthalate	293.2	8.66				
$C_{10}H_{12}$	1,2,3,4-Tetrahydronaphthalene	298.2	2.771	0.29172E+01	0.12832E-02	-0.59453E-05	298-343
$C_{10}H_{12}$	4-Ethylstyrene	298.2	3.350				
$C_{10}H_{12}$	Dicyclopentadiene	313.2	2.43	0.30564E+01	-0.20000E-02	0.82443E-15	313-373
$C_{10}H_{12}O$	Tetrahydro-2-naphthol*	293.2	11.70	0.98978E+02	-0.48267E+00	0.63008E-03	293-363
$C_{10}H_{12}O$	4-Isopropylbenzaldehyde	288.2	10.68				
$C_{10}H_{12}O_2$	4-Allyl-2-methoxyphenol	293.2	9.55	0.52377E+02	-0.24380E+00	0.33333E-03	273-323
$C_{10}H_{12}O_2$	2-Phenylethyl acetate	297.2	4.93				
$C_{10}H_{12}O_2$	Benzyl propanoate	303.0	5.11	0.42301E+01	0.13962E-01	-0.36426E-04	303-358
$C_{10}H_{12}O_2$	Phenyl butanoate	293.2	4.48				
$C_{10}H_{12}O_2$	Propyl benzoate	303.2	5.78	0.10927E+02	-0.20535E-01	0.11745E-04	303-358
$C_{10}H_{12}O_2$	Ethyl phenylacetate	293.2	5.320				
$C_{10}H_{14}$	Butylbenzene	293.2	2.359				
$C_{10}H_{14}$	*sec*-Butylbenzene	293.2	2.357	0.28348E+01	-0.68586E-03	-0.32143E-05	273-323
$C_{10}H_{14}$	*tert*-Butylbenzene	293.2	2.359	0.27924E+01	-0.38350E-03	-0.37500E-05	273-323
$C_{10}H_{14}$	Isobutylbenzene	293.2	2.318	0.28055E+01	-0.92614E-03	-0.25000E-05	273-323
$C_{10}H_{14}$	1-Isopropyl-4-methylbenzene	298.2	2.2322	0.25266E+01	-0.25121E-03	-0.24867E-05	277-333
$C_{10}H_{14}$	*o*-Diethylbenzene	293.2	2.594				
$C_{10}H_{14}$	*m*-Diethylbenzene	293.2	2.369				
$C_{10}H_{14}$	*p*-Diethylbenzene	293.2	2.259				
$C_{10}H_{14}$	1-Ethyl-3,5-dimethylbenzene	293.2	2.275				
$C_{10}H_{14}$	1,2,3,4-Tetramethylbenzene	296.0	2.538	0.33822E+01	-0.33630E-02	0.17475E-05	273-412
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene	356.0	2.223	0.26834E+01	-0.10327E-02	-0.73533E-06	356-430
$C_{10}H_{14}N_2$	*L*-Nicotine	293.2	8.937	0.21347E+02	-0.57177E-01	0.50655E-04	293-363
$C_{10}H_{14}O$	1-Phenyl-2-methyl-2-propanol	298.2	5.71	0.21922E+02	-0.84231E-01	0.99475E-04	298-423
$C_{10}H_{14}O$	Butyl phenyl ether	293.2	3.734				
$C_{10}H_{14}O$	Thymol	333.2	4.259				
$C_{10}H_{15}N$	*N,N*-Diethylaniline	303.2	5.15	0.50773E+01	0.15399E-01	-0.50000E-04	303-328
$C_{10}H_{16}$	γ-Terpinene	298.2	2.2738				
$C_{10}H_{16}$	*d*-Limonene	298.2	2.3746				
$C_{10}H_{16}$	*l*-Limonene	298.2	2.3738				

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_{10}H_{16}$	Terpinolene	298.2	2.2918				
$C_{10}H_{16}$	α-Pinene	298.2	2.1787				
$C_{10}H_{16}$	β-Pinene	298.2	2.4970				
$C_{10}H_{16}$	α-Terpinene	298.2	2.4526				
$C_{10}H_{16}$	β-Myrcene	298.2	2.3				
$C_{10}H_{16}O$	Carvenone	293.2	18.8				
$C_{10}H_{16}O$	*d*-Fenchone	294.2	12.8				
$C_{10}H_{17}Cl$	2-Chlorobornane	368.2	5.21				
$C_{10}H_{18}$	Pinane	298.2	2.1456				
$C_{10}H_{18}$	*cis*-Decahydronaphthalene	293.2	2.219	0.25410E+01	-0.11420E-02	0.15092E-06	293-373
$C_{10}H_{18}$	*trans*-Decahydronaphthalene	293.2	2.184	0.26615E+01	-0.21241E-02	0.16864E-05	293-373
$C_{10}H_{18}O$	Eucalyptol	298.2	4.57				
$C_{10}H_{18}O_2$	Cyclohexyl butanoate	293.2	4.58				
$C_{10}H_{18}O_4$	Diethyl adipate	293.2	6.109	0.14824E+02	-0.40749E-01	0.37600E-04	293-343
$C_{10}H_{20}$	1-Decene	293.2	2.136	0.19091E+01	0.33442E-02	-0.87500E-05	273-323
$C_{10}H_{20}$	*cis*-5-Decene	298.2	2.071				
$C_{10}H_{20}$	*trans*-5-Decene	298.2	2.030				
$C_{10}H_{20}$	5-Methyl-4-nonene	293.2	2.175				
$C_{10}H_{20}$	2,4,6-Trimethyl-3-heptene	293.2	2.293				
$C_{10}H_{20}Br_2$	1,10-Dibromodecane	303.2	6.56	0.17350E+02	-0.50328E-01	0.48633E-04	303-368
$C_{10}H_{20}Cl_2$	1,10-Dichlorodecane	308.2	6.68	-0.57423E+01	0.94220E-01	-0.17500E-03	308-338
$C_{10}H_{20}O$	2-Decanone	287.2	8.3				
$C_{10}H_{20}O$	Menthol	309.3	3.90	0.68202E+01	-0.15894E-01	0.20837E-04	309-358
$C_{10}H_{20}O_2$	2,2-Dimethyloctanoic acid	296.2	2.8				
$C_{10}H_{20}O_2$	Octyl acetate	288.2	4.18	-0.34691E+01	0.58106E-01	-0.10952E-03	288-323
$C_{10}H_{20}O_2$	2-Methylheptyl acetate	288.2	4.27	0.23285E+02	-0.11538E+00	0.17143E-03	288-323
$C_{10}H_{20}O_2$	Pentyl pentanoate	305.6	4.076	0.77641E+01	-0.14335E-01	0.73740E-05	306-393
$C_{10}H_{20}O_2$	Isopentyl pentanoate	292.2	3.6				
$C_{10}H_{20}O_2$	Isopentyl isopentanoate	288.2	4.39	0.14698E+02	-0.57726E-01	0.76190E-04	288-323
$C_{10}H_{20}O_2$	Methyl nonanoate	293.2	3.943				
$C_{10}H_{21}Br$	1-Bromodecane	298.2	4.44	0.11202E+02	-0.33491E-01	0.36314E-04	274-328
$C_{10}H_{21}Cl$	1-Chlorodecane	293.2	4.581	0.68741E+01	-0.12210E-02	-0.22500E-04	293-323
$C_{10}H_{21}NO$	*N,N*-Dibutylacetamide	293.2	19.1				
$C_{10}H_{22}$	Decane	293.2	1.9853	0.24054E+01	-0.15445E-02	0.44643E-06	253-393
$C_{10}H_{22}$	2,7-Dimethyloctane	293.2	1.98				
$C_{10}H_{22}$	4-Propylheptane	293.2	1.9955				
$C_{10}H_{22}O$	1-Decanol	293.2	7.93	0.47195E+02	-0.20740E+00	0.24942E-03	293-343
$C_{10}H_{22}O$	2-Decanol	298.2	5.82	0.13621E+03	-0.81000E+00	0.12500E-02	288-308
$C_{10}H_{22}O$	3-Decanol	298.2	4.05	0.52090E+02	-0.31020E+00	0.50000E-03	288-308
$C_{10}H_{22}O$	4-Decanol	298.2	3.42	-0.11260E+02	0.93960E-01	-0.15000E-03	288-308
$C_{10}H_{22}O$	5-Decanol	298.2	3.24	-0.25832E+01	0.31456E-01	-0.40000E-04	288-308
$C_{10}H_{22}O$	2,2-Dimethyl-1-octanol	293.2	7.86	0.69536E+02	-0.34596E+00	0.46250E-03	293-333
$C_{10}H_{22}O$	Dipentyl ether	298.2	2.798				
$C_{10}H_{22}O$	Diisopentyl ether	293.2	2.817	0.44690E+01	-0.63710E-02	0.25000E-05	293-323
$C_{10}H_{22}OS$	Dipentyl sulfoxide	348.2	18.8				
$C_{10}H_{22}O_5$	Tetraethylene glycol dimethyl ether	298.2	7.68				
$C_{10}H_{22}S$	Dipentyl sulfide	298.2	3.826				
$C_{10}H_{23}N$	Decylamine	293.2	3.31	0.61497E+01	-0.12801E-01	0.10606E-04	293-373
$C_{10}H_{30}O_3Si_4$	Decamethyltetrasiloxane	293.2	2.370				
$C_{10}H_{30}O_5Si_5$	Decamethylcyclopentasiloxane	293.2	2.50				
$C_{11}H_{10}$	1-Methylnaphthalene	293.2	2.915	0.45126E+01	-0.76480E-02	0.75000E-05	293-333
$C_{11}H_{10}$	2-Methylnaphthalene	313.2	2.747				
$C_{11}H_{10}O$	1-Methoxynaphthalene	293.2	4.020	0.71885E+01	-0.14838E-01	0.13750E-04	293-333
$C_{11}H_{10}O$	2-Methoxynaphthalene	353.2	3.563	0.56702E+01	-0.69754E-02	0.28571E-05	353-373
$C_{11}H_{12}O_2$	Ethyl *trans*-cinnamate	293.2	5.63				
$C_{11}H_{12}O_3$	Ethyl benzoylacetate	303.2	13.50	0.93644E+01	0.74280E-01	-0.20000E-03	303-323
$C_{11}H_{14}O_2$	Benzyl butanoate	301.2	4.55				
$C_{11}H_{14}O_2$	Phenyl pentanoate	293.2	4.30				
$C_{11}H_{14}O_2$	Butyl benzoate	303.2	5.52	0.77854E+01	-0.34972E-02	-0.13149E-04	303-358

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_{11}H_{14}O_2$	Isobutyl benzoate	291.2	5.39				
$C_{11}H_{16}$	1,3-Diethyl-5-methylbenzene	293.2	2.264				
$C_{11}H_{16}$	Pentamethylbenzene	334.0	2.358	0.30196E+01	-0.22619E-02	0.83831E-06	334-413
$C_{11}H_{22}$	1-Undecene	293.2	2.137	0.22132E+01	0.13121E-02	-0.53571E-05	273-323
$C_{11}H_{22}O$	2-Undecanone	285.3	8.3				
$C_{11}H_{22}O_2$	Nonyl acetate	293.2	3.87				
$C_{11}H_{22}O_2$	Pentyl hexanoate	288.2	4.22	0.83503E+01	-0.18449E-01	0.14286E-04	288-323
$C_{11}H_{23}Br$	1-Bromoundecane	272.6	4.61				
$C_{11}H_{24}$	Undecane	293.2	1.9972	0.23637E+01	-0.12500E-02	-0.85869E-16	283-363
$C_{11}H_{24}O$	1-Undecanol	313.2	5.98				
$C_{11}H_{25}N$	Undecylamine	293.2	3.25	0.54945E+01	-0.96161E-02	0.66017E-05	293-373
$C_{12}F_{27}N$	Tris(perfluorobutyl)amine	293.2	2.15				
$C_{12}H_8O$	Dibenzofuran	373.2	3.00				
$C_{12}H_{10}$	Biphenyl	348.2	2.53	0.26869E+01	0.63072E-03	-0.30995E-05	348-428
$C_{12}H_{10}N_2O$	*trans*-Azoxybenzene	311.2	5.2				
$C_{12}H_{10}O$	Diphenyl ether	283.2	3.726				
$C_{12}H_{10}O$	2-Acetonaphthone	333.2	13.03	0.14538E+03	-0.73040E+00	0.10000E-02	333-363
$C_{12}H_{10}OS$	Diphenyl sulfoxide	344.7	16.6				
$C_{12}H_{10}O_2S$	Diphenyl sulfone	406.2	21.1				
$C_{12}H_{10}S$	Diphenyl sulfide	298.2	5.43				
$C_{12}H_{11}N$	Diphenylamine	323.2	3.73				
$C_{12}H_{11}NO$	*N*-1-Naphthylenylacetamide	433.2	24.3	0.84739E+02	-0.12391E+00	-0.35714E-04	433-533
$C_{12}H_{12}$	1,6-Dimethylnaphthalene	293.2	2.7250				
$C_{12}H_{12}O$	1-Ethoxynaphthalene	292.2	3.3				
$C_{12}H_{14}O_2$	Propyl cinnamate	293.2	5.45				
$C_{12}H_{14}O_4$	Diethyl phthalate	293.2	7.86				
$C_{12}H_{16}O$	2-Cyclohexylphenol	328.2	3.97				
$C_{12}H_{16}O$	4-Cyclohexylphenol	404.2	4.42				
$C_{12}H_{16}O_2$	Pentyl benzoate	293.2	5.07				
$C_{12}H_{16}O_3$	Pentyl salicylate	301.2	6.25				
$C_{12}H_{16}O_3$	Isopentyl salicylate	293.12	7.26	0.13129E+02	-0.19190E-01	-0.36060E-05	225-397
$C_{12}H_{17}NO$	*N*-Butyl-*N*-phenylacetamide	298.2	11.66				
$C_{12}H_{18}$	Hexylbenzene	293.2	2.3				
$C_{12}H_{18}$	1,3,5-Triethylbenzene	293.2	2.256				
$C_{12}H_{18}$	Hexamethylbenzene	449.0	2.172	0.35710E+01	-0.46912E-02	0.35088E-05	449-489
$C_{12}H_{20}O_2$	*l*-Bornyl acetate	303.2	4.46	0.60791E+01	0.98200E-02	-0.50000E-04	303-323
$C_{12}H_{22}O$	Dicyclohexyl ether	293.2	3.45	0.95324E+01	-0.31740E-01	0.37500E-04	293-333
$C_{12}H_{22}O$	Cyclododecanone	303.2	11.4	0.39327E+02	-0.13248E+00	0.13298E-03	303-423
$C_{12}H_{22}O_6$	Dibutyl tartrate	314.2	9.4				
$C_{12}H_{24}$	1-Dodecene	293.2	2.152	0.22581E+01	0.11106E-02	-0.50000E-05	273-323
$C_{12}H_{24}O_2$	Decyl acetate	293.2	3.75				
$C_{12}H_{24}O_2$	Ethyl decanoate	293.2	3.75	0.70969E+01	-0.15080E-01	0.12500E-04	293-353
$C_{12}H_{24}O_2$	Methyl undecanoate	293.2	3.671				
$C_{12}H_{25}Br$	1-Bromododecane	298.2	4.07	0.86103E+01	-0.20891E-01	0.18994E-04	274-328
$C_{12}H_{25}Cl$	1-Chlorododecane	298.2	4.17	0.10002E+02	-0.27798E-01	0.27559E-04	274-328
$C_{12}H_{25}I$	1-Iodododecane	298.2	3.91	0.34641E+01	0.97404E-02	-0.27602E-04	293-323
$C_{12}H_{26}$	Dodecane	293.2	2.0120	0.23697E+01	-0.12200E-02	-0.36375E-16	283-363
$C_{12}H_{26}O$	1-Dodecanol	303.2	5.82	0.18518E+02	-0.44859E-01	0.99900E-05	303-358
$C_{12}H_{26}O$	2-Butyl-1-octanol	363.2	3.28				
$C_{12}H_{27}BO_3$	Tributyl borate	293.2	2.23				
$C_{12}H_{27}N$	Dodecylamine	303.2	3.07	0.27999E+01	0.44810E-02	-0.11905E-04	303-373
$C_{12}H_{27}N$	Tributylamine	293.2	2.340	0.19846E+01	0.28108E-02	-0.54545E-05	233-293
$C_{12}H_{27}O_4P$	Tributyl phosphate	293.2	8.34	0.26304E+02	-0.88480E-01	0.92857E-04	293-373
$C_{12}H_{28}O_4Si$	Tetrapropoxysilane	298.2	3.21				
$C_{12}H_{28}Sn$	Tetrapropylstannane	293.2	2.267				
$C_{12}H_{30}OSi_2$	Hexaethyldisiloxane	298.2	2.259	0.36559E+01	-0.72406E-02	0.85714E-05	298-333
$C_{13}H_{10}O$	Benzophenone	300.2	12.62	0.34130E+02	-0.10249E+00	0.10268E-03	300-420
$C_{13}H_{10}O_3$	Phenyl salicylate	290.2	6.92	0.26545E+02	-0.11180E+00	0.15220E-03	290-358
$C_{13}H_{12}$	Diphenylmethane	303.2	2.540	0.30638E+01	-0.17286E-02		303-333

Mol. Form.	Name	*T*/K	ε	*a*	*b*	*c*	Range/K
$C_{13}H_{12}O$	Benzyl phenyl ether	313.2	3.748				
$C_{13}H_{18}O_2$	Hexyl benzoate	293.2	4.80				
$C_{13}H_{20}$	Heptylbenzene	293.2	2.26				
$C_{13}H_{20}O$	α-Ionone*	292.4	10.78				
$C_{13}H_{20}O$	β-Ionone*	297.65	11.66				
$C_{13}H_{24}O_4$	Diethyl nonanedioate	303.2	5.133				
$C_{13}H_{26}$	1-Tridecene	293.2	2.139	0.14154E+01	0.66514E-02	-0.14286E-04	273-323
$C_{13}H_{26}O$	7-Tridecanone	303.2	7.6				
$C_{13}H_{26}O_2$	Ethyl undecanoate	293.2	3.55				
$C_{13}H_{26}O_2$	Methyl dodecanoate	293.2	3.539				
$C_{13}H_{27}Br$	1-Bromotridecane	281.15	4.19				
$C_{13}H_{28}$	Tridecane	293.2	2.0213	0.23731E+01	-0.12000E-02	-0.21841E-15	283-363
$C_{13}H_{28}$	5-Butylnonane	293.2	2.0319				
$C_{13}H_{28}O$	1-Tridecanol	333.2	4.02				
$C_{14}H_{10}$	Anthracene	502.0	2.649	0.20571E+02	-0.69169E-01	0.66667E-04	502-516
$C_{14}H_{10}$	Phenanthrene	383.2	2.72				
$C_{14}H_{10}O_2$	Benzil	368.2	13.04	-0.23599E+02	0.22715E+00	-0.34667E-03	368-393
$C_{14}H_{12}O_2$	Benzyl benzoate	303.2	5.26	0.76856E+01	-0.80000E-02	-0.80361E-15	303-358
$C_{14}H_{12}O_3$	Benzyl salicylate	301.2	4.12				
$C_{14}H_{14}$	1,2-Diphenylethane	331.2	2.47	0.31178E+01	-0.21572E-02	0.59800E-06	331-451
$C_{14}H_{14}O$	Dibenzyl ether	293.2	3.821	0.80154E+01	-0.20536E-01	0.21250E-04	293-333
$C_{14}H_{15}N$	Dibenzylamine	293.2	3.446				
$C_{14}H_{16}O_2Si$	Dimethyldiphenoxysilane	298.2	3.500	0.51669E+01	-0.77001E-02	0.70156E-05	283-353
$C_{14}H_{18}O_2$	Pentyl cinnamate	293.2	4.89				
$C_{14}H_{22}$	Octylbenzene	293.2	2.26				
$C_{14}H_{26}O_4$	Diisobutyl adipate	293.2	5.19				
$C_{14}H_{26}O_4$	Diethyl sebacate	303.2	4.995	0.39143E+02	-0.20965E+00	0.32000E-03	303-313
$C_{14}H_{28}O_2$	Dodecyl acetate	293.2	3.6				
$C_{14}H_{28}O_2$	Ethyl laurate	273.2	3.94				
$C_{14}H_{28}O_2$	Methyl tridecanoate	293.2	3.442				
$C_{14}H_{29}Br$	1-Bromotetradecane	293.2	3.84	0.10058E+02	-0.33905E-01	0.43528E-04	274-328
$C_{14}H_{30}$	Tetradecane	293.2	2.0343	0.23832E+01	-0.11900E-02	-0.51229E-16	283-363
$C_{14}H_{30}O$	1-Tetradecanol	318.2	4.42	0.12272E+02	-0.24667E-01	-0.13168E-13	318-358
$C_{14}H_{31}N$	Tetradecylamine	312.55	2.90				
$C_{15}H_{12}O_4$	Phenyl 2-(acetyloxy)benzoate	384.2	4.33				
$C_{15}H_{26}O_6$	Tributyrin	282.8	5.72	0.13152E+02	-0.36684E-01	0.36795E-04	199-283
$C_{15}H_{30}O_2$	Methyl tetradecanoate	293.2	3.352				
$C_{15}H_{31}Br$	1-Bromopentadecane	293.35	3.88				
$C_{15}H_{32}$	Pentadecane	293.2	2.0391	0.23792E+01	-0.11600E-02	-0.71069E-16	283-363
$C_{15}H_{32}O$	1-Pentadecanol	333.2	3.70				
$C_{15}H_{33}N$	Pentadecylamine	313.25	2.85				
$C_{15}H_{33}N$	Triisopentylamine	294.2	2.29				
$C_{16}H_{22}O_4$	Dibutyl phthalate	293.2	6.58	0.12444E+02	-0.20000E-01		293-333
$C_{16}H_{32}O_2$	Hexadecanoic acid	338.2	2.417				
$C_{16}H_{32}O_2$	Ethyl myristate	293.2	3.50	0.52642E+01	-0.60000E-02	-0.47358E-15	293-353
$C_{16}H_{32}O_2$	Methyl pentadecanoate	293.2	3.296				
$C_{16}H_{33}Br$	1-Bromohexadecane	298.2	3.68	0.58668E+01	-0.73333E-02	-0.52666E-14	298-328
$C_{16}H_{33}I$	1-Iodohexadecane	293.2	3.57	0.79531E+01	-0.22859E-01	0.26955E-04	293-323
$C_{16}H_{34}$	Hexadecane	293.2	2.0460	0.23861E+01	-0.11600E-02	0.25555E-15	293-363
$C_{16}H_{34}O$	1-Hexadecanol	333.2	3.69	0.85935E+01	-0.14714E-01	-0.45533E-13	333-363
$C_{16}H_{35}N$	Hexadecylamine	328.35	2.71				
$C_{16}H_{36}Sn$	Tetrabutylstannane	293.2	9.74	0.56115E+02	-0.24812E+00	0.30682E-03	293-313
$C_{17}H_{12}O_3$	2-Naphthyl salicylate	293.0	6.30	0.11229E+02	-0.18857E-01	0.70332E-05	293-353
$C_{17}H_{34}O$	9-Heptadecanone	328.2	5.43	0.44176E+02	-0.21183E+00	0.28571E-03	328-363
$C_{17}H_{34}O_2$	Methyl palmitate	313.2	3.124				
$C_{17}H_{36}$	Heptadecane	293.2	2.0578	0.23627E+01	-0.10400E-02	-0.10397E-12	293-308
$C_{17}H_{36}O$	1-Heptadecanol	333.2	3.41				
$C_{18}H_{26}O_4$	Dipentyl phthalate	293.2	6.00				
$C_{18}H_{28}O_2$	Phenyl laurate	293.2	3.28				

Mol. Form.	**Name**	***T*/K**	**ε**	***a***	***b***	***c***	**Range/K**
$C_{18}H_{30}O_2$	Linolenic acid	293.2	2.825	0.33867E+01	-0.19181E-02		274-368
$C_{18}H_{30}O_4$	Dicyclohexyl adipate	308.2	4.84				
$C_{18}H_{32}O_2$	Linoleic acid	293.2	2.754	0.32073E+01	-0.15477E-02		275-368
$C_{18}H_{34}O_2$	Oleic acid	293.2	2.336	0.25385E+01	-0.69448E-03		275-368
$C_{18}H_{34}O_4$	Dibutyl sebacate	293.2	4.54				
$C_{18}H_{36}O_2$	Stearic acid	293.2	2.314	0.27159E+01	-0.13300E-02		293-373
$C_{18}H_{36}O_2$	Hexadecyl acetate	308.2	3.19	0.47310E+01	-0.50000E-02	0.41338E-14	308-348
$C_{18}H_{36}O_2$	Ethyl palmitate	303.2	3.07	0.57938E+01	-0.12294E-01	0.10919E-04	303-455
$C_{18}H_{36}O_2$	Methyl heptadecanoate	313.2	3.07				
$C_{18}H_{37}Br$	1-Bromooctadecane	303.35	3.53	0.46790E+01	-0.30355E-02	-0.24798E-05	303-332
$C_{18}H_{38}O$	1-Octadecanol	333.2	3.38	0.73784E+01	-0.12000E-01	-0.22871E-13	333-363
$C_{18}H_{39}BO_3$	Trihexyl borate	293.2	2.22				
$C_{18}H_{39}N$	Octadecylamine	326.35	2.67				
$C_{19}H_{16}$	Triphenylmethane	367.2	2.46	0.40201E+01	-0.66507E-02	0.65329E-05	367-448
$C_{19}H_{18}O_3Si$	Methyltriphenoxysilane	298.2	3.628				
$C_{19}H_{32}O_2$	Methyl linolenate	293.2	3.355				
$C_{19}H_{34}O_2$	Methyl linoleate	293.2	3.466				
$C_{19}H_{36}O_2$	Methyl oleate	293.2	3.211				
$C_{19}H_{38}O$	10-Nonadecanone	353.2	5.37				
$C_{19}H_{38}O_2$	Methyl stearate	313.2	3.021				
$C_{19}H_{40}$	Nonadecane	293.2	2.0706				
$C_{20}H_{30}O_4$	Dihexyl phthalate	293.2	5.62				
$C_{20}H_{38}O_2$	Ethyl oleate	301.2	3.17	0.57033E+01	-0.11223E-01	0.93447E-05	301-423
$C_{20}H_{40}O_2$	Octadecyl acetate	308.2	3.07	0.44569E+01	-0.45000E-02	0.33923E-14	308-348
$C_{20}H_{40}O_2$	Ethyl stearate	313.2	2.958	0.70930E+01	-0.19081E-01	0.19555E-04	331-440
$C_{20}H_{40}O_2$	Methyl nonadecanoate	313.2	2.982				
$C_{20}H_{42}O$	1-Eicosanol	338.2	3.13	0.21700E+01	0.12497E-01	-0.28571E-04	338-363
$C_{20}H_{42}O$	Didecyl ether	293.2	2.644	0.41465E+01	-0.62240E-02	0.37500E-05	293-333
$C_{20}H_{60}O_8Si_9$	Eicosamethylnonasiloxane	293.2	2.645	0.57840E+01	-0.16568E-01	0.20000E-04	293-323
$C_{21}H_{21}O_4P$	Tricresyl phosphate*	298.2	6.7				
$C_{21}H_{38}O_6$	1,2,3-Propanetriyl hexanoate	293.2	4.476				
$C_{22}H_{42}O_2$	Butyl oleate	298.2	4.00				
$C_{22}H_{44}O_2$	Butyl stearate	298.2	3.120	0.73894E+02	-0.46261E+00	0.75500E-03	298-343
$C_{22}H_{46}$	Docosane	293.2	2.0840				
$C_{22}H_{46}O$	1-Docosanol	348.2	2.94	0.82062E+01	-0.25069E-01	0.28571E-04	348-373
$C_{24}H_{20}O_4Si$	Tetraphenoxysilane	333.2	3.4915				
$C_{24}H_{38}O_4$	Dioctyl phthalate	293.2	5.22				
$C_{26}H_{50}O_4$	Dioctyl sebacate	299.2	4.01				
$C_{27}H_{50}O_6$	1,2,3-Propanetriyl octanoate	293.2	3.931				
$C_{30}H_{58}O_4$	Ethylene glycol ditetradecanoate	343.2	2.98				
$C_{30}H_{62}$	Triacontane	373.2	1.9112				
$C_{30}H_{62}$	2,6,10,15,19,23-Hexamethyltetracosane	373.2	1.9106				
$C_{34}H_{66}O_4$	Ethylene glycol dipalmitate	348.2	2.89				
$C_{34}H_{68}O_2$	Hexadecyl stearate	333.2	2.61				
$C_{38}H_{74}O_4$	Ethylene glycol distearate	353.2	2.79				
$C_{39}H_{74}O_6$	Glycerol trilaurate	313.2	3.287				
$C_{51}H_{98}O_6$	Glycerol tripalmitate	328.2	2.901	-0.29131E+01	0.32206E-01	-0.44154E-04	328-393
$C_{57}H_{104}O_6$	Glycerol trioleate	293.2	3.109				
$C_{57}H_{104}O_6$	Glycerol trielaidate	313.2	2.980				
$C_{57}H_{110}O_6$	Glycerol tristearate	353.2	2.740				

PERMITTIVITY (DIELECTRIC CONSTANT) OF GASES

This table gives the relative permittivity ε (often called the dielectric constant) of some common gases at a temperature of 20°C and pressure of one atmosphere (101.325 kPa). Values of the permanent dipole moment μ in Debye Units (1 D = 3.33564 × 10^{-30} C m) are also included.

The density dependence of the permittivity is given by the equation

$$\frac{\varepsilon - 1}{\varepsilon + 2} = \rho_m \left(\frac{4\pi N \alpha}{3} + \frac{4\pi N \mu^2}{9kT} \right)$$

where ρ_m is the molar density, N is Avogadro's number, k is the Boltzmann constant, T is the temperature, and α is the molecular polarizability. Therefore, in regions where the gas can be considered ideal, $\varepsilon - 1$ is approximately proportional to the pressure at constant temperature. For nonpolar gases ($\mu = 0$), $\varepsilon - 1$ is inversely proportional to temperature at constant pressure.

The number of significant figures indicates the accuracy of the values given. The values of ε for air, Ar, H_2, He, N_2, O_2, and CO_2 are recommended as reference values; these are accurate to 1 ppm or better.

The second part of the table gives the permittivity of water vapor in equilibrium with liquid water as a function of temperature (derived from Reference 4).

REFERENCE

1. A. A. Maryott and F. Buckley, *Table of Dielectric Constants and Electric Dipole Moments of Substances in the Gaseous State*, National Bureau of Standards Circular 537, 1953.
2. B. A. Younglove, *J. Phys. Chem. Ref. Data*, 11, Suppl. 1, 1982; 16, 577, 1987 (for data on N_2, H_2, O_2, and hydrocarbons over a range of pressure and temperature).
3. Landolt-Börnstein, *Numerical Data and Functional Relationships in Science and Technology*, New Series, Group IV, Vol. 4, Springer-Verlag, Heidelberg, 1980 (for data at high pressures).
4. G. Birnbaum and S. K. Chatterjee, *J. Appl. Phys.*, 23, 220, 1952 (for data on water vapor).

Mol. form.	Name	ε	μ/D
	Compounds not containing carbon		
	Air (dry, CO_2 free)	1.0005364	
Ar	Argon	1.0005172	0
BF_3	Boron trifluoride	1.0011	0
BrH	Hydrogen bromide	1.00279	0.827
ClH	Hydrogen chloride	1.00390	1.109
F_3N	Nitrogen trifluoride	1.0013	0.235
F_6S	Sulfur hexafluoride	1.00200	0
HI	Hydrogen iodide	1.00214	0.448
H_2	Hydrogen	1.0002538	0
H_2S	Hydrogen sulfide	1.00344	0.97
H_3N	Ammonia	1.00622	1.471
He	Helium	1.0000650	0
Kr	Krypton	1.00078	0
NO	Nitric oxide	1.00060	0.159
N_2	Nitrogen	1.0005480	0
N_2O	Nitrous oxide	1.00104	0.161
Ne	Neon	1.00013	0
O_2	Oxygen	1.0004947	0
O_2S	Sulfur dioxide	1.00825	1.633
O_3	Ozone	1.0017	0.534
Xe	Xenon	1.00126	0
	Compounds containing carbon		
CF_4	Tetrafluoromethane	1.00121	0
CO	Carbon monoxide	1.00065	0.110
CO_2	Carbon dioxide	1.000922	0

PERMITTIVITY (DIELECTRIC CONSTANT) OF GASES (continued)

Mol. form.	Name	ε	μ/D
CH_3Br	Bromomethane	1.01028	1.822
CH_3Cl	Chloromethane	1.01080	1.892
CH_3F	Fluoromethane	1.00973	1.858
CH_3I	Iodomethane	1.00914	1.62
CH_4	Methane	1.00081	0
C_2H_2	Acetylene	1.00124	0
C_2H_3Cl	Chloroethylene	1.0075	1.45
C_2H_4	Ethylene	1.00134	0
C_2H_5Cl	Chloroethane	1.01325	2.05
C_2H_6	Ethane	1.00140	0
C_2H_6O	Dimethyl ether	1.0062	1.30
C_3H_6	Propene	1.00228	0.366
C_3H_6	Cyclopropane	1.00178	0
C_3H_8	Propane	1.00200	0.084
C_4H_{10}	Butane	1.00258	0
C_4H_{10}	Isobutane	1.00260	0.132

PERMITTIVITY OF SATURATED WATER VAPOR

t/°C	ε	*t*/°C	ε
0	1.00007	60	1.00144
10	1.00012	70	1.00213
20	1.00022	80	1.00305
30	1.00037	90	1.00428
40	1.00060	100	1.00587
50	1.00095		

AZEOTROPIC DATA FOR BINARY MIXTURES

Liquid mixtures having an extremum (maximum or minimum) vapor pressure at constant temperature, as a function of composition, are called azeotropic mixtures, or simply azeotropes. Mixtures that do not show a maximum or minimum are called zeotropic. Azeotropes in which the pressure is a maximum are often called positive azeotropes, while pressure-minimum azeotropes are called negative azeotropes. The coordinates of an azeotropic point are the azeotropic temperature t_{az}, pressure P_{az}, and liquid-phase composition, usually expressed as mole fractions. At the azeotropic point, the vapor-phase composition is the same as the liquid-phase composition.

This table gives azeotropic data for a number of binary mixtures at normal atmospheric pressure (P_{az} =101.3 kPa). Component 1 of each mixture is given in bold face. The temperature t_{az} and mole fraction x_1 of component 1 are listed for each choice of component 2.

The components are arranged in a modified Hill order, with substances that do not contain carbon preceding those that do contain carbon.

REFERENCES

1. Lide, D.R., and Kehiaian, H.V., *CRC Handbook of Thermophysical and Thermochemical Data*, CRC Press, Boca Raton, FL, 1994.
2. Horsley, L.H., *Azeotropic Data, III*, American Chemical Society, Washington, D.C., 1973.

Molecular formula	Name	t_{az}/°C	x_1
	Water H_2O		
$CHCl_3$	Trichloromethane	56.1	0.160
CH_2O_2	Formic acid	107.2	0.427
CH_3NO_2	Nitromethane	83.6	0.511
CS_2	Carbon disulfide	42.6	0.109
C_2H_3N	Acetonitrile	76.5	0.307
$C_2H_5NO_2$	Nitroethane	87.2	0.624
C_2H_6O	Ethanol	78.2	0.096
$C_4H_8O_2$	Ethyl acetate	70.4	0.312
$C_4H_{10}O$	1-Butanol	92.7	0.753
$C_4H_{10}O$	2-Butanol	87	0.601
C_5H_5N	Pyridine	93.6	0.755
$C_5H_{11}N$	Piperidine	92.8	0.718
C_5H_{12}	Pentane	34.6	0.054
C_6H_5Cl	Chlorobenzene	90.2	0.712
C_6H_6	Benzene	69.3	0.295
C_6H_6O	Phenol	99.5	0.981
C_6H_{10}	Cyclohexene	70.8	0.308
C_6H_{12}	Cyclohexane	69.5	0.300
C_6H_{14}	Hexane	61.6	0.221
C_7H_8	Toluene	84.1	0.444
C_7H_{16}	Heptane	79.2	0.452
C_8H_{10}	1,3-Dimethylbenzene	92	0.767
C_8H_{10}	Ethylbenzene	92	0.744
C_8H_{18}	Octane	89.6	0.673
$C_8H_{18}O$	Dibutyl ether	92.9	0.781
C_9H_{20}	Nonane	94.8	0.970
$C_{12}H_{27}N$	Tributylamine	99.7	0.976
	Tetrachloromethane CCl_4		
CH_2O_2	Formic acid	66.7	0.569
CH_3NO_2	Nitromethane	71.3	0.660
CH_4O	Methanol	55.7	0.445
C_2H_3N	Acetonitrile	65.1	0.566
C_2H_6O	Ethanol	65.0	0.615
C_3H_6O	Acetone	56.1	0.047
C_3H_8O	1-Propanol	73.4	0.820
$C_4H_{10}O$	1-Butanol	76.6	0.951
	Formic acid CH_2O_2		
CS_2	Carbon disulfide	42.6	0.253
	Nitromethane CH_3NO_2		
CS_2	Carbon disulfide	41.2	0.845
	Methanol CH_4O		
C_3H_6O	Acetone	55.5	0.198

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Molecular formula	Name	t_{az}/°C	x_1
$C_3H_6O_2$	Methyl acetate	53.5	0.352
C_5H_{10}	Cyclopentane	38.8	0.263
C_5H_{12}	Pentane	30.9	0.145
$C_5H_{12}O$	*tert*-Butyl methyl ether	51.3	0.315
C_6H_6	Benzene	57.5	0.610
C_6H_{12}	Cyclohexane	53.9	0.601
C_7H_8	Toluene	63.5	0.883
C_7H_{16}	Heptane	59.1	0.769
C_8H_{18}	Octane	62.8	0.881
C_9H_{20}	Nonane	64.1	0.953
	Carbon disulfide CS_2		
C_2H_6O	Ethanol	42.6	0.860
C_3H_6O	Acetone	39.3	0.608
C_3H_8O	1-Propanol	45.7	0.931
$C_4H_8O_2$	Ethyl acetate	46.1	0.974
	Acetonitrile C_2H_3N		
C_2H_6O	Ethanol	72.5	0.469
C_7H_8	Toluene	81.4	0.900
	Acetic acid $C_2H_4O_2$		
$C_4H_8O_2$	1,4-Dioxane	119.5	0.831
C_5H_5N	Pyridine	138.1	0.579
C_6H_6	Benzene	80.1	0.026
C_6H_{12}	Cyclohexane	78.8	0.130
C_6H_{14}	Hexane	68.3	0.084
$C_6H_{15}N$	Triethylamine	163	0.774
C_7H_8	Toluene	100.7	0.375
C_7H_{16}	Heptane	91.7	0.451
C_8H_{10}	Ethylbenzene	114.7	0.774
C_8H_{18}	Octane	105.7	0.688
C_9H_{20}	Nonane	112.9	0.826
	Iodoethane C_2H_5I		
C_6H_{14}	Hexane	64.7	0.420
	Ethanol C_2H_6O		
C_5H_{10}	Cyclopentane	44.7	0.110
C_5H_{12}	Pentane	34.3	0.076
C_6H_6	Benzene	67.9	0.440
C_6H_{12}	Cyclohexane	64.8	0.430
C_6H_{14}	Hexane	58.7	0.332
C_7H_8	Toluene	76.7	0.810
C_8H_{18}	Octane	77	0.898
	Ethylene glycol $C_2H_6O_2$		
C_7H_8	Toluene	110.1	0.034
C_7H_{16}	Heptane	97.9	0.048
$C_8H_{18}O$	Dibutyl ether	139.5	0.125
$C_{10}H_{22}$	Decane	161	0.406
	Dimethyl sulfide C_2H_6S		
C_5H_{12}	Pentane	31.8	0.503
	1,2-Ethanediamine $C_2H_8N_2$		
C_7H_8	Toluene	104	0.406
	Propanenitrile C_3H_5N		
C_6H_{14}	Hexane	63.5	0.134
	Acetone C_3H_6O		
$C_3H_6O_2$	Methyl acetate	55.8	0.544
C_5H_{10}	Cyclopentane	41	0.404
C_6H_{12}	Cyclohexane	53	0.751
	Ethyl formate $C_3H_6O_2$		
C_5H_{12}	Pentane	32.5	0.294
	Methyl acetate $C_3H_6O_2$		
C_6H_{12}	Cyclohexane	55.5	0.801

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AZEOTROPIC DATA FOR BINARY MIXTURES (continued)

Molecular formula	Name	t_{az}/°C	x_1
C_6H_{14}	Hexane	51.8	0.642
	Propanoic acid $C_3H_6O_2$		
C_5H_5N	Pyridine	148.6	0.686
C_7H_{16}	Heptane	97.8	0.027
C_9H_{12}	Propylbenzene	139.5	0.830
	1-Nitropropane $C_3H_7NO_2$		
C_3H_8O	1-Propanol	97.0	0.061
C_7H_{16}	Heptane	96.6	0.149
	1-Propanol C_3H_8O		
$C_4H_8O_2$	1,4-Dioxane	95.3	0.642
C_6H_6	Benzene	77.1	0.209
C_6H_{12}	Cyclohexane	74.7	0.241
C_7H_{16}	Heptane	84.6	0.470
	2-Propanol C_3H_8O		
$C_4H_{11}N$	Butylamine	74.7	0.646
C_5H_{12}	Pentane	35.5	0.071
C_6H_{12}	Cyclohexane	69.4	0.397
C_7H_8	Toluene	80.6	0.773
	Ethyl methyl sulfide C_3H_8S		
C_6H_{12}	Methylcyclopentane	65.6	0.664
C_7H_{16}	2,2-Dimethylpentane	66.4	0.908
	1-Propanethiol C_3H_8S		
C_6H_{12}	Cyclohexane	67.8	0.978
C_6H_{14}	Hexane	64.4	0.557
$C_6H_{14}O$	Diisopropyl ether	65.9	0.714
	Thiophene C_4H_4S		
C_6H_{12}	Cyclohexane	77.9	0.412
C_6H_{14}	Hexane	68.5	0.114
	Butanal C_4H_8O		
C_6H_{14}	Hexane	60	0.296
	2-Butanone C_4H_8O		
C_4H_9Cl	1-Chlorobutane	77	0.440
$C_4H_{11}N$	Butylamine	74	0.353
C_6H_6	Benzene	78.3	0.460
C_6H_{12}	Cyclohexane	71.8	0.438
C_7H_{16}	Heptane	77	0.764
	Butanoic acid $C_4H_8O_2$		
C_5H_5N	Pyridine	163.2	0.912
C_6H_5Cl	Chlorobenzene	131.8	0.035
C_8H_{10}	1,2-Dimethylbenzene	143	0.118
	1,4-Dioxane $C_4H_8O_2$		
C_4H_9Br	1-Bromobutane	98	0.580
	Ethyl acetate $C_4H_8O_2$		
C_6H_{14}	Hexane	65.2	0.394
	Methyl propanoate $C_4H_8O_2$		
C_4H_9Cl	1-Chlorobutane	76.8	0.392
	Propyl formate $C_4H_8O_2$		
C_4H_9Cl	1-Chlorobutane	76.1	0.392
C_6H_6	Benzene	78.5	0.440
C_6H_{12}	Cyclohexane	75	0.469
	1-Butanol $C_4H_{10}O$		
C_5H_5N	Pyridine	118.6	0.704
C_6H_5Cl	Chlorobenzene	115.3	0.659
C_6H_{10}	Cyclohexene	82	0.055
C_7H_8	Toluene	105.5	0.324
C_7H_{16}	Heptane	93.9	0.229
C_8H_{10}	1,2-Dimethylbenzene	116.8	0.811
$C_8H_{18}O$	Dibutyl ether	117.7	0.892

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AZEOTROPIC DATA FOR BINARY MIXTURES (continued)

Molecular formula	Name	t_{az}/°C	x_1
	2-Butanol $C_4H_{10}O$		
C_6H_6	Benzene	78.5	0.161
C_7H_{16}	Heptane	88.1	0.439
	Diethyl ether $C_4H_{10}O$		
C_5H_{12}	Pentane	33.7	0.553
	***tert*-Butyl alcohol $C_4H_{10}O$**		
C_6H_6	Benzene	74.0	0.378
C_7H_{16}	Heptane	78	0.688
	Methyl propyl ether $C_4H_{10}O$		
C_5H_{12}	Pentane	35.6	0.215
	2-Ethoxyethanol $C_4H_{10}O_2$		
C_7H_{16}	Heptane	96.5	0.153
C_9H_{12}	Propylbenzene	134.6	0.842
	2-Furaldehyde $C_5H_4O_2$		
C_7H_{16}	Heptane	98.3	0.055
C_9H_{12}	Propylbenzene	151.4	0.475
	Pyridine C_5H_5N		
C_7H_8	Toluene	110.1	0.249
	Benzene C_6H_6		
C_6H_{10}	Cyclohexene	78.9	0.635
C_6H_{12}	Cyclohexane	77.6	0.538
	Phenol C_6H_6O		
C_6H_7N	2-Methylpyridine	185.5	0.752
C_7H_9N	2,4-Dimethylpyridine	193.4	0.601
C_9H_{12}	1,3,5-Trimethylbenzene	163.5	0.253
$C_{10}H_{22}$	Decane	168	0.449
	Aniline C_6H_7N		
C_9H_{12}	1,3,5-Trimethylbenzene	164.4	0.150
$C_{10}H_{22}O$	Dipentyl ether	177.5	0.675
$C_{12}H_{26}$	Dodecane	180.4	0.821
	2-Methylpyridine C_6H_7N		
C_8H_{18}	Octane	121.1	0.470
	Cyclohexanol $C_6H_{12}O$		
C_8H_{10}	1,2-Dimethylbenzene	143	0.147

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VISCOSITY OF GASES

The following table gives the viscosity of some common gases as a function of temperature. Unless otherwise noted, the viscosity values refer to a pressure of 100 kPa (1 bar). The notation *P*=0 indicates the low pressure limiting value is given. The difference between the viscosity at 100 kPa and the limiting value is generally less than 1%. Viscosity is given in units of μPa s; note that 1 μPa s = 10^{-5} poise. Substances are listed in the modified Hill order (see Introduction).

		Viscosity in micropascal seconds (μPa s)						
		100 K	**200 K**	**300 K**	**400 K**	**500 K**	**600 K**	**Ref.**
	Air	7.1	13.3	18.6	23.1	27.1	30.8	1
Ar	Argon	8.0	15.9	22.9	28.8	34.2	39.0	2,8
BF_3	Boron trifluoride		12.3	17.1	21.7	26.1	30.2	13
ClH	Hydrogen chloride			14.6	19.7	24.3		13
F_6S	Sulfur hexafluoride (*P*=0)			15.3	19.8	23.9	27.7	10
H_2	Hydrogen (*P*=0)	4.2	6.8	9.0	10.9	12.7	14.4	4
D_2	Deuterium (*P*=0)	5.9	9.6	12.6	15.4	17.9	20.3	11
H_2O	Water			10.0	13.3	17.3	21.4	6
D_2O	Deuterium oxide			11.1	13.7	17.7	22.0	7
He	Helium (*P*=0)	9.7	15.3	20.0	24.4	28.4	32.3	8
Kr	Krypton (*P*=0)	8.8	17.1	25.6	33.1	39.8	45.9	8
NO	Nitric oxide		13.8	19.2	23.8	28.0	31.9	13
N_2	Nitrogen (*P*=0)		12.9	17.9	22.2	26.1	29.6	12
N_2O	Nitrous oxide		10.0	15.0	19.4	23.6	27.4	13
Ne	Neon (*P*=0)	14.4	24.3	32.1	38.9	45.0	50.8	8
O_2	Oxygen (*P*=0)	7.5	14.6	20.8	26.1	30.8	35.1	12
O_2S	Sulfur dioxide		8.6	12.9	17.5	21.7		13
Xe	Xenon (*P*=0)	8.3	15.4	23.2	30.7	37.6	44.0	8
CO	Carbon monoxide	6.7	12.9	17.8	22.1	25.8	29.1	13
CO_2	Carbon dioxide		10.0	15.0	19.7	24.0	28.0	9,10
$CHCl_3$	Chloroform			10.2	13.7	16.9	20.1	13
CH_4	Methane		7.7	11.2	14.3	17.0	19.4	10
CH_4O	Methanol				13.2	16.5	19.6	13
C_2H_2	Acetylene			10.4	13.5	16.5		13
C_2H_4	Ethylene		7.0	10.4	13.6	16.5	19.1	3
C_2H_6	Ethane		6.4	9.5	12.3	14.9	17.3	5
C_2H_6O	Ethanol				11.6	14.5	17.0	13
C_3H_8	Propane			8.3	10.9	13.4	15.8	5
C_4H_{10}	Butane			7.5	10.0	12.3	14.6	5
C_4H_{10}	Isobutane			7.6	10.0	12.3	14.6	5
$C_4H_{10}O$	Diethyl ether			7.6	10.1	12.4		13
C_5H_{12}	Pentane			6.7	9.2	11.4	13.4	13
C_6H_{14}	Hexane				8.6	10.8	12.8	13

REFERENCES

1. K. Kadoya, N. Matsunaga, and A. Nagashima, Viscosity and thermal conductivity of dry air in the gaseous phase, *J. Phys. Chem. Ref. Data*, 14, 947, 1985.
2. B. A. Younglove and H. J. M. Hanley, The viscosity and thermal conductivity coefficients of gaseous and liquid argon, *J. Phys. Chem. Ref. Data*, 15, 1323, 1986.
3. P. M. Holland, B. E. Eaton, and H. J. M. Hanley, A Correlation of the viscosity and thermal conductivity data of gaseous and liquid ethylene, *J. Phys. Chem. Ref. Data*, 12, 917, 1983.
4. M. J. Assael, S. Mixafendi, and W. A. Wakeham, The viscosity and thermal conductivity of normal hydrogen in the limit zero density, *J. Phys. Chem. Ref. Data*, 15, 1315, 1986.
5. B. A. Younglove and J. F. Ely, Thermophysical properties of fluids. II. Methane, ethane, propane, isobutane, and normal butane, *J. Phys. Chem. Ref. Data*, 16, 577, 1987.

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6. J. V. Sengers and J. T. R. Watson, Improved international formulations for the viscosity and thermal conductivity of water substance, *J. Phys. Chem. Ref. Data*, 15, 1291, 1986.
7. N. Matsunaga and A. Nagashima, Transport properties of liquid and gaseous D_2O over a wide range of temperature and pressure, *J. Phys. Chem. Ref. Data*, 12, 933, 1983.
8. J. Kestin, et al., Equilibrium and transport properties of the noble gases and their mixtures at low density, *J. Phys. Chem. Ref. Data*, 13, 299, 1984.
9. V. Vescovic, et al., The transport properties of carbon dioxide, *J. Phys. Chem. Ref. Data*, 19, 1990.
10. R. D. Trengove and W. A. Wakeham, The viscosity of carbon dioxide, methane, and sulfur hexafluoride in the limit of zero density, *J. Phys. Chem. Ref. Data*, 16, 175, 1987.
11. M. J. Assael, S. Mixafendi, and W. A. Wakeham, The viscosity of normal deuterium in the limit of zero density, *J. Phys. Chem. Ref. Data*, 16, 189, 1987.
12. W. A. Cole and W. A. Wakeham, The viscosity of nitrogen, oxygen, and their binary mixtures in the limit of zero density, *J. Phys. Chem. Ref. Data*, 14, 209, 1985.
13. C. Y. Ho, Ed., *Properties of Inorganic and Organic Fluids*, *CINDAS Data Series on Materials Properties*, Vol. V-1, Hemisphere Publishing Corp., New York, 1988.

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VISCOSITY OF LIQUIDS

The absolute viscosity of some common liquids at temperatures between –25 and 100°C is given in this table. Values were derived by fitting experimental data to suitable expressions for the temperature dependence. The substances are arranged by molecular formula in the modified Hill order (see Preface). All values are given in units of millipascal seconds (mPa s); this unit is identical to centipoise (cp).

Viscosity values correspond to a nominal pressure of 1 atmosphere. If a value is given at a temperature above the normal boiling point, the applicable pressure is understood to be the vapor pressure of the liquid at that temperature. A few values are given at a temperature slightly below the normal freezing point; these refer to the supercooled liquid.

The accuracy ranges from 1% in the best cases to 5 to 10% in the worst cases. Additional significant figures are included in the table to facilitate interpolation.

REFERENCES

1. Viswanath, D. S. and Natarajan, G., *Data Book on the Viscosity of Liquids*, Hemisphere Publishing Corp., New York, 1989.
2. Daubert, T. E., Danner, R. P., Sibul, H. M., and Stebbins, C. C., *Physical and Thermodynamic Properties of Pure Compounds: Data Compilation*, extant 1994 (core with 4 supplements), Taylor & Francis, Bristol, PA (also available as database).
3. Ho, C. Y., Ed., *CINDAS Data Series on Material Properties*, Vol. V-1, *Properties of Inorganic and Organic Fluids*, Hemisphere Publishing Corp., New York, 1988.
4. Stephan, K. and Lucas, K., *Viscosity of Dense Fluids*, Plenum Press, New York, 1979.
5. Vargaftik, N. B., *Tables of Thermophysical Properties of Liquids and Gases*, 2nd ed., John Wiley, New York, 1975.

Molecular formula	Name	Viscosity in mPa s					
		–25°C	0°C	25°C	50°C	75°C	100°C
	Compounds not containing carbon						
Br_2	Bromine		1.252	0.944	0.746		
Cl_3HSi	Trichlorosilane		0.415	0.326			
Cl_3P	Phosphorous trichloride	0.870	0.662	0.529	0.439		
Cl_4Si	Tetrachlorosilane			99.4	96.2		
H_2O	Water		1.793	0.890	0.547	0.378	0.282
H_4N_2	Hydrazine			0.876	0.628	0.480	0.384
Hg	Mercury			1.526	1.402	1.312	1.245
NO_2	Nitrogen dioxide		0.532	0.402			
	Compounds containing carbon						
CCl_3F	Trichlorofluoromethane	0.740	0.539	0.421			
CCl_4	Tetrachloromethane		1.321	0.908	0.656	0.494	
CS_2	Carbon disulfide		0.429	0.352			
$CHBr_3$	Tribromomethane			1.857	1.367	1.029	
$CHCl_3$	Trichloromethane	0.988	0.706	0.537	0.427		
CHN	Hydrogen cyanide		0.235	0.183			
CH_2Br_2	Dibromomethane	1.948	1.320	0.980	0.779	0.652	
CH_2Cl_2	Dichloromethane	0.727	0.533	0.413			
CH_2O_2	Formic acid			1.607	1.030	0.724	0.545
CH_3I	Iodomethane		0.594	0.469			
CH_3NO	Formamide		7.114	3.343	1.833		
CH_3NO_2	Nitromethane	1.311	0.875	0.630	0.481	0.383	0.317
CH_4O	Methanol	1.258	0.793	0.544			
CH_5N	Methylamine	0.319	0.231				
$C_2Cl_3F_3$	1,1,2-Trichlorotrifluoroethane	1.465	0.945	0.656	0.481		
C_2Cl_4	Tetrachloroethylene		1.114	0.844	0.663	0.535	0.442
C_2HCl_3	Trichloroethylene		0.703	0.545	0.444	0.376	
C_2HCl_5	Pentachloroethane		3.761	2.254	1.491	1.061	
$C_2HF_3O_2$	Trifluoroacetic acid			0.808	0.571		
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethylene	0.786	0.575	0.445			
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethylene	0.522	0.398	0.317	0.261		
$C_2H_2Cl_4$	1,1,1,2-Tetrachloroethane	3.660	2.200	1.437	1.006	0.741	0.570
$C_2H_3ClF_2$	1-Chloro-1,1-difluoroethane	0.477	0.376				

VISCOSITY OF LIQUIDS (continued)

Molecular formula	Name	Viscosity in mPa s					
		–25°C	0°C	25°C	50°C	75°C	100°C
C_2H_3ClO	Acetyl chloride			0.368	0.294		
$C_2H_3Cl_3$	1,1,1-Trichloroethane	1.847	1.161	0.793	0.578	0.428	
C_2H_3N	Acetonitrile		0.400	0.369	0.284	0.234	
$C_2H_4Br_2$	1,2-Dibromoethane			1.595	1.116	0.837	0.661
$C_2H_4Cl_2$	1,1-Dichloroethane			0.464	0.362		
$C_2H_4Cl_2$	1,2-Dichloroethane		1.125	0.779	0.576	0.447	
$C_2H_4O_2$	Acetic acid			1.056	0.786	0.599	0.464
$C_2H_4O_2$	Methyl formate		0.424	0.325			
C_2H_5Br	Bromoethane	0.635	0.477	0.374			
C_2H_5Cl	Chloroethane	0.416	0.319				
C_2H_5I	Iodoethane		0.723	0.556	0.444	0.365	
C_2H_5NO	*N*-Methylformamide		2.549	1.678	1.155	0.824	0.606
$C_2H_5NO_2$	Nitroethane	1.354	0.940	0.688	0.526	0.415	0.337
C_2H_6O	Ethanol	3.262	1.786	1.074	0.694	0.476	
C_2H_6OS	Dimethyl sulfoxide			1.987	1.290		
$C_2H_6O_2$	Ethylene glycol			16.1	6.554	3.340	1.975
C_2H_6S	Dimethyl sulfide		0.356	0.284			
C_2H_6S	Ethanethiol		0.364	0.287			
C_2H_7N	Dimethylamine	0.300	0.232				
C_2H_7NO	Ethanolamine			21.1	8.560	3.935	1.998
C_3H_5Br	3-Bromopropene		0.620	0.471	0.373		
C_3H_5Cl	3-Chloropropene		0.408	0.314			
C_3H_5ClO	Epichlorohydrin	2.492	1.570	1.073	0.781	0.597	0.474
C_3H_5N	Propanenitrile			0.294	0.240	0.202	
C_3H_6O	Acetone	0.540	0.395	0.306	0.247		
C_3H_6O	Allyl alcohol			1.218	0.759	0.505	
C_3H_6O	Propanal			0.321	0.249		
$C_3H_6O_2$	Ethyl formate		0.506	0.380	0.300		
$C_3H_6O_2$	Methyl acetate		0.477	0.364	0.284		
$C_3H_6O_2$	Propanoic acid		1.499	1.030	0.749	0.569	0.449
C_3H_7Br	1-Bromopropane		0.645	0.489	0.387		
C_3H_7Br	2-Bromopropane		0.612	0.458	0.359		
C_3H_7Cl	1-Chloropropane		0.436	0.334			
C_3H_7Cl	2-Chloropropane		0.401	0.303			
C_3H_7I	1-Iodopropane		0.970	0.703	0.541	0.436	0.363
C_3H_7I	2-Iodopropane		0.883	0.653	0.506	0.407	
C_3H_7NO	*N*,*N*-Dimethylformamide		1.176	0.794	0.624		
$C_3H_7NO_2$	1-Nitropropane	1.851	1.160	0.798	0.589	0.460	0.374
C_3H_8O	1-Propanol	8.645	3.815	1.945	1.107	0.685	
C_3H_8O	2-Propanol		4.619	2.038	1.028	0.576	
$C_3H_8O_2$	1,2-Propylene glycol		248	40.4	11.3	4.770	2.750
$C_3H_8O_3$	Glycerol			934	152	39.8	14.8
C_3H_8S	1-Propanethiol		0.503	0.385			
C_3H_8S	2-Propanethiol		0.477	0.357	0.280		
C_3H_9N	Propylamine			0.376			
C_3H_9N	Isopropylamine		0.454	0.325			
C_4H_4O	Furan	0.661	0.475	0.361			
C_4H_5N	Pyrrole		2.085	1.225	0.828	0.612	
$C_4H_6O_3$	Acetic anhydride		1.241	0.843	0.614	0.472	0.377
C_4H_7N	Butanenitrile			0.553	0.418	0.330	0.268
C_4H_8O	2-Butanone	0.720	0.533	0.405	0.315	0.249	
C_4H_8O	Tetrahydrofuran	0.849	0.605	0.456	0.359		
$C_4H_8O_2$	1,4-Dioxane			1.177	0.787	0.569	
$C_4H_8O_2$	Ethyl acetate		0.578	0.423	0.325	0.259	
$C_4H_8O_2$	Methyl propionate		0.581	0.431	0.333	0.266	
$C_4H_8O_2$	Propyl formate		0.669	0.485	0.370	0.293	
$C_4H_8O_2$	Butanoic acid		2.215	1.426	0.982	0.714	0.542

VISCOSITY OF LIQUIDS (continued)

Molecular formula	Name	Viscosity in mPa s –25°C	0°C	25°C	50°C	75°C	100°C
$C_4H_8O_2$	2-Methylpropanoic acid		1.857	1.226	0.863	0.639	0.492
$C_4H_8O_2S$	Sulfolane				6.280	3.818	2.559
C_4H_8S	Tetrahydrothiophene			0.973	0.912		
C_4H_9Br	1-Bromobutane		0.815	0.606	0.471	0.379	
C_4H_9Cl	1-Chlorobutane		0.556	0.422	0.329	0.261	
C_4H_9N	Pyrrolidine	1.914	1.071	0.704	0.512		
C_4H_9NO	*N*,*N*-Dimethylacetamide			1.956	1.279	0.896	0.661
C_4H_9NO	Morpholine			2.021	1.247	0.850	0.627
$C_4H_{10}O$	1-Butanol	12.19	5.185	2.544	1.394	0.833	0.533
$C_4H_{10}O$	2-Butanol			3.096	1.332	0.698	0.419
$C_4H_{10}O$	2-Methyl-2-propanol			4.312	1.421	0.678	
$C_4H_{10}O$	Diethyl ether		0.283	0.224			
$C_4H_{10}O_3$	Diethylene glycol			30.200	11.130	4.917	2.505
$C_4H_{10}S$	Diethyl sulfide		0.558	0.422	0.331	0.267	
$C_4H_{11}N$	Butylamine		0.830	0.574	0.409	0.298	
$C_4H_{11}N$	Isobutylamine		0.770	0.571	0.367		
$C_4H_{11}N$	Diethylamine			0.319	0.239		
$C_4H_{11}NO_2$	Diethanolamine				109.5	28.7	9.100
$C_5H_4O_2$	Furfural		2.501	1.587	1.143	0.906	0.772
C_5H_5N	Pyridine		1.361	0.879	0.637	0.497	0.409
C_5H_{10}	1-Pentene	0.313	0.241	0.195			
C_5H_{10}	2-Methyl-2-butene		0.255	0.203			
C_5H_{10}	Cyclopentane		0.555	0.413	0.321		
$C_5H_{10}O$	Mesityl oxide	1.291	0.838	0.602	0.465	0.381	0.326
$C_5H_{10}O$	2-Pentanone		0.641	0.470	0.362	0.289	0.238
$C_5H_{10}O$	3-Pentanone		0.592	0.444	0.345	0.276	0.227
$C_5H_{10}O_2$	Butyl formate		0.937	0.644	0.472	0.362	0.289
$C_5H_{10}O_2$	Propyl acetate		0.768	0.544	0.406	0.316	0.255
$C_5H_{10}O_2$	Ethyl propanoate		0.691	0.501	0.380	0.299	0.242
$C_5H_{10}O_2$	Methyl butanoate		0.759	0.541	0.406	0.318	0.257
$C_5H_{10}O_2$	Methyl isobutanoate		0.672	0.488	0.373	0.296	
$C_5H_{11}N$	Piperidine			1.573	0.958	0.649	0.474
C_5H_{12}	Pentane	0.351	0.274	0.224			
C_5H_{12}	Isopentane	0.376	0.277	0.214			
$C_5H_{12}O$	1-Pentanol	25.4	8.512	3.619	1.820	1.035	0.646
$C_5H_{12}O$	2-Pentanol			3.470	1.447	0.761	0.465
$C_5H_{12}O$	3-Pentanol			4.149	1.473	0.727	0.436
$C_5H_{12}O$	2-Methyl-1-butanol			4.453	1.963	1.031	0.612
$C_5H_{12}O$	3-Methyl-1-butanol		8.627	3.692	1.842	1.031	0.631
$C_5H_{13}N$	Pentylamine		1.030	0.702	0.493	0.356	
C_6F_6	Hexafluorobenzene			2.789	1.730	1.151	
$C_6H_4Cl_2$	*o*-Dichlorobenzene		1.958	1.324	0.962	0.739	0.593
$C_6H_4Cl_2$	*m*-Dichlorobenzene		1.492	1.044	0.787	0.628	0.525
C_6H_5Br	Bromobenzene		1.560	1.074	0.798	0.627	0.512
C_6H_5Cl	Chlorobenzene	1.703	1.058	0.753	0.575	0.456	0.369
C_6H_5ClO	*o*-Chlorophenol			3.589	1.835	1.131	0.786
C_6H_5ClO	*m*-Chlorophenol				4.041		
C_6H_5F	Fluorobenzene		0.749	0.550	0.423	0.338	
C_6H_5I	Iodobenzene		2.354	1.554	1.117	0.854	0.683
$C_6H_5NO_2$	Nitrobenzene		3.036	1.863	1.262	0.918	0.704
C_6H_6	Benzene			0.604	0.436	0.335	
C_6H_6ClN	*o*-Chloroaniline			3.316	1.913	1.248	0.887
C_6H_6O	Phenol				3.437	1.784	1.099
C_6H_7N	Aniline			3.847	2.029	1.247	0.850
$C_6H_8N_2$	Phenylhydrazine			13.0	4.553	1.850	0.848
C_6H_{10}	Cyclohexene		0.882	0.625	0.467	0.364	
$C_6H_{10}O$	Cyclohexanone			2.017	1.321	0.919	0.671

VISCOSITY OF LIQUIDS (continued)

Molecular formula	Name	Viscosity in mPa s					
		–25°C	0°C	25°C	50°C	75°C	100°C
$C_6H_{11}N$	Hexanenitrile			0.912	0.650	0.488	0.382
C_6H_{12}	Cyclohexane			0.894	0.615	0.447	
C_6H_{12}	Methylcyclopentane	0.927	0.653	0.479	0.364		
C_6H_{12}	1-Hexene	0.441	0.326	0.252	0.202		
$C_6H_{12}O$	Cyclohexanol			57.5	12.3	4.274	1.982
$C_6H_{12}O$	2-Hexanone	1.300	0.840	0.583	0.429	0.329	0.262
$C_6H_{12}O$	4-Methyl-2-pentanone			0.545	0.406		
$C_6H_{12}O_2$	Butyl acetate		1.002	0.685	0.500	0.383	0.305
$C_6H_{12}O_2$	Isobutyl acetate			0.676	0.493	0.370	0.286
$C_6H_{12}O_2$	Ethyl butanoate			0.639	0.453		
$C_6H_{12}O_2$	Diacetone alcohol	28.7	6.621	2.798	1.829	1.648	
$C_6H_{12}O_3$	Paraldehyde			1.079	0.692	0.485	0.362
$C_6H_{13}N$	Cyclohexylamine			1.944	1.169	0.782	0.565
C_6H_{14}	Hexane		0.405	0.300	0.240		
C_6H_{14}	2-Methylpentane		0.372	0.286	0.226		
C_6H_{14}	3-Methylpentane		0.395	0.306			
$C_6H_{14}O$	Dipropyl ether		0.542	0.396	0.304	0.242	
$C_6H_{14}O$	1-Hexanol			4.578	2.271	1.270	0.781
$C_6H_{15}N$	Triethylamine		0.455	0.347	0.273	0.221	
$C_6H_{15}N$	Dipropylamine		0.751	0.517	0.377	0.288	0.228
$C_6H_{15}N$	Diisopropylamine			0.393	0.300	0.237	
$C_6H_{15}NO_3$	Triethanolamine			609	114	31.5	11.7
C_7H_5N	Benzonitrile			1.267	0.883	0.662	0.524
C_7H_7Cl	*o*-Chlorotoluene		1.390	0.964	0.710	0.547	0.437
C_7H_7Cl	*m*-Chlorotoluene		1.165	0.823	0.616	0.482	0.391
C_7H_7Cl	*p*-Chlorotoluene			0.837	0.621	0.483	0.390
C_7H_8	Toluene	1.165	0.778	0.560	0.424	0.333	0.270
C_7H_8O	*o*-Cresol				3.035	1.562	0.961
C_7H_8O	*m*-Cresol			12.9	4.417	2.093	1.207
C_7H_8O	Benzyl alcohol			5.474	2.760	1.618	1.055
C_7H_8O	Anisole			1.056	0.747	0.554	0.427
C_7H_9N	*N*-Methylaniline		4.120	2.042	1.222	0.825	0.606
C_7H_9N	*o*-Methyl aniline		10.3	3.823	1.936	1.198	0.839
C_7H_9N	*m*-Methyl aniline		8.180	3.306	1.679	1.014	0.699
C_7H_9N	Benzylamine			1.624	1.080	0.769	0.577
C_7H_{14}	Methylcyclohexane		0.991	0.679	0.501	0.390	0.316
C_7H_{14}	1-Heptene		0.441	0.340	0.273	0.226	
$C_7H_{14}O$	2-Heptanone			0.714	0.407	0.297	
$C_7H_{14}O_2$	Heptanoic acid			3.840	2.282	1.488	1.041
C_7H_{16}	Heptane	0.757	0.523	0.387	0.301	0.243	
C_7H_{16}	3-Methylhexane			0.350			
$C_7H_{16}O$	1-Heptanol			5.810	2.603	1.389	0.849
$C_7H_{16}O$	2-Heptanol			3.955	1.799	0.987	0.615
$C_7H_{16}O$	3-Heptanol				1.957	0.976	0.584
$C_7H_{16}O$	4-Heptanol			4.207	1.695	0.882	0.539
$C_7H_{17}N$	Heptylamine			1.314	0.865	0.600	0.434
C_8H_8	Styrene		1.050	0.695	0.507	0.390	0.310
C_8H_8O	Acetophenone			1.681			0.634
$C_8H_8O_2$	Methyl benzoate			1.857			
$C_8H_8O_3$	Methyl salicylate					1.102	0.815
C_8H_{10}	Ethylbenzene		0.872	0.631	0.482	0.380	0.304
C_8H_{10}	*o*-Xylene		1.084	0.760	0.561	0.432	0.345
C_8H_{10}	*m*-Xylene		0.795	0.581	0.445	0.353	0.289
C_8H_{10}	*p*-Xylene			0.603	0.457	0.359	0.290
$C_8H_{10}O$	Phenetole			1.197	0.817	0.594	0.453
$C_8H_{11}N$	*N*,*N*-Dimethylaniline		1.996	1.300	0.911	0.675	0.523
$C_8H_{11}N$	*N*-Ethylaniline		3.981	2.047	1.231	0.825	0.596

VISCOSITY OF LIQUIDS (continued)

Molecular formula	Name	Viscosity in mPa s					
		–25°C	0°C	25°C	50°C	75°C	100°C
C_8H_{16}	Ethylcyclohexane		1.139	0.784	0.579		
$C_8H_{16}O_2$	Octanoic acid			5.020	2.656	1.654	1.147
C_8H_{18}	Octane		0.700	0.508	0.385	0.302	0.243
$C_8H_{18}O$	1-Octanol			7.288	3.232	1.681	0.991
$C_8H_{18}O$	4-Methyl-3-heptanol		1.904	1.085	0.702	0.497	0.375
$C_8H_{18}O$	5-Methyl-3-heptanol		2.052	1.178	0.762	0.536	0.401
$C_8H_{18}O$	2-Ethyl-1-hexanol		20.7	6.271	2.631	1.360	0.810
$C_8H_{18}O$	Dibutyl ether	1.417	0.918	0.637	0.466	0.356	0.281
$C_8H_{19}N$	Dibutylamine		1.509	0.918	0.619	0.449	0.345
$C_8H_{19}N$	Diisobutylamine		1.115	0.723	0.511	0.384	0.303
C_9H_7N	Quinoline			3.337	1.892	1.201	0.833
C_9H_{10}	Indane		2.230	1.357	0.931	0.692	0.545
C_9H_{12}	Cumene		1.075	0.737	0.547		
$C_9H_{14}O$	Isophorone		4.201	2.329	1.415	0.923	0.638
$C_9H_{18}O$	5-Nonanone			1.199	0.834	0.619	0.484
$C_9H_{18}O_2$	Nonanoic acid			7.011	3.712	2.234	1.475
C_9H_{20}	Nonane		0.964	0.665	0.488	0.375	0.300
$C_9H_{20}O$	1-Nonanol			9.123	4.032		
$C_{10}H_{10}O_4$	Dimethyl phthalate		63.2	14.4	5.309	2.824	1.980
$C_{10}H_{14}$	Butylbenzene			0.950	0.683	0.515	
$C_{10}H_{18}$	*cis*-Decahydronaphthalene	12.8	5.645	3.042	1.875	1.271	0.924
$C_{10}H_{18}$	*trans*-Decahydronaphthalene	6.192	3.243	1.948	1.289	0.917	0.689
$C_{10}H_{20}O_2$	Decanoic acid				4.327	2.651	
$C_{10}H_{22}$	Decane	2.188	1.277	0.838	0.598	0.453	0.359
$C_{10}H_{22}O$	1-Decanol			10.9	4.590		
$C_{11}H_{24}$	Undecane		1.707	1.098	0.763	0.562	0.433
$C_{12}H_{10}O$	Diphenyl ether				2.130	1.407	1.023
$C_{12}H_{26}$	Dodecane		2.277	1.383	0.930	0.673	0.514
$C_{13}H_{12}$	Diphenylmethane					1.265	0.929
$C_{13}H_{28}$	Tridecane		2.909	1.724	1.129	0.796	0.594
$C_{14}H_{30}$	Tetradecane			2.128	1.376	0.953	0.697
$C_{16}H_{22}O_4$	Dibutyl phthalate	483	66.4	16.6	6.470	3.495	2.425
$C_{16}H_{34}$	Hexadecane			3.032	1.879	1.260	0.899
$C_{18}H_{38}$	Octadecane				2.487	1.609	1.132

THERMAL CONDUCTIVITY OF GASES

This table gives the thermal conductivity of several gases as a function of temperature. Unless otherwise noted, the values refer to a pressure of 100 kPa (1 bar) or to the saturation vapor pressure if that is less than 100 kPa. The notation $P = 0$ indicates the low pressure limiting value is given. In general, the $P = 0$ and $P = 100$ kPa values differ by less than 1%. Units are milliwatts per meter kelvin. Substances are listed in the modified Hill order.

		Thermal conductivity in mW/m K						
MF	**Name**	**100 K**	**200 K**	**300 K**	**400 K**	**500 K**	**600 K**	**Ref.**
	Air	9.4	18.4	26.2	33.3	39.7	45.7	1
Ar	Argon	6.2	12.4	17.9	22.6	26.8	30.6	2,8
BF_3	Boron trifluoride			19.0	24.6			11
ClH	Hydrogen chloride		9.2	14.5	19.5	24.0	28.1	11
F_6S	Sulfur hexafluoride (*P* = 0)			13.0	20.6	27.5	33.8	16
H_2	Hydrogen (*P* = 0)	68.6	131.7	186.9	230.4			4
H_2O	Water			18.7	27.1	35.7	47.1	6
	Deuterium oxide				27.0	36.5	47.6	7
H_2S	Hydrogen sulfide			14.6	20.5	26.4	32.4	11
H_3N	Ammonia			24.4	37.4	51.6	66.8	11
He	Helium (*P* = 0)	75.5	119.3	156.7	190.6	222.3	252.4	8
Kr	Krypton (*P* = 0)	3.3	6.4	9.5	12.3	14.8	17.1	8
NO	Nitric oxide		17.8	25.9	33.1	39.6	46.2	11
N_2	Nitrogen	9.8	18.7	26.0	32.3	38.3	44.0	12
N_2O	Nitrous oxide		9.8	17.4	26.0	34.1	41.8	11
Ne	Neon (*P* = 0)	22.3	37.6	49.8	60.3	69.9	78.7	8
O_2	Oxygen	9.3	18.4	26.3	33.7	41.0	48.1	10
O_2S	Sulfur dioxide			9.6	14.3	20.0	25.6	11
Xe	Xenon (*P* = 0)	2.0	3.6	5.5	7.3	8.9	10.4	8
CCl_2F_2	Dichlorodifluoromethane			9.9	15.0	20.1	25.2	13
CF_4	Tetrafluoromethane (*P* = 0)			16.0	24.1	32.2	39.9	16
CO	Carbon monoxide (*P* = 0)			25.0	32.3	39.2	45.7	14
CO_2	Carbon dioxide		9.6	16.8	25.1	33.5	41.6	9
$CHCl_3$	Trichloromethane			7.5	11.1	15.1		11
CH_4	Methane		22.5	34.1	49.1	66.5	84.1	5,15
CH_4O	Methanol				26.2	38.6	53.0	11
$C_2Cl_2F_4$	1,2-Dichlorotetrafluoro-ethane			10.25	15.7	21.1		13
$C_2Cl_3F_3$	1,1,2-Trichlorotrifluoro-ethane			9.0	13.6	18.3		13
C_2H_2	Acetylene			21.4	33.3	45.4	56.8	11
C_2H_4	Ethylene		11.1	20.5	34.6	49.9	68.6	3
C_2H_6	Ethane		11.0	21.3	35.4	52.2	70.5	5
C_2H_6O	Ethanol			14.4	25.8	38.4	53.2	11
C_3H_6O	Acetone			11.5	20.2	30.6	42.7	11
C_3H_8	Propane			18.0	30.6	45.5	61.9	5
C_4F_8	Perfluorocyclobutane			12.5	19.5			13
C_4H_{10}	Butane			16.4	28.4	43.0	59.1	5
C_4H_{10}	Isobutane			16.1	27.9	42.1	57.6	5
$C_4H_{10}O$	Diethyl ether			15.1	25.0	37.1		11
C_5H_{12}	Pentane			14.4	24.9	37.8	52.7	11
C_6H_{14}	Hexane				23.4	35.4	48.7	11

REFERENCES

1. Kadoya, K. Matsunaga, N., and Nagashima, A., Viscosity and thermal conductivity of dry air in the gaseous phase, *J. Phys. Chem. Ref. Data*, 14, 947, 1985.
2. Younglove, B. A. and Hanley, H. J. M., The viscosity and thermal conductivity coefficients of gaseous and liquid argon, *J. Phys. Chem. Ref. Data*, 15, 1323, 1986.
3. Holland, P. M., Eaton, B. E., and Hanley, H. J. M., A correlation of the viscosity and thermal conductivity data of gaseous and liquid ethylene, *J. Phys. Chem. Ref. Data*, 12, 917, 1983.

4. Assael, M. J., Mixafendi, S., and Wakeham, W. A., The viscosity and thermal conductivity of normal hydrogen in the limit of zero density, *J. Phys. Chem. Ref. Data*, 15, 1315, 1986.
5. Younglove, B. A. and Ely, J. F., Thermophysical properties of fluids. II. Methane, ethane, propane, isobutane, and normal butane, *J. Phys. Chem. Ref. Data*, 16, 577, 1987.
6. Sengers, J. V. and Watson, J. T. R., Improved international formulations for the viscosity and thermal conductivity of water substance, *J. Phys. Chem. Ref. Data*, 15, 1291, 1986.
7. Matsunaga, N. and Nagashima, A., Transport properties of liquid and gaseous D_2O over a wide range of temperature and pressure, *J. Phys. Chem. Ref. Data*, 12, 933, 1983.
8. Kestin, J. et al., Equilibrium and transport properties of the noble gases and their mixtures at low density, *J. Phys. Chem. Ref. Data*, 13, 229, 1984.
9. Vescovic, V. et al., The transport properties of carbon dioxide, *J. Phys. Chem. Ref. Data*, 19, 1990.
10. Younglove, B. A., Thermophysical properties of fluids. I. Argon, ethylene, parahydrogen, nitrogen, nitrogen trifluoride, and oxygen, *J. Phys. Chem. Ref. Data*, 11, Suppl. 1, 1982.
11. Ho, C. Y., Ed., *Properties of Inorganic and Organic Fluids*, *CINDAS Data Series on Materials Properties*, Volume V-1, Hemisphere Publishing Corp., New York, 1988.
12. Stephen, K., Krauss, R., and Laesecke, A., Viscosity and thermal conductivity of nitrogen for a wide range of fluid states, *J. Phys. Chem. Ref. Data*, 16, 993, 1987.
13. Krauss, R. and Stephan, K., Thermal conductivity of refrigerants in a wide range of temperature and pressure, *J. Phys. Chem. Ref. Data*, 18, 43, 1989.
14. Millat, J. and Wakeham, W. A., The thermal conductivity of nitrogen and carbon monoxide in the limit of zero density, *J. Phys. Chem. Ref. Data*, 18, 565, 1989.
15. Friend, D. G., Ely, J. F., and Ingham, H., Thermophysical properties of methane, *J. Phys. Chem. Ref. Data*, 18, 583, 1989.
16. Uribe, F. J., Mason, E. A., and Kestin, J., Thermal conductivity of nine polyatomic gases at low density, *J. Phys. Chem. Ref. Data*, 19, 1123, 1990.

THERMAL CONDUCTIVITY OF LIQUIDS

This table gives the thermal conductivity of some common liquids at temperatures between -25 and 100°C. All values are given in units of watts per meter kelvin (W/m K). Values refer to nominal atmospheric pressure (about 100 kPa); when an entry is given at a temperature above the normal boiling point of the substance, the pressure is understood to be the saturation vapor pressure at that temperature.

Substances are arranged by molecular formula in the modified Hill order, with compounds not containing carbon preceding those that do contain carbon.

The values for water, benzene, toluene, heptane, and dimethyl phthalate are particularly well determined and can be used for calibration purposes.

REFERENCES

1. Daubert, T. E., Danner, R. P., Sibul, H. M., and Stebbins, C. C., *Physical and Thermodynamic Properties of Pure Compounds: Data Compilation*, extant 1994 (core with 4 supplements), Taylor & Francis, Bristol, PA (also available as database).
2. Marsh, K. N., Ed., *Recommended Reference Materials for the Realization of Physicochemical Properties,* Blackwell Scientific Publications, Oxford, 1987.

Molecular formula	Name	Thermal conductivity in W/m K					
		–25°C	0°C	25°C	50°C	75°C	100°C
Cl_4Si	Silicon tetrachloride			0.099	0.096		
H_2O	Water		0.5610	0.6071	0.6435	0.6668	0.6791
Hg	Mercury	7.25	7.77	8.25	8.68	9.07	9.43
CCl_4	Tetrachloromethane		0.104	0.099	0.093	0.088	
CS_2	Carbon disulfide		0.154	0.149			
$CHCl_3$	Trichloromethane	0.127	0.122	0.117	0.112	0.107	0.102
CH_2Br_2	Dibromomethane	0.120	0.114	0.108	0.103	0.097	
CH_4O	Methanol	0.214	0.207	0.200	0.193		
C_2Cl_4	Tetrachloroethylene		0.117	0.110	0.104	0.097	0.091
C_2HCl_3	Trichloroethylene	0.133	0.124	0.116	0.108	0.100	
$C_2H_3Cl_3$	1,1,1-Trichloroethane		0.106	0.101	0.096		
C_2H_3N	Acetonitrile	0.208	0.198	0.188	0.178	0.168	
$C_2H_4O_2$	Acetic acid			0.158	0.153	0.149	0.144
C_2H_5Cl	Chloroethane	0.145	0.132	0.119	0.106	0.093	
C_2H_5NO	*N*-Methylformamide			0.203	0.201	0.199	0.196
C_2H_6O	Ethanol		0.176	0.169	0.162		
$C_2H_6O_2$	Ethylene glycol		0.256	0.256	0.256	0.256	0.256
C_2H_7NO	Ethanolamine			0.299	0.286	0.274	0.261
C_3H_5ClO	Epichlorohydrin	0.142	0.137	0.131	0.125	0.119	0.114
C_3H_6O	Acetone		0.169	0.161			
$C_3H_6O_2$	Methyl acetate	0.174	0.164	0.153	0.143	0.133	0.122
C_3H_7NO	*N,N*-Dimethylformamide			0.184	0.178	0.171	0.165
C_3H_8O	1-Propanol	0.162	0.158	0.154	0.149	0.145	0.141
C_3H_8O	2-Propanol	0.146	0.141	0.135	0.129	0.124	0.118
$C_3H_8O_2$	1,2-Propanediol		0.202	0.200	0.199	0.198	0.197
$C_3H_8O_3$	Glycerol			0.292	0.295	0.297	0.300
C_3H_9N	Trimethylamine	0.143	0.133				
C_4H_4O	Furan	0.142	0.134	0.126			
C_4H_4S	Thiophene			0.199	0.195	0.191	0.186
C_4H_6	2-Butyne	0.137	0.129	0.121			
C_4H_8O	2-Butanone	0.158	0.151	0.145	0.139	0.133	
C_4H_8O	Tetrahydrofuran	0.132	0.126	0.120	0.114		
$C_4H_8O_2$	1,4-Dioxane			0.159	0.147	0.135	0.123
$C_4H_8O_2$	Ethyl acetate	0.162	0.153	0.144	0.135	0.126	
$C_4H_{10}O$	1-Butanol		0.158	0.154	0.149		
$C_4H_{10}O$	Diethyl ether	0.150	0.140	0.130	0.120	0.110	0.100
C_5H_5N	Pyridine		0.169	0.165	0.161	0.158	
C_5H_8	Cyclopentene	0.143	0.136	0.129			
C_5H_{10}	1-Pentene	0.131	0.124	0.116			
C_5H_{10}	Cyclopentane	0.140	0.133	0.126			
C_5H_{12}	Pentane	0.132	0.122	0.113	0.103	0.095	0.087
$C_5H_{12}O$	1-Pentanol		0.157	0.153	0.149	0.145	
C_6H_5Cl	Chlorobenzene	0.136	0.131	0.127	0.122	0.117	0.112

Molecular formula	Name	Thermal conductivity in W/m K –25°C	0°C	25°C	50°C	75°C	100°C
C_6H_6	Benzene			0.1411	0.1329	0.1247	
C_6H_6O	Phenol				0.156	0.153	0.151
C_6H_{10}	Cyclohexene	0.142	0.136	0.130	0.124	0.118	
$C_6H_{10}O$	Mesityl oxide	0.170	0.163	0.156	0.149	0.142	0.134
C_6H_{12}	Cyclohexane			0.123	0.117	0.111	
C_6H_{12}	1-Hexene	0.137	0.129	0.121	0.113		
$C_6H_{12}O$	Cyclohexanol			0.134	0.131		
$C_6H_{12}O$	2-Hexanone	0.151	0.145	0.139	0.133	0.127	0.121
C_6H_{14}	Hexane	0.137	0.128	0.120	0.111	0.102	0.093
$C_6H_{14}O$	1-Hexanol	0.159	0.154	0.150	0.145	0.141	0.137
C_7H_6O	Benzaldehyde			0.151	0.141	0.131	0.121
C_7H_8	Toluene	0.1461	0.1386	0.1311	0.1236	0.1161	
C_7H_8O	Anisole	0.170	0.163	0.156	0.150	0.143	0.136
C_7H_{16}	Heptane	0.1378	0.1303	0.1228	0.1152	0.1077	
$C_7H_{16}O$	1-Heptanol		0.166	0.159	0.153	0.147	0.141
C_8H_8	Styrene	0.148	0.142	0.137	0.131	0.126	0.120
C_8H_{10}	Ethylbenzene			0.130	0.124	0.118	0.112
C_8H_{10}	*o*-Xylene			0.131	0.126	0.120	0.114
C_8H_{10}	*m*-Xylene			0.130	0.124	0.118	0.113
C_8H_{10}	*p*-Xylene			0.130	0.124	0.118	0.112
C_8H_{18}	Octane	0.143	0.135	0.128	0.120	0.113	0.106
$C_8H_{18}O$	1-Octanol		0.168	0.161	0.154	0.147	0.141
C_9H_{12}	Cumene			0.128	0.120	0.112	0.107
C_9H_{12}	Mesitylene	0.147	0.141	0.136	0.130	0.124	0.118
C_9H_{20}	Nonane	0.144	0.138	0.131	0.124	0.118	0.111
$C_9H_{20}O$	1-Nonanol		0.166	0.161	0.155	0.149	0.143
$C_{10}H_{10}O_4$	Dimethyl phthalate		0.1501	0.1473	0.1443	0.1409	0.1373
$C_{10}H_{14}$	*p*-Cymene	0.132	0.127	0.122	0.117	0.112	0.107
$C_{10}H_{22}$	Decane	0.144	0.138	0.132	0.126	0.119	0.113
$C_{10}H_{22}O$	1-Decanol			0.162	0.156	0.150	0.145
$C_{11}H_{24}$	Undecane			0.140	0.135	0.129	0.123
$C_{12}H_{10}O$	Diphenyl ether				0.139	0.135	0.131
$C_{12}H_{26}$	Dodecane		0.157	0.152	0.146	0.140	0.135
$C_{12}H_{26}O$	1-Dodecanol			0.146	0.142	0.139	0.135
$C_{13}H_{28}$	Tridecane			0.137	0.132	0.127	0.122
$C_{14}H_{30}$	Tetradecane			0.136	0.131	0.126	0.121
$C_{14}H_{30}O$	1-Tetradecanol				0.167	0.162	0.157
$C_{16}H_{22}O_4$	Dibutyl phthalate	0.144	0.140	0.136	0.133	0.129	0.125
$C_{16}H_{34}$	Hexadecane			0.140	0.135	0.130	0.125
$C_{18}H_{38}$	Octadecane				0.146	0.142	0.137

DIFFUSION IN GASES

This table gives binary diffusion coefficients D_{12} for a number of common gases as a function of temperature. Values refer to atmospheric pressure. The diffusion coefficient is inversely proportional to pressure as long as the gas is in a regime where binary collisions dominate. See Reference 1 for a discussion of the dependence of D_{12} on temperature and composition.

The first part of the table gives data for several gases in the presence of a large excess of air. The remainder applies to equimolar mixtures of gases. Each gas pair is ordered alphabetically according to the most common way of writing the formula. The listing of pairs then follows alphabetical order by the first constituent.

REFERENCES

1. Marrero, T. R., and Mason, E. A., *J. Phys. Chem. Ref. Data*, 1, 1, 1972.
2. Kestin, J., et al., *J. Phys. Chem. Ref. Data*, 13, 229, 1984.

D_{12}/cm^2 s^{-1} for p = 101.325 kPa and the Specified T/K

System	200	273.15	293.15	373.15	473.15	573.15	673.15
Large Excess of Air							
Ar-air		0.167	0.148	0.289	0.437	0.612	0.810
CH_4-air			0.106	0.321	0.485	0.678	0.899
CO-air			0.208	0.315	0.475	0.662	0.875
CO_2-air			0.160	0.252	0.390	0.549	0.728
H_2-air		0.668	0.627	1.153	1.747	2.444	3.238
H_2O-air			0.242	0.399	0.638	0.873	1.135
He-air		0.617	0.580	1.057	1.594	2.221	2.933
SF_6-air				0.150	0.233	0.329	0.438
Equimolar Mixture							
Ar-CH_4				0.306	0.467	0.657	0.876
Ar-CO		0.168	0.187	0.290	0.439	0.615	0.815
Ar-CO_2		0.129	0.078	0.235	0.365	0.517	0.689
Ar-H_2		0.698	0.794	1.228	1.876	2.634	3.496
Ar-He	0.381	0.645	0.726	1.088	1.617	2.226	2.911
Ar-Kr	0.064	0.117	0.134	0.210	0.323	0.456	0.605
Ar-N_2		0.168	0.190	0.290	0.439	0.615	0.815
Ar-Ne	0.160	0.277	0.313	0.475	0.710	0.979	1.283
Ar-O_2		0.166	0.189	0.285	0.430	0.600	0.793
Ar-SF_6				0.128	0.202	0.290	0.389
Ar-Xe	0.052	0.095	0.108	0.171	0.264	0.374	0.498
CH_4-H_2			0.782	1.084	1.648	2.311	3.070
CH_4-He			0.723	0.992	1.502	2.101	2.784
CH_4-N_2			0.220	0.317	0.480	0.671	0.890
CH_4-O_2			0.210	0.341	0.523	0.736	0.978
CH_4-SF_6				0.167	0.257	0.363	0.482
CO-CO_2			0.162	0.250	0.384		
CO-H_2	0.408	0.686	0.772	1.162	1.743	2.423	3.196
CO-He	0.365	0.619	0.698	1.052	1.577	2.188	2.882
CO-Kr		0.131	0.581	0.227	0.346	0.485	0.645
CO-N_2	0.133	0.208	0.231	0.336	0.491	0.673	0.878
CO-O_2			0.202	0.307	0.462	0.643	0.849
CO-SF_6				0.144	0.226	0.323	0.432
CO_2-C_3H_8			0.084	0.133	0.209		
CO_2-H_2	0.315	0.552	0.412	0.964	1.470	2.066	2.745
CO_2-H_2O			0.162	0.292	0.496	0.741	1.021
CO_2-He	0.300	0.513	0.400	0.878	1.321		
CO_2-N_2			0.160	0.253	0.392	0.553	0.733
CO_2-N_2O	0.055	0.099	0.113	0.177	0.276		
CO_2-Ne	0.131	0.227	0.199	0.395	0.603	0.847	

DIFFUSION IN GASES (continued)

System	200	273.15	293.15	373.15	473.15	573.15	673.15
CO_2-O_2			0.159	0.248	0.380	0.535	0.710
CO_2-SF_6				0.099	0.155		
D_2-H_2	0.631	1.079	1.219	1.846	2.778	3.866	5.103
H_2-He	0.775	1.320	1.490	2.255	3.394	4.726	6.242
H_2-Kr	0.340	0.601	0.682	1.053	1.607	2.258	2.999
H_2-N_2	0.408	0.686	0.772	1.162	1.743	2.423	3.196
H_2-Ne	0.572	0.982	0.317	1.684	2.541	3.541	4.677
H_2-O_2		0.692	0.756	1.188	1.792	2.497	3.299
H_2-SF_6			0.208	0.649	0.998	1.400	1.851
H_2-Xe		0.513	0.122	0.890	1.349	1.885	2.493
H_2O-N_2			0.242	0.399			
H_2O-O_2			0.244	0.403	0.645	0.882	1.147
He-Kr	0.330	0.559	0.629	0.942	1.404	1.942	2.550
He-N_2	0.365	0.619	0.698	1.052	1.577	2.188	2.882
He-Ne	0.563	0.948	1.066	1.592	2.362	3.254	4.262
He-O_2		0.641	0.697	1.092	1.640	2.276	2.996
He-SF_6			1.109	0.592	0.871	1.190	1.545
He-Xe	0.282	0.478	0.538	0.807	1.201	1.655	2.168
Kr-N_2		0.131	0.149	0.227	0.346	0.485	0.645
Kr-Ne	0.131	0.228	0.258	0.392	0.587	0.812	1.063
Kr-Xe	0.035	0.064	0.073	0.116	0.181	0.257	0.344
N_2-Ne			0.258	0.483	0.731	1.021	1.351
N_2-O_2			0.202	0.307	0.462	0.643	0.849
N_2-SF_6				0.148	0.231	0.328	0.436
N_2-Xe		0.107	0.123	0.188	0.287	0.404	0.539
Ne-Xe	0.111	0.193	0.219	0.332	0.498	0.688	0.901
O_2-SF_6			0.097	0.154	0.238	0.334	0.441

DIFFUSION COEFFICIENTS IN LIQUIDS AT INFINITE DILUTION

This table lists diffusion coefficients D_{AB} at infinite dilution for some binary liquid mixtures. Although values are given to two decimal places, measurements in the literature are often in poor agreement. Therefore most values in the table cannot be relied upon to better than 10%.

Solvents are listed in alphabetical order, as are the solutes within each solvent group.

REFERENCE

Landolt-Börnstein, *Numerical Data and Functional Relationships in Science and Technology*, Sixth Edition, Vol. II/5a, 1969.

Solute	Solvent	t/°C	D_{AB} 10^{-5} cm^2 s^{-1}
Acetic acid	Acetone	25	3.31
Benzoic acid	Acetone	25	2.62
Formic acid	Acetone	25	3.77
Nitrobenzene	Acetone	20	2.94
Tetrachloromethane	Acetone	25	3.29
Trichloromethane	Acetone	25	3.64
Water	Acetone	25	4.56
Acetic acid	Benzene	25	2.09
Aniline	Benzene	25	1.96
Benzoic acid	Benzene	25	1.38
Bromobenzene	Benzene	8	1.45
2-Butanone	Benzene	30	2.09
Chloroethylene	Benzene	8	1.77
Cyclohexane	Benzene	25	2.25
Ethanol	Benzene	25	3.02
Formic acid	Benzene	25	2.28
Heptane	Benzene	25	1.78
Methanol	Benzene	25	3.80
Toluene	Benzene	25	1.85
1,2,4-Trichlorobenzene	Benzene	8	1.34
Trichloromethane	Benzene	25	2.26
Adipic acid	1-Butanol	30	0.40
Benzene	1-Butanol	25	1.00
Biphenyl	1-Butanol	25	0.63
Butyric acid	1-Butanol	30	0.51
p-Dichlorobenzene	1-Butanol	25	0.82
Methanol	1-Butanol	30	0.59
Oleic acid	1-Butanol	30	0.25
Propane	1-Butanol	25	1.57
Water	1-Butanol	25	0.56
Benzene	Cyclohexane	25	1.41
Tetrachloromethane	Cyclohexane	25	1.49
Toluene	Cyclohexane	25	1.57
Allyl alcohol	Ethanol	20	0.98
Benzene	Ethanol	25	1.81
Iodine	Ethanol	25	1.32
Iodobenzene	Ethanol	20	1.00
3-Methyl-1-butanol	Ethanol	20	0.81
Pyridine	Ethanol	20	1.10
Tetrachloromethane	Ethanol	25	1.50
Water	Ethanol	25	1.24
Acetic acid	Ethyl acetate	20	2.18
Acetone	Ethyl acetate	20	3.18
2-Butanone	Ethyl acetate	30	2.93
Ethyl benzoate	Ethyl acetate	20	1.85
Nitrobenzene	Ethyl acetate	20	2.25
Water	Ethyl acetate	25	3.20
Benzene	Heptane	25	3.91
Toluene	Heptane	25	3.72
Bromobenzene	Hexane	8	2.60
2-Butanone	Hexane	30	3.74
Dodecane	Hexane	25	2.73
Iodine	Hexane	25	4.45
Methane	Hexane	25	0.09
Propane	Hexane	25	4.87
Tetrachloromethane	Hexane	25	3.70
Toluene	Hexane	25	4.21
Acetone	Tetrachloromethane	25	1.75
Benzene	Tetrachloromethane	25	1.42
Cyclohexane	Tetrachloromethane	25	1.30
Ethanol	Tetrachloromethane	25	1.90
Iodine	Tetrachloromethane	30	1.63
Trichloromethane	Tetrachloromethane	25	1.66
Acetic acid	Toluene	25	2.26
Benzene	Toluene	25	2.54
Benzoic acid	Toluene	25	1.49
Cyclohexane	Toluene	25	2.42
Formic acid	Toluene	25	2.65
Water	Toluene	25	6.19
Acetone	Trichloromethane	25	2.55
Benzene	Trichloromethane	25	2.89
2-Butanone	Trichloromethane	25	2.13
Butyl acetate	Trichloromethane	25	1.71
Diethyl ether	Trichloromethane	25	2.15
Ethanol	Trichloromethane	15	2.20
Ethyl acetate	Trichloromethane	25	2.02
Acetic acid	Water	25	1.29
Acetone	Water	25	1.28
Acetonitrile	Water	15	1.26
Alanine	Water	25	0.91
Allyl alcohol	Water	15	0.90
Aniline	Water	20	0.92
Arabinose	Water	20	0.69
Benzene	Water	20	1.02
1-Butanol	Water	25	0.56
Caprolactam	Water	25	0.87
Chloroethylene	Water	25	1.34
Cyclohexane	Water	20	0.84
Diethylamine	Water	20	0.97
Ethanol	Water	25	1.24
Ethanolamine	Water	25	1.08
Ethyl acetate	Water	20	1.00
Ethylbenzene	Water	20	0.81
Ethylene glycol	Water	25	1.16
Glucose	Water	25	0.67
Glycerol	Water	25	1.06
Glycine	Water	25	1.05
Lactose	Water	15	0.38
Maltose	Water	15	0.38
Mannitol	Water	15	0.50
Methane	Water	25	1.49
Methanol	Water	15	1.28
3-Methyl-1-butanol	Water	10	0.69
Methylcyclopentane	Water	20	0.85
Phenol	Water	20	0.89
1-Propanol	Water	15	0.87
Propene	Water	25	1.44
Pyridine	Water	25	0.58
Raffinose	Water	15	0.33
Sucrose	Water	25	0.52
Toluene	Water	20	0.85
Urea	Water	25	1.38
Urethane	Water	15	0.80

VAPOR PRESSURE OF SATURATED SALT SOLUTIONS

This table gives the vapor pressure of water above saturated solutions of some common salts at ambient temperatures. Data on pure water are given on the last line for comparison.

The references provide additional information on water activity, osmotic coefficient, and enthalpy of vaporization.

REFERENCES

1. Apelblat, A., *J. Chem. Thermodynamics*, 24, 619, 1992.
2. Apelblat, A., *J. Chem. Thermodynamics*, 25, 63, 1993.
3. Apelblat, A., *J. Chem. Thermodynamics*, 25, 1513, 1993.
4. Apelblat, A. and Korin, E., *J. Chem. Thermodynamics*, 30, 59, 1998.

Vapor Pressure in kPa

Salt	10°C	15°C	20°C	25°C	30°C	35°C	40°C	Ref.
$BaCl_2$	0.971	1.443	2.073	2.887	3.903	5.133	6.576	1
$Ca(NO_3)_2$	0.701	1.015	1.381	1.772	2.154	2.487		1
$CuSO_4$	1.113	1.574	2.189	2.996	4.037	5.363		3
$FeSO_4$	0.978	1.516	2.208	3.035	3.950	4.884		3
KBr	0.953	1.338	1.853	2.533	3.419	4.563		3
KIO_3	1.100	1.564	2.177	2.970	3.979	5.236	6.778	4
K_2CO_3	0.541	0.802	1.134	1.536	1.997	2.499	3.016	1
LiCl	0.128	0.193	0.279	0.384				2
$Mg(NO_3)_2$	0.726	0.999	1.339	1.749	2.231	2.782	3.397	1
$MnCl_2$	0.697	1.064	1.515	2.020	2.535	3.002		3
NH_4Cl	0.971	1.328	1.836	2.481				2
NH_4NO_3	0.853	1.152	1.524	1.972				2
$(NH_4)_2SO_4$	0.901	1.319	1.871	2.573	3.439	4.474		3
NaBr	0.722	1.004	1.376	1.858	2.475	3.255	4.229	4
NaCl	0.921	1.285	1.768	2.401	3.218	4.262	5.581	4
$NaNO_2$	0.703	0.994	1.381	1.888	2.540	3.368	4.403	4
$NaNO_3$	0.884	1.244	1.719	2.335	3.121	4.109	5.333	4
RbCl	0.862	1.215	1.684	2.298	3.088	4.089	5.343	4
$ZnSO_4$	0.945	1.401	1.986	2.698	3.523	4.431	5.382	1
Water	1.228	1.706	2.339	3.169	4.246	5.627	7.381	

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DIFFUSION OF GASES IN WATER

This table gives values of the diffusion coefficient, *D*, for diffusion of several common gases in water at various temperatures. For simple one-dimensional transport, the diffusion coefficient describes the time-rate of change of concentration, d*c*/d*t*, through the equation

$$dc/dt = D\, d^2c/dx^2$$

where *x* is, for example, the perpendicular distance from a gas-liquid interface. The values below have been selected from the references indicated; in some cases data have been refitted to permit interpolation in temperature.

Gas-liquid diffusion coefficients are difficult to measure, and large differences are found between values obtained by different authors and through different experimental methods. See References 1 and 2 for a discussion of measurement techniques.

REFERENCES

1. Jähne, B., Heinz, G., and Dietrich, W., *J. Geophys. Res*., 92, 10767, 1987.
2. Himmelblau, D. M., *Chem. Rev*. 64, 527, 1964.
3. Boerboom, A. J. H., and Kleyn, G., *J. Chem. Phys*., 50, 1086, 1969.
4. O'Brien, R. N., and Hyslop, W. F., *Can. J. Chem.*, 55, 1415, 1977.
5. Maharajh, D. M., and Walkley, J., *Can. J. Chem.*, 51, 944, 1973.
6. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, Sixth Edition*, II/5a, *Transport Phenomena I (Viscosity and Diffusion)*, Springer-Verlag, Heidelberg, 1969.

	$D/10^{-5}$ cm^2 s^{-1}						
	10˚C	**15˚C**	**20˚C**	**25˚C**	**30˚C**	**35˚C**	**Ref.**
Ar				2.5			3,4
$CHCl_2F$				1.80			5
CH_3Br				1.35			5
CH_3Cl				1.40			5
CH_4	1.24	1.43	1.62	1.84	2.08	2.35	1
CO_2	1.26	1.45	1.67	1.91	2.17	2.47	1
C_2H_2	1.43	1.59	1.78	1.99	2.23		2
Cl_2		1.13	1.5	1.89			2,6
HBr				3.15			6
HCl				3.07			6
H_2	3.62	4.08	4.58	5.11	5.69	6.31	1
H_2S				1.36			2,6
He	5.67	6.18	6.71	7.28	7.87	8.48	1,3
Kr	1.20	1.39	1.60	1.84	2.11	2.40	1,3
NH_3		1.3	1.5				2
NO_2			1.23	1.4	1.59		2,6
N_2				2.0			2
N_2O		1.62	2.11	2.57			2,6
Ne	2.93	3.27	3.64	4.03	4.45	4.89	1,3
O_2		1.67	2.01	2.42			2,6
Rn	0.81	0.96	1.13	1.33	1.55	1.80	1
SO_2			1.62	1.83	2.07	2.32	2
Xe	0.93	1.08	1.27	1.47	1.70	1.95	1,3

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PROPERTIES OF ICE AND SUPERCOOLED WATER

The common form of ice at ambient temperature and pressure is hexagonal ice, designated as ice I_h (see phase diagram on p. 12-174). The data given here refer to that form. Data have been taken from the references indicated; values have been interpolated and smoothed in some cases. All properties are sensitive to the method of preparation of the sample, since air or other gases are sometimes occluded. For this reason there is often disagreement among values found in the literature.

Density values (except at 0°C) and the thermal expansion coefficient were calculated from the temperature variation in the crystal lattice constants of ice (see Ref. 1). The thermal expansion coefficient appears to become negative around -200°C, but there is considerable scatter in the data.

Density of ice I_h and supercooled water in g cm^{-3}

t/°C	ρ (ice)	ρ (supercooled water)
0	0.9167	0.9998
-10	0.9187	0.9982
-20	0.9203	0.9935
-30	0.9216	0.9839
-40	0.9228	
-50	0.9240	
-60	0.9252	
-80	0.9274	
-100	0.9292	
-120	0.9305	
-140	0.9314	
-160	0.9331	
-180	0.9340	
Ref.	1	8

Phase transition properties:

$\Delta_{fus}H$(0°C) = 333.6 J/g (Ref. 2)

$\Delta_{sub}H$(0°C) = 2838 J/g (Ref. 2)

Other properties of ice I_h :

α_V: cubic thermal expansion coefficient, $\alpha_V = -(1/V)(\partial V/\partial t)_p$

κ : adiabatic compressibility, $\kappa = -(1/V)(\partial V/\partial p)_S$

ε : relative permittivity (dielectric constant)

k : thermal conductivity

c_p: specific heat capacity at constant pressure

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t/°C	α_V/10^{-6} °C^{-1}	κ/10^{-5} MPa^{-1}	ε	k/W cm^{-1} °C^{-1}	c_p/J g^{-1} °C^{-1}
0	159	13.0	91.6	0.0214	2.11
–10	155	12.8	94.4	0.023	2.03
–20	149	12.7	97.5	0.024	1.96
–30	143	12.5	99.7	0.025	1.88
–40	137	12.4	101.9	0.026	1.80
–50	130	12.2	106.9	0.028	1.72
–60	122	12.1	119.5	0.030	1.65
–80	105	11.9		0.033	1.50
–100	85	11.6		0.037	1.36
–120	77	11.4		0.042	1.23
–140	60	11.3		0.049	1.10
–160	45	11.2		0.057	0.97
–180	30	11.1		0.070	0.83
–200		11.0		0.087	0.67
–220		10.9		0.118	0.50
–240		10.9		0.20	0.29
–250		10.9		0.32	0.17
Ref.	1,2,3,5	1,5	6	7	1

REFERENCES

1. Eisenberg, D., and Kauzmann, W., *The Structure and Properties of Water*, Oxford University Press, Oxford, 1969.
2. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series*, V/1b, Springer-Verlag, Heidelberg, 1982.
3. LaPlaca, S., and Post, B., *Acta Cryst*., 13, 503, 1960. [Thermal expansion of lattice]
4. Brill, R., and Tippe, A., *Acta Cryst*., 23, 343, 1967. [Thermal expansion of lattice]
5. Leadbetter, A. J., *Proc. Roy. Soc. A* 287, 403, 1965. [Compressibility and thermal expansion]
6. Auty, R. P., and Cole, R. H., *J. Chem. Phys*., 20, 1309, 1952. [Dielectric constant]
7. Slack, G. A., *Phys. Rev. B*, 22, 3065, 1980. [Thermal conductivity]
8. Hare, D. E., and Sorensen, C. M., *J. Chem. Phys*., 87, 4840, 1987. [Supercooled water]
9. Hobbs, P. V., *Ice Physics,* Clarendon Press, Oxford, 1974.

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PROPERTIES OF LIQUID HELIUM

The following data were obtained by a critical evaluation of all existing experimental measurements on liquid helium, using a fitting procedure described in the reference. All values refer to liquid helium at saturated vapor pressure; temperatures are on the ITS-90 scale. Several properties show a singularity at the lambda point (2.1768 K).

p : vapor pressure
ρ : density
C_s : molar heat capacity
$\Delta_{vap}H$: molar enthalpy of vaporization
ε : relative permittivity (dielectric constant)
σ : surface tension
α : coefficient of linear expansion
η : viscosity
λ : thermal conductivity

REFERENCE

Donnelly, R. J., and Barenghi, C. F., *J. Phys. Chem. Reference Data* 27, 1217, 1998.

T/K	p/kPa	ρ/g cm^{-3}	C_s /J mol^{-1}K^{-1}	$\Delta_{vap}H$/J mol^{-1}	ε	σ /mN m^{-1}	$10^3\alpha$/K^{-1}	η/μPa s	λ /W cm^{-1}K^{-1}
0.0		0.1451397	0	59.83	1.057255		0.000		
0.5		0.1451377	0.010	70.24	1.057254	0.3530	0.107		
1.0	0.01558	0.1451183	0.415	80.33	1.057246	0.3471	0.309	3.873	
1.5	0.4715	0.1451646	4.468	89.35	1.057265	0.3322	-2.36	1.346	
2.0	3.130	0.1456217	21.28	93.07	1.057449	0.3021	-12.2	1.468	
2.5	10.23	0.1448402	9.083	92.50	1.057135	0.2623	39.4	3.259	0.1497
3.0	24.05	0.1412269	9.944	94.11	1.055683	0.2161	61.5	3.517	0.1717
3.5	47.05	0.1360736	12.37	92.84	1.053615	0.1626	88.7	3.509	0.1868
4.0	81.62	0.1289745	15.96	87.00	1.050770	0.1095	129	3.319	0.1965
4.5	130.3	0.1188552	21.8	75.86	1.046725	0.0609	211		
5.0	196.0		44.7	47.67		0.0157			

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SURFACE TENSION OF AQUEOUS MIXTURES

The composition dependence of the surface tension of binary mixtures of several compounds with water is given in this table. The data are tabulated as a function of the mass percent of the non-aqueous component. Data for methanol, ethanol, 1-propanol, and 2-propanol are taken from Reference 1, which also gives values at other temperatures.

REFERENCES

1. Vazquez, G., Alvarez, E., and Navaza, J. M., *J. Chem. Eng. Data*, 40, 611, 1995.
2. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series*, IV/16, *Surface Tension*, Springer-Verlag, Heidelberg, 1997.

Surface Tension in mN/m^2 for the Specified Mass %

Compound	*t*/°C	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Acetic acid	30	71.2	51.4	43.3	41.2	38.2	37.4	36.1	33.5	31.5	30.2	26.3
Acetone	25	72.0	44.9	40.5	36.7	33.0	30.1	29.4	29.4	27.6	24.5	23.1
Acetonitrile	20	72.8	48.5	40.2	34.1	31.6	30.6	30.0	29.6	29.1	28.7	28.4
1,2-Butanediol	25	72.0	66.1	60.4	55.1	50.1	45.6	43.3	41.9	40.8	39.2	35.8
1,3-Butanediol	30	71.2	58.1	51.6	48.7	45.8	43.9	42.4	41.2	40.0	39.0	37.0
1,4-Butanediol	30	71.2	61.2	56.9	54.2	52.0	50.7	49.5	47.9	46.6	45.2	43.8
Butanoic acid	30	71.2	42.4	37.5	35.5	34.8	32.2	30.8	29.2	27.4	26.3	25.5
2-Butanone	20	72.8	41.6	32.2				25.2				24.6
γ-Butyrolactone	30	71.2	64	58	53	50	48	46	45	44	42.8	42.7
Chloroacetic acid	25	72.0	59.8	53.6	51.3	49.7	48.3	47.5	46.1			
Diethanolamine	25	72.0	66.8	63.2	60.7	58.8	57.2	55.7	54.3	52.7	50.6	47.2
N,N-Dimethylacetamide	25	72.0	72.0	72.0	72.4	73.5	74.9	75.4	73.0	65.7	54.7	36.4
N,N-Dimethylformamide	25	72.0	65.4	59.2	53.8	49.6	47.3	46.9	44.9	42.3	38.4	35.2
1,4-Dioxane	25	72.0					41.2	39.6	37.9	36.2	34.5	33.7
Ethanol	25	72.01	47.53	37.97	32.98	30.16	27.96	26.23	25.01	23.82	22.72	21.82
Ethylene glycol	20	72.8	68.5	64.9	61.9		57.0					48.2
Formic acid	20	72.8	66	60	55.7	52.2	50.3	48.8	47.1	44.7	40.9	38.0
Glycerol	25	72.0	70.5	69.5	68.5	67.9	67.4	66.9	66.5	65.7	64.5	62.5
Methanol	25	72.01	56.18	47.21	41.09	36.51	32.86	29.83	27.48	25.54	23.93	22.51
Morpholine	20	72.8	65.1	60.7	58.9	56.7	53.0	49.6	47.0	43.7	41.8	38.7
Nitric acid	20	72.8	71.9	70.7	68.9	66.6	63.8	60.6	56.8	52.6	47.9	42.6
Propanoic acid	30	71.2	46.6	42.2	37.7	35.6	33.1	31.7	30.2	28.2	27.4	25.8
1-Propanol	25	72.01	34.32	27.84	25.98	25.26	24.80	24.49	24.08	23.86	23.59	23.28
2-Propanol	25	72.01	40.42	30.57	26.82	25.27	24.26	23.51	22.68	22.14	21.69	21.22
1,2-Propylene glycol	30	71.2	60.5	54.9	50.7	47.2	44.5	41.5	38.6	37.6	36.3	35.5
1,3-Propylene glycol	30	71.2	62.6	58.8	55.7	53.8	52.8	51.7	50.8	49.6	48.2	47.0
Pyridine	25	72.0	52.8	51.2	48.0	46.8	46.6	45.8	45.0	43.6	40.9	37.0
Sulfolane	20	72.8					62.5	61.6	59.6	57.1	54.9	50.9
Sulfuric acid	50	67.9	73.5	75.1	73.6	71.2	68.0	64.1	60.0	56.4	53.6	51.7
Trichloroacetaldehyde	25	72.0	56.7	51.0	46.7	44.1	43.0	42.5	41.5	38.9	34.7	29.4
Trichloroacetic acid	25	72.0	55.8	46.5	42.8	41.6	40.6	39.4	38.3	37.4	36.5	

VISCOSITY OF CARBON DIOXIDE ALONG THE SATURATION LINE

The table below gives the viscosity of gas and liquid CO_2 along the liquid-vapor saturation line.

REFERENCES

1. Fenghour, A., Wakeham, W. A., and Vesovic, V., *J. Phys. Chem. Ref. Data*, 27, 31, 1998.
2. Angus, S., et al., *International Tables for the Fluid State: Carbon Dioxide*, Pergamon Press, Oxford, 1976.

		Gas	Liquid
***T*/K**	***P*/kPa**	**η/μPa s**	**η/μPa s**
205	227	10.33	
210	327	10.60	
215	465	10.87	
220	600	11.13	241.68
225	735	11.41	221.72
230	894	11.69	203.75
235	1075	11.98	187.48
240	1283	12.27	172.67
245	1519	12.58	159.13
250	1786	12.90	146.69
255	2085	13.24	135.20
260	2419	13.61	124.30
265	2790	14.02	114.63
270	3203	14.47	105.21
275	3658	14.99	96.44
280	4160	15.61	87.89
285	4712	16.37	79.64
290	5315	17.36	71.47
295	5984	18.79	63.01
300	6710	21.29	53.33
302	6997	23.52	48.30

PROPERTIES OF AMINO ACIDS

This table gives selected properties of some important amino acids and closely related compounds. The first part of the table lists the 20 "standard" amino acids that are the basic constituents of proteins (structures of these amino acids may be found in the following table). The second part includes other amino acids and related compounds of biochemical importance. Within each part of the table the compounds are listed by name in alphabetical order.

Symbol — Three-letter symbol for the standard amino acids
M_r — Molecular weight
t_m — Melting point
pK_a , pK_b , pK_c , pK_d — Negative of the logarithm of the acid dissociation constants for the COOH and NH_2 groups (and, in some cases, other groups) in the molecule (at 25°C)
pI — pH at the isoelectric point
S — Solubility in water at 25°C in units of grams of compound per kilogram of water; when quantitative data are not available, the notations sl.s. (for slightly soluble) and v.s. (for very soluble) are used.

Data on the enthalpy of formation of many of these compounds are included in the table "Standard Thermodynamic Properties of Chemical Substances" in Section 5 of this Handbook. Absorption spectra and optical rotation data can be found in Reference 3. Partial molar volume and other thermodynamic properties, including solubility as a function of temperature, are given in References 3 and 5. Most of the pK values come from Reference 7.

REFERENCES

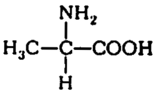
1. Dawson, R. M. C., Elliott, D. C., Elliott, W. H., and Jones, K. M., *Data for Biochemical Research*, 3rd ed., Clarendon Press, Oxford, 1986.
2. Budavari, S., Ed., *The Merck Index, Twelfth Edition*, Merck & Co., Rahway, NJ, 1996.
3. Sober, H. A., Ed., *CRC Handbook of Biochemistry. Selected Data for Molecular Biology*, CRC Press, Boca Raton, FL, 1968.
4. Voet, D. and Voet, J. G., *Biochemistry, Second Edition*, John Wiley & Sons, New York, 1995.
5. Hinz, H. J., Ed., *Thermodynamic Data for Biochemistry and Biotechnology,* Springer-Verlag, Heidelberg, 1986.
6. Fasman, G. D., Ed., *Practical Handbook of Biochemistry and Molecular Biology,* CRC Press, Boca Raton, FL, 1989.
7. Smith, R. M., and Martell, A. E., *NIST Standard Reference Database 46: Critically Selected Stability Constants of Metal Complexes Database, Version 3.0*, National Institute of Standards and Technology, Gaithersburg, MD, 1997.
8. Jin, Z. and Chao, K. C., *J. Chem. Eng. Data*, 37, 199, 1992.

The standard amino acids:

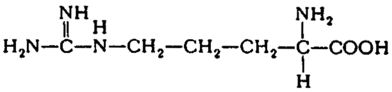
Symbol	Name	Mol. form.	M_r	t_m/°C	pK_a	pK_b	pK_c	pI	S/g kg^{-1}
Ala	Alanine	$C_3H_7NO_2$	89.09	297	2.33	9.71		6.00	165.0
Arg	Arginine	$C_6H_{14}N_4O_2$	174.20	244	2.03	9.00	12.10	10.76	182.6
Asn	Asparagine	$C_4H_8N_2O_3$	132.12	235	2.16	8.73		5.41	25.1
Asp	Aspartic acid	$C_4H_7NO_4$	133.10	270	1.95	9.66	3.71	2.77	4.95
Cys	Cysteine	$C_3H_7NO_2S$	121.16	240	1.91	10.28	8.14	5.07	v.s.
Glu	Glutamic acid	$C_5H_9NO_4$	147.13	160	2.16	9.58	4.15	3.22	8.61
Gln	Glutamine	$C_5H_{10}N_2O_3$	146.15	185	2.18	9.00		5.65	42
Gly	Glycine	$C_2H_5NO_2$	75.07	290	2.34	9.58		5.97	250.9
His	Histidine	$C_6H_9N_3O_2$	155.16	287	1.70	9.09	6.04	7.59	43.5
Ile	Isoleucine	$C_6H_{13}NO_2$	131.17	284	2.26	9.60		6.02	34.2
Leu	Leucine	$C_6H_{13}NO_2$	131.17	293	2.32	9.58		5.98	22.0
Lys	Lysine	$C_6H_{14}N_2O_2$	146.19	224	2.15	9.16	10.67	9.74	5.8
Met	Methionine	$C_5H_{11}NO_2S$	149.21	281	2.16	9.08		5.74	56
Phe	Phenylalanine	$C_9H_{11}NO_2$	165.19	283	2.18	9.09		5.48	27.9
Pro	Proline	$C_5H_9NO_2$	115.13	221	1.95	10.47		6.30	1623
Ser	Serine	$C_3H_7NO_3$	105.09	228	2.13	9.05		5.68	50.2
Thr	Threonine	$C_4H_9NO_3$	119.12	256	2.20	8.96		5.60	98.1
Trp	Tryptophan	$C_{11}H_{12}N_2O_2$	204.23	289	2.38	9.34		5.89	13.2
Tyr	Tyrosine	$C_9H_{11}NO_3$	181.19	343	2.24	9.04	10.10	5.66	0.46
Val	Valine	$C_5H_{11}NO_2$	117.15	315	2.27	9.52		5.96	88.5

STRUCTURES OF COMMON AMINO ACIDS

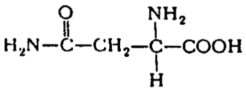
Alanine
(Ala, A)



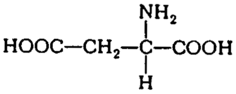
Arginine
(Arg, R)



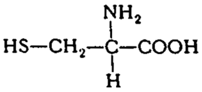
Asparagine
(Asn, N)



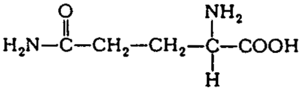
Aspartic acid
(Asp, D)



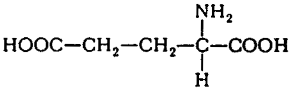
Cysteine
(Cys, C)



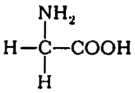
Glutamine
(Gln, Q)



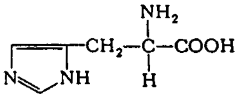
Glutamic acid
(Glu, E)



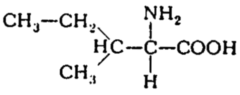
Glycine
(Gly, G)



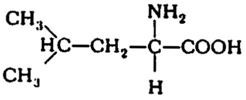
Histidine
(His, H)



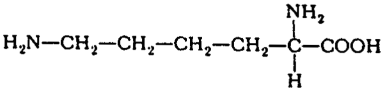
Isoleucine
(Ile, I)



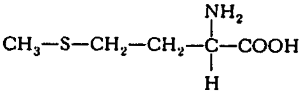
Leucine
(Leu, L)



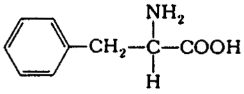
Lysine
(Lys, K)



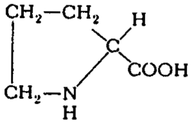
Methionine
(Met, M)



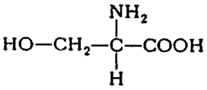
Phenylalanine
(Phe, F)



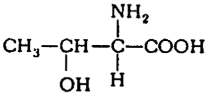
Proline
(Pro, P)



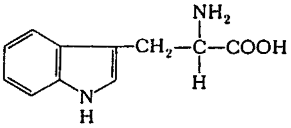
Serine
(Ser, S)



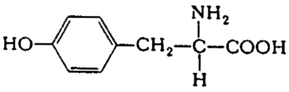
Threonine
(Thr, T)



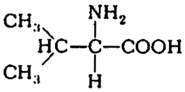
Tryptophan
(Trp, W)



Tyrosine
(Tyr, Y)



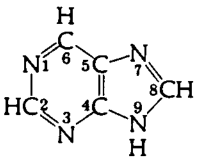
Valine
(Val, V)



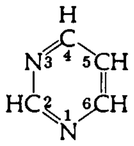
PROPERTIES OF PURINE AND PYRIMIDINE BASES

This table lists some of the important purine and pyrimidine bases that occur in nucleic acids. The pK_a values (negative logarithm of the acid dissociation constant) are given for each ionization stage. The last column gives the aqueous solubility *S* at the indicated temperature in units of grams per 100 grams of solution.

The numbering system in the rings is:



Purine



Pyrimidine

REFERENCES

1. R. M. C. Dawson, et al., *Data for Biochemical Research*, 3rd Ed., Clarendon Press, Oxford, 1986.
2. S. Budavari, Ed., *The Merck Index*, 11th Ed., Merk and Co., Rahway, NJ., 1989.

Common name	**Systematic name**	**Mol form.**	**Mol. wt.**	**pK_a values**			***S*/mass % (temp.)**
			Pyrimidines				
Cytosine	4-Amino-2-hydroxypyrimidine	$C_4H_5N_3O$	111.10	4.5	12.2		0.76 (25°C)
5-Methylcytosine	4-Amino-2-hydroxy-5-methylpyrimidine	$C_5H_7N_3O$	125.13	4.6	12.4		0.45 (25°C)
5-Hydroxymethyl-cytosine	4-Amino-2-hydroxy-5-hydroxy-methylpyrimidine	$C_5H_7N_3O_2$	141.13	4.3	13		
Uracil	2,4-Dihydroxypyrimidine	$C_4H_4N_2O_2$	112.09	0.5	9.5	>13	0.36 (25°C)
Thymine	5-Methyluracil	$C_5H_6N_2O_2$	126.11	9.9	>13		0.4 (25°C)
Orotic acid	Uracil-6-carboxylic acid	$C_5H_4N_2O_4$	156.10	2.4	9.5	>13	0.18 (18°C)
			Purines				
Adenine	6-Aminopurine	$C_5H_5N_5$	135.14	<1	4.1	9.8	0.09 (25°C)
Guanine	2-Amino-6-hydroxypurine	$C_5H_5N_5O$	151.13	3.3	9.2	12.3	0.004 (40°C)
7-Methylguanine	7-Methyl-2-amino-6-hydroxypurine	$C_6H_7N_5O$	165.16	3.5	9.9		
Isoguanine	6-Amino-2-hydroxypurine	$C_5H_5N_5O$	151.13	4.5	9.0		0.006 (25°C)
Xanthine	2,6-Dioxopurine	$C_5H_4N_4O_2$	152.11	0.8	7.4	11.1	0.05 (20°C)
Hypoxanthine	6-Hydroxypurine	$C_5H_4N_4O$	136.11	2.0	8.9	12.1	0.07 (19°C)
Uric acid	2,6,8-Trihydroxypurine	$C_5H_4N_4O_3$	168.11	5.4	11.3		0.002 (20°C)

THE GENETIC CODE

This table gives the correspondence between a messenger RNA codon and the amino acid which it specifies. The symbols for bases in the codon are:

U: uracil
C: cytosine
A: adenine
G: guanine

The amino acid symbols are given in the table entitled "Structures of Common Amino Acids". A chain-initiating codon is indicated by **init** and a chain-terminating codon by **term**.

Example: UCA codes for **Ser**, UAC codes for **Tyr**, etc.

	Second position				
First position	**U**	**C**	**A**	**G**	**Third position**
U	Phe	Ser	Tyr	Cys	U
	Phe	Ser	Tyr	Cys	C
	Leu	Ser	**term**	**term**	A
	Leu	Ser	**term**	Trp	G
C	Leu	Pro	His	Arg	U
	Leu	Pro	His	Arg	C
	Leu	Pro	Gln	Arg	A
	Leu	Pro	Gln	Arg	G
A	Ile	Thr	Asn	Ser	U
	Ile	Thr	Asn	Ser	C
	Ile	Thr	Lys	Arg	A
	Met (**init**)	Thr	Lys	Arg	G
G	Val	Ala	Asp	Gly	U
	Val	Ala	Asp	Gly	C
	Val	Ala	Glu	Gly	A
	Val (**init**)	Ala	Glu	Gly	G

PROPERTIES OF FATTY ACIDS

This table gives the systematic names and selected properties of some of the more important fatty acids of five or more carbon atoms. Compounds are listed first by degree of saturation and, secondly, by number of carbon atoms. The following data are included:

M_r: Molecular weight
t_m: Melting point in °C
S: Aqueous solubility at 20°C in units of grams of solute per 100 grams of water

REFERENCES

1. Dawson, R. M. C., Elliott, D. C., Elliott, W. H., and Jones, K. M., *Data for Biochemical Research*, Third Edition, Clarendon Press, Oxford, 1986.
2. Fasman, G. D., Ed., *Practical Handbook of Biochemistry and Molecular Biology*, CRC Press, Boca Raton, FL, 1989.

Common name	Systematic name	Mol. form.	M_r	t_m/°C	S
		Saturated			
Valeric acid	Pentanoic acid	$C_5H_{10}O_2$	102.13	-34	2.5
Isovaleric acid	3-Methylbutanoic acid	$C_5H_{10}O_2$	102.13	-29.3	4.3
Caproic acid	Hexanoic acid	$C_6H_{12}O_2$	116.16	-3	0.967
Enanthic acid	Heptanoic acid	$C_7H_{14}O_2$	130.19	-7.5	0.24
Caprylic acid	Octanoic acid	$C_8H_{16}O_2$	144.21	16.3	0.080
Pelargonic acid	Nonanoic acid	$C_9H_{18}O_2$	158.24	12.3	0.0284
Capric acid	Decanoic acid	$C_{10}H_{20}O_2$	172.27	31.9	0.015
Lauric acid	Dodecanoic acid	$C_{12}H_{24}O_2$	200.32	43.2	0.0055
Tridecylic acid	Tridecanoic acid	$C_{13}H_{26}O_2$	214.35	41.5	0.0033
Myristic acid	Tetradecanoic acid	$C_{14}H_{28}O_2$	228.38	53.9	0.0020
Pentadecylic acid	Pentadecanoic acid	$C_{15}H_{30}O_2$	242.40	52.3	0.0012
Palmitic acid	Hexadecanoic acid	$C_{16}H_{32}O_2$	256.43	63.1	0.00072
Margaric acid	Heptadecanoic acid	$C_{17}H_{34}O_2$	270.46	61.3	0.00042
Stearic acid	Octadecanoic acid	$C_{18}H_{36}O_2$	284.48	69.6	0.00029
Arachidic acid	Eicosanoic acid	$C_{20}H_{40}O_2$	312.54	76.5	
Phytanic acid	3,7,11,15-Tetramethylhexadecanoic acid	$C_{20}H_{40}O_2$	312.54	-65	
Behenic acid	Docosanoic acid	$C_{22}H_{44}O_2$	340.59	81.5	
Lignoceric acid	Tetracosanoic acid	$C_{24}H_{48}O_2$	368.64	87.5	
Cerotic acid	Hexacosanoic acid	$C_{26}H_{52}O_2$	396.70	88.5	
Montanic acid	Octacosanoic acid	$C_{28}H_{56}O_2$	424.75	90.9	
		Monounsaturated			
Caproleic acid	9-Decenoic acid	$C_{10}H_{18}O_2$	170.25	26.5	
Palmitoleic acid	*cis*-9-Hexadecenoic acid	$C_{16}H_{30}O_2$	254.41	-0.1	
Oleic acid	*cis*-9-Octadecenoic acid	$C_{18}H_{34}O_2$	282.47	13.4	
Elaidic acid	*trans*-9-Octadecenoic acid	$C_{18}H_{34}O_2$	282.47	45	
Vaccenic acid	*trans*-11-Octadecenoic acid	$C_{18}H_{34}O_2$	282.47	44	
Erucic acid	*cis*-13-Docosenoic acid	$C_{22}H_{42}O_2$	338.57	34.7	
Brassidic acid	*trans*-13-Docosenoic acid	$C_{22}H_{42}O_2$	338.57	61.9	
Nervonic acid	*cis*-15-Tetracosenoic acid	$C_{24}H_{46}O_2$	366.63	43	
		Diunsaturated			
Linoleic acid	*cis,cis*-9,12-Octadecadienoic acid	$C_{18}H_{32}O_2$	280.45	-12	
		Triunsaturated			
cis-Eleostearic acid	*trans,cis,trans*-9,11,13-Octadecatrienoic acid	$C_{18}H_{30}O_2$	278.44	49	
trans-Eleostearic acid	*trans,trans,trans*-9,11,13-Octadecatrienoic acid	$C_{18}H_{30}O_2$	278.44	71.5	
Linolenic acid	*cis,cis,cis*-9,12,15-Octadecatrienoic acid	$C_{18}H_{30}O_2$	278.44	-11	
		Tetraunsaturated			
Arachidonic acid	5,8,11,14-Eicosatetraenoic acid, (all-*trans*)	$C_{20}H_{32}O_2$	304.47	-49.5	

CARBOHYDRATE NAMES AND SYMBOLS

The following table lists the systematic names and symbols for selected carbohydrates and some of their derivatives. The symbols for monosaccharide residues and derivatives are recommended by IUPAC for use in describing the structures of oligosaccharide chains. A more complete list can be found in the reference.

REFERENCE

McNaught, A. D.,*Pure Appl. Chem.*, 68, 1919-2008, 1996.

Common Name	Symbol	Systematic Name
Abequose	Abe	3,6-Dideoxy-D-*xylo*-hexose
N-Acetyl-2-deoxyneur-2-enaminic acid	Neu2en5Ac	
N-Acetylgalactosamine	GalNAc	
N-Acetylglucosamine	GlcNAc	
N-Acetylneuraminic acid	Neu5Ac	
Allose	All	*allo*-Hexose
Altrose	Alt	*altro*-Hexose
Apiose	Api	3-*C*-(Hydroxymethyl)-*glycero*-tetrose
Arabinitol	Ara-ol	Arabinitol
Arabinose	Ara	*arabino*-Pentose
Arcanose		2,6-Dideoxy-3-*C*-methyl-3-*O*-methyl-*xylo*-hexose
Ascarylose		3,6-Dideoxy-L-*arabino*-hexose
Boivinose		2,6-Dideoxy-D-gulose
Chalcose		4,6-Dideoxy-3-*O*-methyl-D-*xylo*-hexose
Cladinose		2,6-Dideoxy-3-*C*-methyl-3-*O*-methyl-L-*ribo*-hexose
Colitose		3,6-Dideoxy-L-*xylo*-hexose
Cymarose		6-Deoxy-3-*O*-methyl-*ribo*-hexose
3-Deoxy-D-*manno*-oct-2-ulosonic acid	Kdo	
2-Deoxyribose	dRib	2-Deoxy-*erythro*-pentose
2,3-Diamino-2,3-dideoxy-D-glucose	GlcN3N	
Diginose		2,6-Dideoxy-3-*O*-methyl-*lyxo*-hexose
Digitalose		6-Deoxy-3-*O*-methyl-D-galactose
Digitoxose		2,6-Dideoxy-D-*ribo*-hexose
3,4-Di-*O*-methylrhamnose	$Rha3,4Me_2$	
Ethyl glucopyranuronate	Glc*p*A6Et	
Evalose		6-Deoxy-3-*C*-methyl-D-mannose
Fructose	Fru	*arabino*-Hex-2-ulose
Fucitol	Fuc-ol	6-Deoxy-D-galactitol
Fucose	Fuc	6-Deoxygalactose
β-D-Galactopyranose 4-sulfate	β-D-Gal*p*4*S*	
Galactosamine	GalN	2-Amino-2-deoxygalactose
Galactose	Gal	*galacto*-Hexose
Glucitol	Glc-ol	
Glucosamine	GlcN	2-Amino-2-deoxyglucose
Glucose	Glc	*gluco*-Hexose
Glucuronic acid	GlcA	
N-Glycoloylneuraminic acid	Neu5Gc	
Gulose	Gul	*gulo*-Hexose
Hamamelose		2-*C*-(Hydroxymethyl)-D-ribose
Idose	Ido	*ido*-Hexose
Iduronic acid	IdoA	
Lactose	Lac	β-D-Galactopyranosyl-(1→4)-D-glucose
Lyxose	Lyx	*lyxo*-Pentose
Maltose		α-D-Glucopyranosyl-(1→4)-D-glucose
Mannose	Man	*manno*-Hexose
2-*C*-Methylxylose	Xyl2*C*Me	
Muramic acid	Mur	2-Amino-3-*O*-[(R)-1-carboxyethyl]-2-deoxy-D-glucose
Mycarose		2,6-Dideoxy-3-*C*-methyl-L-*ribo*-hexose
Mycinose		6-Deoxy-2,3-di-*O*-methyl-D-allose
Neuraminic acid	Neu	5-Amino-3,5-dideoxy-D-*glycero*-D-*galacto*-non-2-ulosonic acid

CARBOHYDRATE NAMES AND SYMBOLS (continued)

Common Name	Symbol	Systematic Name
Panose		α-D-Glucopyranosyl-(1→6)-α-D-glucopyranosyl-(1→ 4)-D-glucose
Paratose		3,6-Dideoxy-D-*ribo*-hexose
Primeverose		β-D-Xylopyranosyl-(1→6)-D-glucose
Psicose	Psi	*ribo*-Hex-2-ulose
Quinovose	Qui	6-Deoxyglucose
Raffinose		β-D-Fructofuranosyl-α-D-galactopyranosyl-(1→6)-α-D-glucopyranoside
Rhamnose	Rha	6-Deoxymannose
Rhodinose		2,3,6-Trideoxy-L-*threo*-hexose
Ribose	Rib	*ribo*-Pentose
Ribose 5-phosphate	Rib5*P*	
Ribulose	Ribulo (Rul)	*erythro*-Pent-2-ulose
Rutinose		α-L-Rhamnopyranosyl-(1→6)-D-glucose
Sarmentose		2,6-Dideoxy-3-*O*-methyl-D-*xylo*-hexose
Sedoheptulose		D-*altro*-Hept-2-ulose
Sorbose	Sor	*xylo*-Hex-2-ulose
Streptose		5-Deoxy-3-*C*-formyl-L-lyxose
Sucrose		β-D-Fructofuranosyl-α-D-glucopyranoside
Tagatose	Tag	*lyxo*-Hex-2-ulose
Talose	Tal	*talo*-Hexose
Turanose		α-D-Glucopyranosyl-(1→3)-D-fructose
Tyvelose	Tyv	3,6-Dideoxy-D-*arabino*-hexose
Xylose	Xyl	*xylo*-Pentose
Xylulose	Xylulo (Xul)	*threo*-Pent-2-ulose

BIOLOGICAL BUFFERS

This table of frequently used buffers gives the pK_a value at 25°C and the useful pH range of each buffer. The buffers are listed in order of increasing pH.

The table is reprinted with permission of Sigma Chemical Company, St. Louis, Mo.

Acronym	Name	Mol. wt.	pK_a	Useful pH range
MES	2-(*N*-Morpholino)ethanesulfonic acid	195.2	6.1	5.5—6.7
BIS TRIS	*Bis*(2-hydroxyethyl)iminotris(hydroxymethyl)methane	209.2	6.5	5.8—7.2
ADA	*N*-(2-Acetamido)-2-iminodiacetic acid	190.2	6.6	6.0—7.2
ACES	2-[(2-Amino-2-oxoethyl)amino]ethanesulfonic acid	182.2	6.8	6.1—7.5
PIPES	Piperazine-*N*,*N′*-*bis*(2-ethanesulfonic acid)	302.4	6.8	6.1—7.5
MOPSO	3-(*N*-Morpholino)-2-hydroxypropanesulfonic acid	225.3	6.9	6.2—7.6
BIS TRIS PROPANE	1,3-*Bis*[*tris*(hydroxymethyl)methylamino]propane	282.3	6.8[a]	6.3—9.5
BES	*N*,*N*-*Bis*(2-hydroxyethyl)-2-aminoethanesulfonic acid	213.2	7.1	6.4—7.8
MOPS	3-(*N*-Morpholino)propanesulfonic acid	209.3	7.2	6.5—7.9
HEPES	*N*-(2-Hydroxyethyl)piperazine-*N′*-(2-ethanesulfonic acid)	238.3	7.5	6.8—8.2
TES	*N*-*Tris*(hydroxymethyl)methyl-2-aminoethanesulfonic acid	229.2	7.5	6.8—8.2
DIPSO	3-[*N*,*N*-*Bis*(2-hydroxyethyl)amino]-2-hydroxypropanesulfonic acid	243.3	7.6	7.0—8.2
TAPSO	3-[*N*-*Tris*(hydroxymethyl)methylamino)-2-hydroxypropanesulfonic acid	259.3	7.6	7.0—8.2
TRIZMA	Tris(hydroxymethyl)aminomethane	121.1	8.1	7.0—9.1
HEPPSO	*N*-(2-hydroxyethyl)piperazine-*N′*-(2-hydroxypropanesulfonic acid)	268.3	7.8	7.1—8.5
POPSO	Piperazine-*N*,*N′*-*bis*(2-hydroxypropanesulfonic acid)	362.4	7.8	7.2—8.5
EPPS	*N*-(2-Hydroxyethyl)piperazine-*N′*-(3-propanesulfonic acid)	252.3	8.0	7.3—8.7
TEA	Triethanolamine	149.2	7.8	7.3—8.3
TRICINE	*N*-*Tris*(hydroxymethyl)methylglycine	179.2	8.1	7.4—8.8
BICINE	*N*,*N*-*Bis*(2-hydroxyethyl)glycine	163.2	8.3	7.6—9.0
TAPS	*N*-*Tris*(hydroxymethyl)methyl-3-aminopropanesulfonic acid	243.3	8.4	7.7—9.1
AMPSO	3-[(1,1-Dimethyl-2-hydroxyethyl)amino]-2-hydroxypropanesulfonic acid	227.3	9.0	8.3—9.7
CHES	2-(*N*-Cyclohexylamino)ethanesulfonic acid	207.3	9.3	8.6—10.0
CAPSO	3-(Cyclohexylamino)-2-hydroxy-1-propanesulfonic acid	237.3	9.6	8.9—10.3
AMP	2-Amino-2-methyl-1-propanol	89.1	9.7	9.0—10.5
CAPS	3-(Cyclohexylamino)-1-propanesulfonic acid	221.3	10.4	9.7—11.1

[a] pK_a = 9.0 for the second dissociation stage.

TYPICAL pH VALUES OF BIOLOGICAL MATERIALS AND FOODS

This table gives typical pH ranges for various biological fluids and common foods. All values refer to 25°C.

Biological Materials

Blood, human	7.35-7.45
Blood, dog	6.9-7.2
Spinal fluid, human	7.3-7.5
Saliva, human	6.5-7.5
Gastric contents, human	1.0-3.0
Duodenal contents, human	4.8-8.2
Feces, human	4.6-8.4
Urine, human	4.8-8.4
Milk, human	6.6-7.6
Bile, human	6.8-7.0

Foods

Apples	2.9-3.3
Apricots	3.6-4.0
Asparagus	5.4-5.8
Bananas	4.5-4.7
Beans	5.0-6.0
Beers	4.0-5.0
Beets	4.9-5.5
Blackberries	3.2-3.6
Bread, white	5.0-6.0
Butter	6.1-6.4
Cabbage	5.2-5.4
Carrots	4.9-5.3
Cheese	4.8-6.4
Cherries	3.2-4.0
Cider	2.9-3.3
Corn	6.0-6.5
Crackers	6.5-8.5
Dates	6.2-6.4
Eggs, fresh white	7.6-8.0
Flour, wheat	5.5-6.5
Gooseberries	2.8-3.0
Grapefruit	3.0-3.3
Grapes	3.5-4.5
Hominy (lye)	6.8-8.0
Jams, fruit	3.5-4.0
Jellies, fruit	2.8-3.4
Lemons	2.2-2.4
Limes	1.8-2.0
Maple syrup	6.5-7.0
Milk, cows	6.3-6.6
Olives	3.6-3.8
Oranges	3.0-4.0
Oysters	6.1-6.6
Peaches	3.4-3.6
Pears	3.6-4.0
Peas	5.8-6.4
Pickles, dill	3.2-3.6
Pickles, sour	3.0-3.4
Pimento	4.6-5.2
Plums	2.8-3.0
Potatoes	5.6-6.0
Pumpkin	4.8-5.2
Raspberries	3.2-3.6
Rhubarb	3.1-3.2
Salmon	6.1-6.3
Sauerkraut	3.4-3.6
Shrimp	6.8-7.0
Soft drinks	2.0-4.0
Spinach	5.1-5.7
Squash	5.0-5.4
Strawberries	3.0-3.5
Sweet potatoes	5.3-5.6
Tomatoes	4.0-4.4
Tuna	5.9-6.1
Turnips	5.2-5.6
Vinegar	2.4-3.4
Water, drinking	6.5-8.0
Wines	2.8-3.8

CHEMICAL COMPOSITION OF THE HUMAN BODY

The elemental composition of the “standard man” of mass 70 kg is given below.

REFERENCES

1. Padikal, T.N., and Fivozinsky, S.P., *Medical Physics Data Book, National Bureau of Standards Handbook 138*, U. S. Government Printing Office, Washington, DC, 1981.
2. Snyde, W.S., et al., *Reference Man: Anatomical, Physiological, and Metabolic Characteristics*, Pergamon, New York, 1975.

Element	Amount (g)	Percent of total body mass
Oxygen	43,000	61
Carbon	16,000	23
Hydrogen	7000	10
Nitrogen	1800	2.6
Calcium	1000	1.4
Phosphorus	780	1.1
Sulfur	140	0.20
Potassium	140	0.20
Sodium	100	0.14
Chlorine	95	0.12
Magnesium	19	0.027
Silicon	18	0.026
Iron	4.2	0.006
Fluorine	2.6	0.0037
Zinc	2.3	0.0033
Rubidium	0.32	0.00046
Strontium	0.32	0.00046
Bromine	0.20	0.00029
Lead	0.12	0.00017
Copper	0.072	0.00010
Aluminum	0.061	0.00009
Cadmium	0.050	0.00007
Boron	<0.048	0.00007
Barium	0.022	0.00003
Tin	<0.017	0.00002
Manganese	0.012	0.00002
Iodine	0.013	0.00002
Nickel	0.010	0.00001
Gold	<0.010	0.00001
Molybdenum	<0.0093	0.00001
Chromium	<0.0018	0.000003
Cesium	0.0015	0.000002
Cobalt	0.0015	0.000002
Uranium	0.00009	0.0000001
Beryllium	0.000036	
Radium	$3.1 \cdot 10^{-11}$	

STANDARD TRANSFORMED GIBBS ENERGY OF FORMATION FOR IMPORTANT BIOCHEMICAL SPECIES

Petr Vanýsek

This table lists transformed values of the standard Gibbs energy of formation for several molecules and ions of biochemical importance. Values of $\Delta_f G'^{o}$ are given at pH 7, 298.15 K, and 100 kPa for infinite dilution and for two finite ionic strengths, I = 0.1 mol/L and I = 0.25 mol/L. The charge of the species (z_i) is also given.

The table can be used for calculating practical (pH 7) reduction potentials for important biological processes. Such listing is more compact than offering reduction potentials, which would require tabulating a large number of reactant-product combinations.

To calculate the standard apparent reduction potential E'^{o} for reduction of acetaldehyde to ethanol at infinite dilution, for example, write first the reaction:

$$CH_3CHO + 2H^+ + 2\ e^- \rightleftharpoons CH_3CH_2OH$$

The change in hydrogen count can be accomplished by adding H^+, which in turn has to be compensated by adding the appropriate number of electrons (reduction). The correct count of electrons is needed in the subsequent equation for the reduction potential:

$$E'^{o} = [-\ 1/nF] \cdot [\Delta_f G'^{o}\,(\text{product}) - \Delta_f G'^{o}(\text{reactant})]$$

where n is the number of electrons to be added and F is the Faraday constant.

Specifically, for the above reaction:

$$E'^{o} = [-1/(2{\cdot}9.6485{\cdot}10^4\ \text{C mol}^{-1})] \cdot [58.1{\cdot}10^3\ \text{J mol}^{-1} - 20.83{\cdot}10^3\ \text{J mol}^{-1}] = -0.193\ \text{V}.$$

REFERENCE

Alberty, R. A., *Arch. Biochem. Biophys.*, **353**, 116-130, 1998; **358**, 25-39, 1998.

	$\Delta_f G'^{o}$ /kJ mol^{-1}			
Compound	$I = 0$	I = 0.1 mol/L	I = 0.25 mol/L	z_i
Acetaldehyde	20.83	23.27	24.06	0
Acetate	-249.44	-248.22	-247.82	-1
Acetone	80.03	83.71	84.89	0
cis-Aconitate	-797.26	-800.94	-802.12	-3
Adenine	512.07	515.13	516.12	0
Adenosine	519.43	527.39	529.96	0
Adenosine diphosphate (ADP)	-1234.36	-1230.97	-1230.12	-3
Adenosine monophosphate (AMP)	-367.5	-361.99	-360.29	-2
Adenosine triphosphate (ATP)	-2098	-2097.55	-2097.89	-4
Alanine	-91.31	-87.02	-85.64	0
Ammonium	80.52	82.35	82.94	1
Arabinose	-342.67	-336.55	-334.57	0
L-Asparagine	-206.28	-201.38	-199.8	0
Aspartate	-456.15	-453.09	-452.1	-1
1-Butanol	227.72	233.84	235.82	0
Butyrate	-72.94	-69.26	-68.08	-1
Carbonate	-547.33	-547.15	-547.1	-2
iso-Citrate	-956.82	-958.84	-959.58	-3
Citrate	-963.46	-965.49	-966.23	-3
CO(aq)	-119.9	-119.9	-119.9	0
CO(g)	-137.17	-137.17	-137.17	0
CO_2(g)	-394.36	-394.36	-394.36	0
Creatine	100.41	105.92	107.69	0
Creatinine	256.55	260.84	262.22	0
L-Cysteine	-59.23	-55.01	-53.65	0
L-Cystine	-187.03	-179.69	-177.32	0
Cytochrome c [oxidized]	0	-5.51	-7.29	3
Cytochrome c [reduced]	-24.54	-26.96	-27.75	2
Ethanol	58.1	61.77	62.96	0

STANDARD TRANSFORMED GIBBS ENERGY OF FORMATION FOR IMPORTANT BIOCHEMICAL SPECIES (continued)

Compound	$\Delta_f G'^o$ /kJ mol^{-1}			
	$I = 0$	$I = 0.1$ mol/L	$I = 0.25$ mol/L	z_i
Ethyl acetate	-18	-13.1	-11.52	0
Ferredoxin [oxidized]	0	-0.61	-0.81	1
Ferredoxin [reduced]	38.07	38.07	38.07	0
Flavin adenine dinucleotide [oxidized]	1238.65	1255.17	1260.51	-2
Flavin adenine dinucleotide [reduced]	1279.68	1297.43	1303.16	-2
Flavin mononucleotide [oxidized]	759.17	768.35	771.32	-2
Flavin mononucleotide [reduced]	800.2	810.61	813.97	-2
Formate	-311.04	-311.04	-311.04	-1
Fructose	-436.03	-428.69	-426.32	0
Fructose-6-phosphate	-1321.71	-1317.16	-1315.74	-1
Fumarate	-521.96	-523.18	-523.58	-2
Galactose	-429.45	-422.11	-419.74	0
Galactose-1-phosphate	-1317.5	-1313.01	-1311.6	-2
Glucose	-436.42	-429.08	-426.71	0
Glucose-1-phosphate	-1318.03	-1313.34	-1311.89	-2
Glucose-6-phosphate	-1325	-1320.37	-1318.92	-2
Glutamate	-377.82	-373.54	-372.16	-1
Glutamine	-128.46	-122.34	-120.36	0
Glutathione [oxidized]	1198.69	1214.6	1219.74	-2
Glutathione [reduced]	625.56	633.52	636.09	-1
Glycerol	-177.83	-172.93	-171.35	0
Glycerol-3-phosphate	-1080.22	-1077.83	-1077.14	-1
Glycine	-180.13	-177.07	-176.08	0
Glycolate	-411.08	-409.86	-409.46	-1
Glycylglycine	-200.55	-195.65	-194.07	0
Glyoxylate	-428.64	-428.64	-428.64	-1
$H_2(aq)$	97.51	98.74	99.13	0
$H_2(g)$	79.91	81.17	81.53	0
H_2O	-157.28	-156.05	-155.66	0
β-Hydroxypropionate	-318.62	-316.17	-315.38	-1
Hydrogen peroxide	-54.12	-52.89	-52.5	0
Hypoxanthine	249.33	251.77	252.56	0
Indole	503.49	507.78	509.16	0
L-Isoleucine	175.53	183.49	186.06	0
Lactate	-316.94	-314.49	-313.7	-1
Lactose	-688.29	-674.82	-670.48	0
L-Leucine	-167.18	-175.14	-177.71	0
Lyxose	-349.58	-343.46	-341.48	0
Malate	-682.83	-682.83	-682.83	-2
Maltose	-695.65	-682.19	-677.84	0
D-Mannitol	-383.22	-374.65	-371.89	0
Mannose	-431.51	-424.17	-421.8	0
Methane	109.11	111.55	112.34	0
Methanol	-15.45	-13.04	-12.25	0
L-Methionine	-63.4	-56.67	-54.49	0
Methylamine	199.88	202.94	203.93	1
$N_2(aq)$	18.07	18.07	18.07	0
$N_2(g)$	0	0	0	0
Nicotinamide adenine dinucleotide (NAD) [reduced]	1101.47	1115.55	1120.09	-2
Nicotinamide adenine dinucleotide (NAD) [oxidized]	1038.86	1054.17	1059.11	-1
Nicotinamide adenine dinucleotide phosphate (NADP) [reduced]	1064.85	1070.97	1072.95	-4
Nicotinamide adenine dinucleotide phosphate (NADP) [oxidized]	998.91	1008.7	1011.86	-3

STANDARD TRANSFORMED GIBBS ENERGY OF FORMATION FOR IMPORTANT BIOCHEMICAL SPECIES (continued)

		$\Delta_f G'^o$ /kJ mol^{-1}		
Compound	***I*** **= 0**	***I*** **= 0.1 mol/L**	***I*** **= 0.25 mol/L**	z_i
$O_2(aq)$	16.4	16.4	16.4	0
$O_2(g)$	0	0	0	0
Oxalate	-673.9	-676.35	-677.14	-2
Oxaloacetate	-713.37	-714.6	-714.99	-2
Oxalosuccinate	-979.06	-979.06	-979.06	-2
2-Oxoglutarate	-633.59	-633.59	-633.59	-2
Palmitate	979.25	997.6	1003.54	-1
L-Phenylalanine	232.42	239.15	241.33	0
Phosphate	-1058.56	-1059.17	-1059.49	-2
1-Propanol	143.84	148.74	150.32	0
2-Propanol	134.43	139.32	140.9	0
Pyrophosphate	-1937.66	-1941.82	-1943.35	-1
Pyruvate	-352.4	-351.18	-350.78	-1
Retinal	1118.78	1135.91	1141.45	0
Retinol	1170.77	1189.13	1195.06	0
Ribose	-339.23	-333.11	-331.13	0
Ribose-1-phosphate	-1215.87	-1212.24	-1211.14	-2
Ribose-5-phosphate	-1223.95	-1220.32	-1219.22	-2
Ribulose	-336.38	-330.26	-328.28	0
L-Serine	-231.18	-226.89	225.81	0
D-Sorbose	-432.47	-425.13	-422.76	0
Succinate	-530.62	-530.62	-530.62	-2
Sucrose	-685.66	-672.2	-667.85	0
Thioredoxin [oxidized]	0	0	0	0
Thioredoxin [reduced]	54.03	55.26	55.65	0
L-Tryptophane	366.88	374.22	376.59	0
L-Tyrosine	68.82	75.55	77.73	0
Ubiquinone [oxidized]	3596.07	3651.15	3668.94	0
Ubiquinone [reduced]	3586.16	3642.47	3660.65	0
Urate	-206.1	-204.85	204.45	-1
Urea	-42.92	-40.53	-39.73	0
L-Valine	-80.87	-87.6	-89.78	0
Xylose	-350.93	-344.81	-342.83	0
D-Xylulose	-346.59	-340.47	-338.49	0

PREPARATION OF SPECIAL ANALYTICAL REAGENTS

Aluminon (qualitative test for aluminum). Aluminon is a trade name for the ammonium salt of aurintricarboxylic acid. Dissolve 1 g of the salt in 1 L of distilled water. Shake the solution well to insure thorough mixing.

Bang's reagent (for glucose estimation). Dissolve 100 g of K_2CO_3, 66 g of KCl and 160 g of $KHCO_3$ in the order given in about 700 mL of water at 30°C. Add 4.4 g of $CuS0_4$ and dilute to 1 L after the CO_2 is evolved. This solution should be shaken only in such a manner as not to allow entry of air. After 24 hours 300 mL are diluted to 1 L with saturated KCl solution, shaken gently and used after 24 hours; 50 mL is equivalent to 10 mg glucose.

Barfoed's reagent (test for glucose). See Cupric acetate.

Baudisch's reagent. See Cupferron.

Benedict's solution (qualitative reagent for glucose). With the aid of heat, dissolve 173 g of sodium citrate and 100 g of Na_2CO_3 in 800 mL of water. Filter, if necessary, and dilute to 850 mL. Dissolve 17.3 g of $CuSO_4 \cdot 5H_2O$ in 100 mL of water. Pour the latter solution, with constant stirring, into the carbonate-citrate solution, and dilute to 1 L.

Benzidine hydrochloride solution (for sulfite determination). Make a paste of 8 g of benzidine hydrochloride ($C_{12}H_8(NH_3)_2 \cdot 2HCl$) and 20 mL of water, add 20 mL of HCl (sp. gr. 1.12) and dilute to 1 L with water. Each mL of this solution is equivalent to 0.00357 g of H_2SO_4.

Bertrand's reagent (glucose estimation). Consists of the following solutions:

1. Dissolve 200 g of Rochelle salt and 150 g of NaOH in sufficient water to make 1 L of solution.
2. Dissolve 40 g of $CuSO_4$ in enough water to make 1 L of solution.
3. Dissolve 50 g of $Fe_2(SO_4)_3$ and 200 g of H_2SO_4 (sp. gr. 1.84) in sufficient water to make 1 L of solution.
4. Dissolve 5 g of $KMnO_4$ in sufficient water to make 1 L of solution.

Bial's reagent (for pentose). Dissolve 1 g of orcinol (5-methyl-1,3-benzenediol) in 500 mL of 30% HCl to which 30 drops of a 10% solution of $FeCl_3$ has been added.

Boutron — Boudet soap solution:

1. Dissolve 100 g of pure castile soap in about 2.5 L of 56% ethanol.
2. Dissolve 0.59 g of $Ba(NO_3)_2$ in 1 L of water.

Adjust the castile soap solution so that 2.4 mL of it will give a permanent lather with 40 mL of solution (b). When adjusted, 2.4 mL of soap solution is equivalent to 220 parts per million of hardness (as $CaCO_3$) for a 40 mL sample. See also Soap solution.

Brucke's reagent (protein precipitation). See Potassium iodide-mercuric iodide.

Clarke's soap solution (estimation of hardness in water).

1. Dissolve 100 g of pure powdered castile soap in 1 L of 80% ethanol and allow to stand over night.
2. Prepare a solution of $CaCl_2$ by dissolving 0.5 g of $CaCO_3$ in HCl (sp. gr. 1.19), neutralize with NH_4OH and make slightly alkaline to litmus, and dilute to 500 mL. One mL is equivalent to 1 mg of $CaCO_3$.

Titrate (1) against (2) and dilute (1) with 80% ethanol until 1 mL of the resulting solution is equivalent to 1 mL of (2) after making allowance for the lather factor (the amount of standard soap solution required to produce a permanent lather in 50 mL of distilled water). One mL of the adjusted solution after subtracting the lather factor is equivalent to 1 mg of $CaCO_3$. See also Soap solution.

Cobalticyanide paper (Rinnmann's test for Zn). Dissolve 4 g of $K_3Co(CN)_6$ and 1 g of $KClO_3$ in 100 mL of water. Soak filter paper in solution and dry at 100°C. Apply drop of zinc solution and burn in an evaporating dish. A green disk is obtained if zinc is present.

Cochineal. Extract 1 g of cochineal for 4 days with 20 mL of alcohol and 60 mL of distilled water. Filter.

Congo red. Dissolve 0.5 g of congo red in 90 mL of distilled water and 10 mL of alcohol.

Cupferron (Baudisch's reagent for iron analysis). Dissolve 6 g of the ammonium salt of *N*-hydroxy-*N*-nitrosoaniline (cupferron) in 100 mL of H_2O. Reagent good for 1 week only and must be kept in the dark.

Cupric acetate (Barfoed's reagent for reducing monosaccharides). Dissolve 66 g of cupric acetate and 10 mL of glacial acetic acid in water and dilute to 1 L.

Cupric oxide, ammoniacal; Schweitzer's reagent (dissolves cotton, linen, and silk, but not wool).

1. Dissolve 5 g of cupric sulfate in 100 mL of boiling water, and add sodium hydroxide until precipitation is complete. Wash the precipitate well, and dissolve it in a minimum quantity of ammonium hydroxide.
2. Bubble a slow stream of air through 300 mL of strong ammonium hydroxide containing 50 g of fine copper turnings. Continue for 1 hour.

Cupric sulfate in glycerin-potassium hydroxide (reagent for silk). Dissolve 10 g of cupric sulfate, $CuSO_4 \cdot 5H_2O$, in 100 mL of water and add 5 g of glycerol. Add KOH solution slowly until a deep blue solution is obtained.

Cupron (precipitates copper). Dissolve 5 g of benzoinoxime in 100 mL of 95% ethanol.

Cuprous chloride, acidic (reagent for CO in gas analysis).

1. Cover the bottom of a 2-L flask with a layer of cupric oxide about 0.5 inch deep, suspend a coil of copper wire so as to reach from the bottom to the top of the solution, and fill the flask with hydrochloric acid (sp. gr. 1.10). Shake occasionally. When the solution becomes nearly colorless, transfer to reagent bottles, which should also contain copper wire. The stock bottle may be refilled with dilute hydrochloric acid until either the cupric oxide or the copper wire is used up. Copper sulfate may be substituted for copper oxide in the above procedure.
2. Dissolve 340 g of $CuCl_2 \cdot 2H_2O$ in 600 mL of conc. HCl and reduce the cupric chloride by adding 190 mL of a saturated solution of stannous chloride or until the solution is colorless. The stannous chloride is prepared by treating 300 g of metallic tin in a 500 mL flask with conc. HCl until no more tin goes into solution.
3. (Winkler method). Add a mixture of 86 g of CuO and 17 g of finely divided metallic Cu, made by the reduction of CuO with hydrogen, to a solution of HCl, made by diluting 650 mL of conc. HCl with 325 mL of water. After the mixture has been added slowly and with frequent stirring, a spiral of copper wire is suspended in the bottle, reaching all the way to the bottom. Shake occasionally, and when the solution becomes colorless, it is ready for use.

Cuprous chloride, ammoniacal (reagent for CO in gas analysis).

1. The acid solution of cuprous chloride as prepared above is neutralized with ammonium hydroxide until an ammonia odor persists. An excess of metallic copper must be kept in the solution.

2. Pour 800 mL of acidic cuprous chloride, prepared by the Winkler method, into about 4 L of water. Transfer the precipitate to a 250 mL graduate. After several hours, siphon off the liquid above the 50 mL mark and refill with 7.5% NH_4OH solution which may be prepared by diluting 50 mL of conc. NH_4OH with 150 mL of water. The solution is well shaken and allowed to stand for several hours. It should have a faint odor of ammonia.

Dichlorofluorescein indicator. Dissolve 1 g in 1 L of 70% alcohol or 1 g of the sodium salt in 1 L of water.

Dimethyglyoxime, 0.01 N. Dissolve 0.6 g of dimethylglyoxime (2,3-butanedione oxime) in 500 mL of 95% ethanol. This is an especially sensitive test for nickel, a very definite crimson color being produced.

Diphenylamine (reagent for rayon). Dissolve 0.2 g in 100 mL of concentrated sulfuric acid.

Diphenylamine sulfonate (for titration of iron with $K_2Cr_2O_7$). Dissolve 0.32 g of the barium salt of diphenylamine sulfonic acid in 100 mL of water, add 0.5 g of sodium sulfate and filter off the precipitate of $BaSO_4$.

Diphenylcarbazide. Dissolve 0.2 g of diphenylcarbazide in 10 mL of glacial acetic acid and dilute to 100 mL with 95% ethanol.

Esbach's reagent (estimation of protein). To a water solution of 10 g of picric acid and 20 g of citric acid, add sufficient water to make 1 L of solution.

Eschka's compound. Two parts of calcined ("light") magnesia are thoroughly mixed with 1 part of anhydrous sodium carbonate.

Fehling's solution (reagent for reducing sugars.)

1. Copper sulfate solution. Dissolve 34.66 g of $CuSO_4{\cdot}5H_2O$ in water and dilute to 500 mL.

2. Alkaline tartrate solution. Dissolve 173 g of potassium sodium tartrate (Rochelle salt, $KNaC_4H_4O_6{\cdot}4H_2O$) and 50 g of NaOH in water and dilute when cold to 500 mL.

Mix equal volumes of the two solutions at the time of using.

Ferric-alum indicator. Dissolve 140 g of ferric ammonium sulfate crystals in 400 mL of hot water. When cool, filter, and make up to a volume of 500 mL with dilute nitric acid.

Folin's mixture (for uric acid). To 650 mL of water add 500 g of $(NH_4)_2SO_4$, 5 g of uranium acetate, and 6 g of glacial acetic acid. Dilute to 1 L.

Formaldehyde — sulfuric acid (Marquis' reagent for alkaloids). Add 10 mL of formaldehyde solution to 50 mL of sulfuric acid.

Froehde's reagent. See Sulfomolybdic acid.

Fuchsin (reagent for linen). Dissolve 1 g of fuchsin in 100 mL of alcohol.

Fuchsin — sulfurous acid (Schiff's reagent for aldehydes). Dissolve 0.5 g of fuchsin and 9 g of sodium bisulfite in 500 mL of water, and add 10 mL of HCl. Keep in well-stoppered bottles and protect from light.

Gunzberg's reagent (detection of HCl in gastric juice). Prepare as needed a solution containing 4 g of phloroglucinol (1,3,5-benzenetriol) and 2 g of vanillin in 100 mL of absolute ethanol.

Hager's reagent. See Picric acid.

Hanus solution (for iodine number). Dissolve 13.2 g of resublimed iodine in 1 L of glacial acetic acid which will pass the dichromate test for reducible matter. Add sufficient bromine to double the halogen content, determined by titration (3 mL is about the proper amount). The iodine may be dissolved by the aid of heat, but the solution should be cold when the bromine is added.

Iodine, tincture of. To 50 mL of water add 70 g of I_2 and 50 g of KI. Dilute to 1 L with alcohol.

Iodo-potassium iodide (Wagner's reagent for alkaloids). Dissolve 2 g of iodine and 6 g of KI in 100 mL of water.

Litmus (indicator). Extract litmus powder three times with boiling alcohol, each treatment consuming an hour. Reject the alcoholic extract. Treat residue with an equal weight of cold water and filter; then exhaust with five times its weight of boiling water, cool and filter. Combine the aqueous extracts.

Magnesia mixture (reagent for phosphates and arsenates). Dissolve 55 g of magnesium chloride and 105 g of ammonium chloride in water, barely acidify with hydrochloric acid, and dilute to 1 L. The ammonium hydroxide may be omitted until just previous to use. The reagent, if completely mixed and stored for any period of time, becomes turbid

Magnesium uranyl acetate. Dissolve 100 g of $UO_2(C_2H_3O_2)_2{\cdot}2H_2O$ in 60 mL of glacial acetic acid and dilute to 500 mL. Dissolve 330 g of $Mg(C_2H_3O_2)_2{\cdot}4H_2O$ in 60 mL of glacial acetic acid and dilute to 200 mL. Heat solutions to the boiling point until clear, pour the magnesium solution into the uranyl solution, cool and dilute to 1 L. Let stand over night and filter if necessary.

Marme's reagent. See Potassium-cadmium iodide.

Marquis' reagent. See Formaldehyde-sulfuric acid.

Mayer's reagent (white precipitate with most alkaloids in slightly acid solutions). Dissolve 1.358 g of $HgCl_2$ in 60 mL of water and pour into a solution of 5 g of KI in 10 mL of H_2O. Add sufficient water to make 100 mL.

Methyl orange indicator. Dissolve 1 g of methyl orange in 1 L of water. Filter, if necessary.

Methyl orange, modified. Dissolve 2 g of methyl orange and 2.8 g of xylene cyanole FF in 1 L of 50% alcohol.

Methyl red indicator. Dissolve 1 g of methyl red in 600 mL of alcohol and dilute with 400 mL of water.

Methyl red, modified. Dissolve 0.50 g of methyl red and 1.25 g of xylene cyanole FF in 1 L of 90% alcohol. Or, dissolve 1.25 g of methyl red and 0.825 g of methylene blue in 1 L of 90% alcohol.

Millon's reagent (for albumins and phenols). Dissolve 1 part of mercury in 1 part of cold fuming nitric acid. Dilute with twice the volume of water and decant the clear solution after several hours.

Molisch's reagent. See 1-Naphthol.

1-Naphthol (Molisch's reagent for wool). Dissolve 15 g of 1-naphthol in 100 mL of alcohol or chloroform.

Nessler's reagent (for ammonia). Dissolve 50 g of KI in the smallest possible quantity of cold water (50 mL). Add a saturated solution of mercuric chloride (about 22 g in 350 mL of water will be needed) until an excess is indicated by the formation of a precipitate. Then add 200 mL of 5 N NaOH and dilute to 1 L. Let settle, and draw off the clear liquid.

Nickel oxide, ammoniacal (reagent for silk). Dissolve 5 g of nickel sulfate in 100 mL of water, and add sodium hydroxide solution until nickel hydroxide is completely precipitated. Wash the precipitate well and dissolve in 25 mL of concentrated ammonium hydroxide and 25 mL of water.

Nitron (detection of nitrate radical). Dissolve 10 g of nitron (1,4-diphenyl-3-(phenylamino)-1,2,4-triazolium hydroxide) in 5 mL of glacial acetic acid and 95 mL of water. The solution may be filtered with slight suction through an alumdum crucible and kept in a dark bottle.

1-Nitroso-2-naphthol. Make a saturated solution in 50% acetic acid (1 part of glacial acetic acid with 1 part of water). Does not keep well.

Nylander's solution (carbohydrates). Dissolve 20 g of bismuth subnitrate and 40 g of Rochelle salt in 1 L of 8% NaOH solution. Cool and filter.

Obermayer's reagent (for indoxyl in urine). Dissolve 4 g of $FeCl_3$ in 1 L of HCl (sp. gr. 1.19).

Oxine. Dissolve 14 g of 8-hydroxyquinoline in 30 mL of glacial acetic acid. Warm slightly, if necessary. Dilute to 1 L.

Oxygen absorbent. Dissolve 300 g of ammonium chloride in 1 L of water and add 1 L of concentrated ammonium hydroxide solution. Shake the solution thoroughly. For use as an oxygen absorbent, a bottle half full of copper turnings is filled nearly full with the NH_4Cl-NH_4OH solution and the gas passed through.

Pasteur's salt solution. To 1 L of distilled water add 2.5 g of potassium phosphate, 0.25 g of calcium phosphate, 0.25 g of magnesium sulfate, and 12.00 g of ammonium tartrate.

Pavy's solution (glucose reagent). To 120 mL of Fehling's solution, add 300 mL of NH_4OH (sp. gr. 0.88) and dilute to 1 L with water.

Phenanthroline ferrous ion indicator. Dissolve 1.485 g of 1,10-phenanthroline monohydrate in 100 mL of 0.025 M ferrous sulfate solution.

Phenolphthalein. Dissolve 1 g of phenolphthalein in 50 mL of alcohol and add 50 mL of water.

Phenolsulfonic acid (determination of nitrogen as nitrate). Dissolve 25 g of phenol in 150 mL of conc. H_2SO_4, add 75 mL of fuming H_2SO_4 (15% SO_3), stir well and heat for 2 hours at 100°C.

Phloroglucinol solution (pentosans). Make a 3% phloroglucinol (1,3,5-benzenetriol) solution in alcohol. Keep in a dark bottle.

Phosphomolybdic acid (Sonnenschein's reagent for alkaloids).

1. Prepare ammonium phosphomolybdate and after washing with water, boil with nitric acid and expel NH_3; evaporate to dryness and dissolve in 2 M nitric acid.
2. Dissolve ammonium molybdate in HNO_3 and treat with phosphoric acid. Filter, wash the precipitate, and boil with aqua regia until the ammonium salt is decomposed. Evaporate to dryness. The residue dissolved in 10 % HNO_3 constitutes Sonnenschein's reagent.

Phosphoric acid — sulfuric acid mixture. Dilute 150 mL of conc. H_2SO_4 and 100 mL of conc. H_3PO_4 (85%) with water to a volume of 1 L.

Phosphotungstic acid (Schcibicr's reagent for alkaloids).

1. Dissolve 20 g of sodium tungstate and 15 g of sodium phosphate in 100 mL of water containing a little nitric acid.
2. The reagent is a 10% solution of phosphotungstic acid in water. Thc.phosphotungstic acid is prepared by evaporating a mixture of 10 g of sodium tungstate dissolved in 5 g of phosphoric acid (sp. gr. 1.13) and enough boiling water to effect solution. Crystals of phosphotungstic acid separate.

Picric acid (Hager's reagent for alkaloids, wool and silk). Dissolve 1 g of picric acid in 100 mL of water.

Potassium antimonate (reagent for sodium). Boil 22 g of potassium antimonate with 1 L of water until nearly all of the salt has dissolved, cool quickly, and add 35 mL of 10% potassium hydroxide. Filter after standing overnight.

Potassium-cadmium iodide (Marme's reagent for alkaloids). Add 2 g of CdI_2 to a boiling solution of 4 g of KI in 12 mL of water, and then mix with 12 mL of saturated KI solution.

Potassium hydroxide (for CO_2 absorption). Dissolve 360 g of KOH in water and dilute to 1 L.

Potassium iodide — mercuric iodide (Brucke's reagent for proteins). Dissolve 50 g of KI in 500 mL of water, and saturate with mercuric iodide (about 120 g). Dilute to 1 L.

Potassium pyrogallate (for oxygen absorption). For mixtures of gases containing less than 28% oxygen, add 100 mL of KOH solution (50 g of KOH to 100 mL of water) to 5 g of pyrogallol. For mixtures containing more than 28% oxygen the KOH solution should contain 120 g of KOH to 100 mL of water.

Pyrogallol, alkaline.

1. Dissolve 75 g of pyrogallic acid in 75 mL of water.
2. Dissolve 500 g of KOH in 250 mL of water. When cool, adjust until sp. gr. is 1.55.

For use, add 270 mL of solution (2) to 30 mL of solution (1).

Rosolic acid (indicator). Dissolve 1 g of rosolic acid in 10 mL of alcohol and add 100 mL of water.

Scheibler's reagent. See Phosphotungstic acid.

Schiff's reagent. See Fuchsin-sulfurous acid.

Schweitzer's reagent. See Cupric oxide, ammoniacal.

Soap solution (reagent for hardness in water). Dissolve 100 g of dry castile soap in 1 L of 80% alcohol (5 parts alcohol to 1 part water). Allow to stand several days and dilute with 70% to 80% alcohol until 6.4 mL produces a permanent lather with 20 mL of standard calcium solution. The latter solution is made by dissolving 0.2 g of $CaCO_3$ in a small amount of dilute HCl, evaporating to dryness and making up to 1 L.

Sodium bismuthate (oxidation of manganese). Heat 20 parts of NaOH nearly to redness in an iron or nickel crucible and add slowly 10 parts of basic bismuth nitrate which has been previously dried. Add 2 parts of sodium peroxide, and pour the brownish-yellow fused mass onto an iron plate to cool. When cold, break up in a mortar, extract with water, and collect on an asbestos filter.

Sodium hydroxide (for CO_2 absorption). Dissolve 330 g of NaOH in water and dilute to 1 L.

Sodium nitroprusside (reagent for hydrogen sulfide and wool). Use a freshly prepared solution of 1 g of sodium nitroferricyanide in 10 mL of water.

Sodium oxalate (primary standard). Dissolve 30 g of the commercial salt in 1 L of water, make slightly alkaline with sodium hydroxide, and let stand until perfectly clear. Filter and evaporate the filtrate to 100 mL. Cool and filter. Pulverize the residue and wash it several times with small volumes of water. The procedure is repeated until the mother liquor is free from sulfate and is neutral to phenolphthalein.

Sodium plumbite (reagent for wool). Dissolve 5 g of sodium hydroxide in 100 mL of water. Add 5 g of litharge (PbO) and boil until dissolved.

Sodium polysulfide. Dissolve 480 g of $Na_2S \cdot 9H_2O$ in 500 mL of water, add 40 g of NaOH and 18 g of sulfur. Stir thoroughly and dilute to 1 L with water.

Sonnenschein's reagent. See Phosphomolybdic acid.

Starch solution.

1. Make a paste with 2 g of soluble starch and 0.01 g of HgI_2 with a small amount of water. Add the mixture slowly to 1 L of boiling water and boil for a few minutes. Keep in a glass stoppered bottle. If other than soluble starch is used, the solution will not clear on boiling; it should be allowed to stand and the clear liquid decanted.
2. A solution of starch which keeps indefinitely is made as follows: Mix 500 mL of saturated NaCl solution (filtered), 80 mL of glacial acetic acid, 20 mL of water and 3 g of starch. Bring slowly to a boil and boil for 2 minutes.
3. Make a paste with 1 g of soluble starch and 5 mg of HgI_2, using as little cold water as possible. Then pour about 200 mL of boiling water on the paste and stir immediately. This will give a clear solution if the paste is prepared correctly and the water actually boiling. Cool and add 4 g of KI. Starch solution decomposes on standing due to bacterial action, but this solution will keep well if stored under a layer of toluene.

Stoke's reagent. Dissolve 30 g of $FeSO_4$ and 20 g of tartaric acid in water and dilute to 1 L. Just before using, add concentrated NH_4OH until the precipitate first formed is redissolved.

Sulfanilic acid (reagent for nitrites). Dissolve 0.5 g of sulfanilic acid in a mixture of 15 mL of glacial acetic acid and 135 mL of recently boiled water.

Sulfomolybdic acid (Froehde's reagent for alkaloids and glucosides). Dissolve 10 g of molybdic acid or sodium molybdate in 100 mL of conc. H_2SO_4.

Tannic acid (reagent for albumin, alkaloids, and gelatin). Dissolve 10 g of tannic acid in 10 mL of alcohol and dilute with water to 100 mL.

Titration mixture. (residual chlorine in water analyasis). Prepare 1 L of dilute HCl (100 mL of HCl (sp. gr. 1.19) in sufficient water to make 1 L). Dissolve 1 g of *o*-tolidine in 100 mL of the dilute HCl and dilute to 1 L with dilute HCl solution.

Trinitrophenol solution. See Picric acid.

Turmeric tincture (reagent for borates). Digest ground turmeric root with several quantities of water which are discarded. Dry the residue and digest it several days with six times its weight of alcohol. Filter.

Uffelmann's reagent (turns yellow in presence of lactic acid). To a 2% solution of pure phenol in water, add a water solution of $FeCl_3$ until the phenol solution becomes violet in color.

Wagner's reagent. See Iodo-potassium iodide.

Wagner's solution (used in phosphate rock analysis to prevent precipitation of iron and aluminum). Dissolve 25 g of citric acid and 1 g of salicylic acid in water and dilute to 1 L. Use 50 mL of the reagent.

Wij's iodine monochloride solution (for iodine number). Dissolve 13 g of resublimed iodine in 1 L of glacial acetic acid which will pass the dichromate test for reducible matter. Set aside 25 mL of this solution. Pass into the remainder of the solution dry chlorine gas (dried and washed by passing through H_2SO_4 (sp. gr. 1.84)) until the characteristic color of free iodine has been discharged. Now add the iodine solution which was reserved, until all free chlorine has been destroyed. A slight excess of iodine does little or no harm, but an excess of chlorine must be avoided. Preserve in well stoppered, amber colored bottles. Avoid use of solutions which have been prepared for more than 30 days.

Wij's special solution (for iodine number). To 200 mL of glacial acetic acid that will pass the dichromate test for reducible matter, add 12 g of dichloramine T (*N*,*N*-dichloro-4-methyl-benzenesulfonamide), and 16.6 g of dry KI (in small quantities with continual shaking until all the KI has dissolved). Make up to 1 L with the same quality of acetic acid used above and preserve in a dark colored bottle.

Zimmermann-Reinhardt reagent (determination of iron). Dissolve 70 g of $MnSO_4 \cdot 4H_2O$ in 500 mL of water, add 125 mL of conc. H_2SO_4 and 125 mL of 85% H_3P0_4, and dilute to 1 L.

Zinc chloride solution, basic (reagent for silk). Dissolve 1000 g of zinc chloride in 850 mL of water, and add 40 g of zinc oxide. Heat until solution is complete.

Zinc uranyl acetate (reagent for sodium). Dissolve 10 g of $UO_2(C_2H_3O_2)_2 \cdot 2H_2O$ in 6 g of 30% acetic acid with heat, if necessary, and dilute to 50 mL. Dissolve 30 g of $Zn(C_2H_3O_2)_2 \cdot H_2O$ in 3 g of 30% acetic acid and dilute to 50 mL. Mix the two solutions, add 50 mg of NaCl, allow to stand overnight and filter.

STANDARD SOLUTIONS OF ACIDS, BASES, AND SALTS

For each compound listed, the last column of this table gives the mass in grams which is contained in 1 liter of a solution whose amount-of-substance concentration divided by the equivalence factor of the compound equals 0.1 mol/L. In the older literature such a solution is often referred to as a "decinormal solution" (0.1 N).

REFERENCE

Compendium of Analytical Nomenclature (IUPAC), Pergamon Press, Oxford, 1978.

Name	Formula	Atomic or molecular weight	Equivalence factor	Mass in grams
Acetic acid	$HC_2H_3O_2$	60.0530	1	6.0053
Ammonia	NH_3	17.0306	1	1.7031
Ammonium ion	NH_4^+	18.0386	1	1.8039
Ammonium chloride	NH_4Cl	53.4916	1	5.3492
Ammonium sulfate	$(NH_4)_2SO_4$	132.1388	1/2	6.6069
Ammonium thiocyanate	NH_4CNS	76.1204	1	7.6120
Barium	Ba	137.34	1/2	6.867
Barium carbonate	$BaCO_3$	197.3494	1/2	9.8675
Barium chloride hydrate	$BaCl_2 \cdot 2H_2O$	244.2767	1/2	12.2138
Barium hydroxide	$Ba(OH)_2$	171.3547	1/2	8.5677
Barium oxide	BaO	153.3394	1/2	7.6670
Bromine	Br	79.909	1	7.9909
Calcium	Ca	40.08	1/2	2.004
Calcium carbonate	$CaCO_3$	100.0894	1/2	5.0045
Calcium chloride	$CaCl_2$	110.9860	1/2	5.5493
Calcium chloride hydrate	$CaCl_2 \cdot 6H_2O$	219.0150	1/2	10.9508
Calcium hydroxide	$Ca(OH)_2$	74.0947	1/2	3.7047
Calcium oxide	CaO	56.0794	1/2	2.8040
Chlorine	Cl	35.453	1	3.5453
Citric acid	$C_6H_8O_7 \cdot H_2O$	210.1418	1/3	7.0047
Cobalt	Co	58.9332	1/2	2.9466
Copper	Cu	63.54	1/2	3.177
Copper oxide (cupric)	CuO	79.5394	1/2	3.9770
Copper sulfate hydrate	$CuSO_4 \cdot 5H_2O$	249.6783	1/2	12.4839
Hydrochloric acid	HCl	36.4610	1	3.6461
Hydrocyanic acid	HCN	27.0258	1	2.7026
Iodine	I	126.9044	1	12.6904
Lactic acid	$C_3H_6O_3$	90.0795	1	9.0080
Malic acid	$C_4H_6O_5$	134.0894	1/2	6.7045
Magnesium	Mg	24.312	1/2	1.2156
Magnesium carbonate	$MgCO_3$	84.3214	1/2	4.2161
Magnesium chloride	$MgCl_2$	95.2180	1/2	4.7609
Magnesium chloride hydrate	$MgCl_2 \cdot 6H_2O$	203.2370	1/2	10.1623
Magnesium oxide	MgO	40.3114	1/2	2.0156
Manganese	Mn	54.938	1/2	2.7469
Manganese sulfate	$MnSO_4$	150.9996	1/2	7.5500
Mercuric chloride	$HgCl_2$	271.4960	1/2	13.5748
Nickel	Ni	58.71	1/2	2.9356
Nitric acid	HNO_3	63.0129	1	6.3013
Oxalic acid	$H_2C_2O_4$	90.0358	1/2	4.5018
Oxalic acid hydrate	$H_2C_2O_4 \cdot 2H_2O$	126.0665	1/2	6.3033
Oxalic acid anhydride	C_2O_3	72.0205	1/2	3.6010
Phosphoric acid	H_3PO_4	97.9953	1/3	3.2665
Potassium	K	39.102	1	3.9102
Potassium bicarbonate	$KHCO_3$	100.1193	1	10.0119
Potassium carbonate	K_2CO_3	138.2134	1/2	6.9106
Potassium chloride	KCl	74.5550	1	7.4555

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STANDARD SOLUTIONS OF ACIDS, BASES, AND SALTS (continued)

Name	Formula	Atomic or molecular weight	Equivalence factor	Mass in grams
Potassium cyanide	KCN	65.1199	1	6.5120
Potassium hydroxide	KOH	56.1094	1	5.6109
Potassium oxide	K_2O	94.2034	1/2	4.7102
Potassium tartrate	$K_2H_4C_4O_6$	226.2769	1/2	11.3139
Silver	Ag	107.87	1	10.787
Silver nitrate	$AgNO_3$	169.8749	1	16.9875
Sodium	Na	22.9898	1	2.2990
Sodium bicarbonate	$NaHCO_3$	84.0071	1	8.4007
Sodium carbonate	Na_2CO_3	105.9890	1/2	5.2995
Sodium chloride	NaCl	58.4428	1	5.8443
Sodium hydroxide	NaOH	39.9972	1	3.9997
Sodium oxide	Na_2O	61.9790	1/2	3.0990
Sodium sulfide	Na_2S	78.0436	1/2	3.9022
Succinic acid	$H_2C_4H_4O_4$	118.0900	1/2	5.9045
Sulfuric acid	H_2SO_4	98.0775	1/2	4.9039
Tartaric acid	$C_4H_6O_6$	150.0888	1/2	7.5044
Zinc	Zn	65.37	1/2	3.269
Zinc sulfate hydrate	$ZnSO_4 \cdot 7H_2O$	287.5390	1/2	14.3769

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STANDARD SOLUTIONS OF OXIDATION AND REDUCTION REAGENTS

For each reagent listed, the last column of this table gives the mass in grams which is contained in a solution whose amount-of-substance concentration divided by the equivalence factor of the compound equals 0.1 mol/L. The equivalence factor given refers to the most common reactions of the reagent. In the older literature such a solution is often called a “decinormal solution” (0.1 N).

REFERENCE

Compendium of Analytical Nomenclature (IUPAC), Pergamon Press, Oxford, 1978.

Name	Formula	Atomic or molecular weight	Equivalence factor	Mass in grams
Antimony	Sb	121.75	1/2	6.0875
Arsenic	As	74.9216	1/2	3.7461
Arsenic trisulfide	As_2S_3	246.0352	1/4	6.1509
Arsenous oxide	As_2O_3	197.8414	1/4	4.9460
Barium peroxide	BaO_2	169.3388	1/2	8.4669
Barium peroxide hydrate	$BaO_2 \cdot 8H_2O$	313.4615	1/2	15.6730
Calcium	Ca	40.08	1/2	2.004
Calcium carbonate	$CaCO_3$	100.0894	1/2	5.0045
Calcium hypochlorite	$Ca(OCl)_2$	142.9848	1/4	3.5746
Calcium oxide	CaO	56.0794	1/2	2.8040
Chlorine	Cl	35.453	1	3.5453
Chromium trioxide	CrO_3	99.9942	1/3	3.3331
Ferrous ammonium sulfate	$FeSO_4(NH_4)SO_4 \cdot 6H_2O$	392.0764	1	39.2076
Hydroferrocyanic acid	$H_4Fe(CN)_6$	215.9860	1	21.5986
Hydrogen peroxide	H_2O_2	34.0147	1/2	1.7007
Hydrogen sulfide	H_2S	34.0799	1/2	1.7040
Iodine	I	126.9044	1	12.6904
Iron	Fe	55.847	1	5.5847
Iron oxide (ferrous)	FeO	71.8464	1	7.1846
Iron oxide (ferric)	Fe_2O_3	159.6922	1/2	7.9846
Lead peroxide	PbO_2	239.1888	1/2	11.9594
Manganese dioxide	MnO_2	86.9368	1/2	4.3468
Nitric acid	HNO_3	63.0129	1/3	2.1004
Nitrogen trioxide	N_2O_3	76.0116	1/4	1.9002
Nitrogen pentoxide	N_2O_5	108.0104	1/6	1.8001
Oxalic acid	$C_2H_2O_4$	90.0358	1/2	4.5018
Oxalic acid hydrate	$C_2H_2O_4 \cdot 2H_2O$	126.0665	1/2	6.3033
Oxygen	O	15.9994	1/2	0.8000
Potassium dichromate	$K_2Cr_2O_7$	294.1918	1/6	4.9032
Potassium chlorate	$KClO_3$	122.5532	1/6	2.0425
Potassium chromate	K_2CrO_4	194.1076	1/3	6.4733
Potassium ferrocyanide	$K_4Fe(CN)_6$	368.3621	1	36.8362
Potassium ferrocyanide hydrate	$K_4Fe(CN)_6 \cdot 3H_2O$	422.4081	1	42.2408
Potassium iodide	KI	166.0064	1	16.6006
Potassium nitrate	KNO_3	101.1069	1/3	3.3702
Potassium perchlorate	$KClO_4$	138.5526	1/8	1.7319
Potassium permanganate	$KMnO_4$	158.0376	1/5	3.1608
Sodium chlorate	$NaClO_3$	106.4410	1/6	1.7740
Sodium nitrate	$NaNO_3$	84.9947	1/3	2.8332
Sodium thiosulfate hydrate	$Na_2S_2O_3 \cdot 5H_2O$	248.1825	1	24.8183
Stannous chloride	$SnCl_2$	189.5960	1/2	9.4798
Stannous oxide	SnO	134.6894	1/2	6.7345
Sulfur dioxide	SO_2	64.0628	1/2	3.2031
Tin	Sn	118.69	1/2	5.935

ORGANIC ANALYTICAL REAGENTS FOR THE DETERMINATION OF INORGANIC SUBSTANCES

G. Ackermann, L. Sommer, and D. Thorburn Burns

Determination	Reagents	Ref.
Aluminium	Alizarin Red S	Onishi, Part II a, p 28. (5), Snell, *Metals I,* p 587. (7)
	Aluminon	Fries/Getrost, p 16. (2), Onishi, IIa, p 21. (5), Snell, *Metals I,* p 590. (7)
	Aluminon + Cetyltrimethylammonium bromide	Huaxue Shiji, *8*, 85, (1986)
	Chrome Azurol S	Onishi, Part IIa, p 26. (5), Snell, *Metals I,* p 605. (7)
	Chrome Azurol S + Cetyltrimethylammonium bromide	Marczenko, p 133 (3), Snell, *Metals I,* p 606. (7)
	Chromazol KS + Cetylpyridinium bromide	*Analyst*, *107*, 428, (1982).
	Eriochrome Cyanine R	Fries/Getrost, p 19 (2), Onishi, Part IIa p 25. (5), Snell, *Metals I,* p 611. (7)
	Eriochrome Cyanine R + Cetyltrimethylammonium bromide	Snell, *Metals I,* p 613. (7), *Analyst, 107*, 1431, (1982).
	8-Hydroxyquinoline	Fries/Getrost, p 22 (2), Marczenko, p 131 (3), Onishi, Part IIa, p 31. (5), Snell, *Metals I , p* 622 (7)
Ammonia	Phenol + Sodium hypochlorite	Boltz, p 210 (1), Marczenko, p 413 (3), Snell, *Nonmetals*, p 604 (9)
Antimony	Brilliant Green	Onishi, Part IIa, p 102. (5), Snell, *Metals I,* p 384. (7)
	Bromopyrogallol Red	*Talanta*, *13*, 507, (1966).
	Rhodamine B	Fries/Getrost, p 32, (2), Marczenko, p 141. (3), Onishi, Part IIa, p 93. (5), Snell, *Metals I,* p 404. (7)
	Silver diethyldithiocarbamate	Fries/Getrost, p 36. (2)
Arsenic	Silver diethyldithiocarbamate	Fries/Getrost, p 41. (2), Marczenko, p 153. (3), Onishi, Part IIa, p 153. (5), Snell, *Metals I,* p 370. (7)
Barium	Sulfonazo III	Fries/Getrost, p 46. (2), Snell, *Metals II,* p 1782. (8), Onishi, Part IIa, p 202. (5)
Beryllium	Beryllon II	Snell, *Metals I,* p 667. (7)
	Chrome Azurol S	Marczenko, p 163. (3), Snell, *Metals I,* p 672. (7)
	Chrome Azurol S + Cetyltrimethylammonium bromide	Marczenko, p 164. (3), Snell, *Metals I,* p 673. (7)
	Eriochrome Cyanine R	Snell, *Metals I,* p 675. (7), *Talanta*, *31*, 249, (1984).
	Eriochrome Cyanine R + Cetyltrimethylammonium bromide	Zh, *Anal. Khim.*, *33*, 1298, (1978).
Bismuth	Dithizone	Onishi, Part IIa, p 262. (5), Snell, *Metals I*, p 303. (7)
	Pyrocatechol Violet	Fres. Z. *Anal. Chem.*, *186*, 418, (1962).
	Pyrocatechol Violet + Cetyltrimethylammonium bromide	Zh. *Anal. Khim.*, *38*, 216, (1983).
	Thiourea	Onishi, Part IIa, p 260. (5), Snell, *Metals I,* p 317. (7)
	Xylenol Orange	Friez/Getrost, p 57. (2), Marczenko, p 172. (3), Snell, *Metals I,* p 320. (7)
Boron	Azomethine H	Snell, Nonmetals, p 165. (9)
	Carminic acid	Boltz, p 14. (1), Fries/Getrost, p 65. (2), Snell, Nonmetals, p 170. (9), Williams, p 35. (11)
	Curcumin	Boltz, p 8. (1), Fries/Getrost, p 68. (2), Marczenko, p 180. (3), Snell, Nonmetals, p 180. (9), Fres. Z. *Anal. Chem., 323*, 266, (1986).

ORGANIC ANALYTICAL REAGENTS FOR THE DETERMINATION OF INORGANIC SUBSTANCES (continued)

Determination	Reagents	Ref.
	Methylene Blue	Boltz, p 21. (1), Marczenko, p 183. (3), Snell, Nonmetals, p 205. (9), T*alanta, 31*, 547, (1984).
Bromide	Fluorescein	Boltz, p 48. (1), Snell, Nonmetals, p 276., Fres. Z. *Anal. Chem., 301*, 28 (1980).
	Phenol Red	Boltz, p 44. (1), Marczenko, p 190. (3), Snell, Nonmetals, p 28. (9)
Cadmium	2-(5-Bromo-2-pyridylazo)-5-diethylaminophenol	Marczenko, p 197. (3)
	Cadion	Onishi, Part IIa, p 323. (5)
	Dithizone	Fries/Getrost, p 78. (2), Onishi, Part IIa, p 315. (5), Snell, *Metals I,* p 279. (7), West, p 25. (10).
	4–(2-Pyridylazo)resorcinol	Fres. Z. *Anal. Chem., 310*, 51, (1982).
Calcium	Chlorophosphonazo III	Marczenko, p 207. (3), Snell, *Metals II,* p 1744. (8)
	Glyoxal-bis(2-hydroxyanil)	Fries/Getrost, p 86. (2), Onishi, Part IIa, p 352. (5), Snell, *Metals I,* p 1762. (8)
	Murexide	Onishi, Part IIa, p 357. (5), Snell, *Metals II,* p 1769. (8)
	Phthalein Purple	*Anal. Chim. Acta*, *34*, 71 (1966).
Cerium	*N*-benzoyl-*N*-phenylhydroxylamine	*Anal. Chim. Acta*, *48*, 155, (1969).
	8-Hydroxyquinoline	Fries/Getrost, p 93. (2), Marczenko, p 220. (3), Onishi, Part IIa, p 383. (7)
Chlorine	*N,N*-Diethyl-1,4-phenylenediamine	Boltz, p 92. (1), Fries/Getrost, p 101. (2), Snell, Nonmetals, p 225. (9), *Analyst, 90*, 187, (1965).
Chromium	1,5-Diphenylcarbazide	Fries/Getrost, p 105. (2), Onishi, Part IIa, p 412. (5), Snell, *Metals I,* p 714. (7), West, p 12. (10)
	4-(2-Pyridylazo)resorcinol	Snell, *Metals I,* p 736. (7), West, p 17. (10)
	4-(2-Pyridylazo)resorcinol + Tetradecyldimethyl-benzylammonium chloride	West, p 17. (10), A*nal. Chim. Acta, 67*, 297, (1973).
	4-(2-Pyridylazo)resorcinol + Hydrogen peroxide	Fres. Z. *Anal. Chem., 304*, 382, (1980).
Cobalt	Nitroso-R salt	Fries/Getrost, p 118. (2), Onishi, Part IIa, p 454. (5), Snell, *Metals I,* p 953. (7)
	1-Nitroso-2-naphthol	Fries/Getrost, p 111. (2), Marczenko, p 246. (3), Snell, *Metals I,* p 947. (5)
	2-Nitroso-1-naphthol	Fries/Getrost, p 113. (2), Onishi, Part IIa, p 459. (5), Snell, *Metals I,* p 949. (7), West, p 45. (10)
	4-(2-Pyridylazo)resorcinol	Snell, *Metals I,* p 969. (7), West, p 44. (10)
	4-(2-Pyridylazo)resorcinol + Diphenylguanidine	Zh. *Anal. Khim.*, *35*, 1306, (1980).
Copper	Bathocuproine	Fries/Getrost, p 135. (2), Snell, *Metals I,* p 148. (7)
	Bathocuproine disulfonic acid	Fries/Getrost, p 137. (2), West, p 52. (10)
	Dithizone	Marczenko, p 258. (3), Onishi, Part IIa, p 529. (5), Snell, *Metals I,* p 199. (7)
	Neocuproine	Snell, *Metals I,* p 217. (5), West, p 51. (10)
	Cuprizone	Onishi, Part IIa, p 534. (5), Snell, *Metals I,* p 157. (7), West, p 53. (10)
	4-(2-pyridylazo)resorcinol + Tetradecyldimethyl-benzylammonium chloride	*Anal. Chim.* Acta, *138*, 321, (1982).
Cyanide	Barbituric Acid + Pyridine	Fries/Getrost, p 153. (2), Snell, Nonmetals, p 653. (9)
	Barbituric Acid + Pyridine-4-carboxylic acid	*Anal. Chim. Acta*, *99*, 197, (1978).

ORGANIC ANALYTICAL REAGENTS FOR THE DETERMINATION OF INORGANIC SUBSTANCES (continued)

Determination	Reagents	Ref.
Fluoride	Alizarin Fluorine blue + Lanthanum(III) ion	Boltz, p 129. (1), Fries/Getrost, p 158. (2), Snell, *Nonmetals*, p 333. (9), Williams, p 354. (11)
	Eriochrome Cyanine R + Zirconium(IV) ion	Boltz, p 119. (1), Snell, *Nonmetals*, p 359. (2), Williams, p 357. (10)
Gallium	Pyrocatechol violet + Diphenylguanidine	Snell, *Metals I,* p 500. (7)
	8-Hydroxyquinoline	Onishi Pt IIa, p 582. (5), Snell, *Metals I,* p 505. (7)
	1-(2-Pyridylazo)-2-naphthol	Snell, *Metals I,* p 512. (7)
	4-(2-Pyridylazo)resorcinol	Snell, *Metals I,* p 513. (7)
	Rhodamine B	Marczenko, p 284. (3), Onishi, Part IIa, p 578. (5), Snell, *Metals I,* p 515. (7)
	Xylenol Orange	Fries/Getrost, p 166. (2), Snell, *Metals I,* p 523. (7)
	Xylenol Orange + 8-Hydroxyquinoline	*Zh. Anal. Khim., 26,* 75, (1971).
Germanium	Brilliant Green + Molybdate	Snell, *Metals I,* p 562. (7)
	Phenylfluorone	Fries/Getrost, p 168. (2), Marczenko, p 292. (3), Onishi, Part IIa, p 607. (5), Snell, *Metals I,* p 570. (7)
Gold	5-(4-Diethylaminobenzylidene) rhodanine	Fries/Getrost, p 173. (2), Onishi, Part IIa, p 631. (5), Snell, *Metals II,* p 1516. (8)
	Rhodamine B	Fries/Getrost, p 175. (2), Marczenko, p 301. (3), Onishi, Part IIa, p 637. (5), Snell, *Metals II,* p 513. (8)
Hafnium	Arsenazo III	Snell, *Metals II,* p 1184. (8), *Talanta, 19,* 807, (1972).
Indium	Bromopyrogallol Red	Snell, *Metals I,* p 469. (7)
	Chrome Azurol S	Snell, *Metals I,* p 474. (7)
	Chrome Azurol S + Cetyltrimethylammonium bromide	*Anal. Chim. Acta, 67,* 107, (1973).
	Dithizone	Fries/Getrost, p 179. (2), Onishi, Part IIa, p 672. (5), Snell, *Metals I,* p 474. (7)
	8-Hydroxyquinoline	Onishi, Part IIa, p 670. (5), Snell, *Metals I,* p 475. (7)
	1-(2-Pyridylazo)-2-naphthol	Snell, *Metals I,* p 480. (7)
	4-(2-Pyridylazo)resorcinol	Marczenko, p 309. (3), Snell, Metals I, p 480. (7)
Iodide	Neocuproine + Copper(II)	*Anal. Chim. Acta, 69*, 321, (1974).
Iodine	Starch	Boltz, p 162. (1), Marczenko, p 316. (3), Snell, *Nonmetals,* p 307. (9)
Iridium	Rhodamine 6G + Tin(II)	Marczenko, p 323. (3)
	N,N-Dimethyl-4-nitrosoaniline	*Anal. Chem., 27,* 1776, (1955).
Iron	Bathophenanthroline	Fries/Getrost, p 189. (2), Onishi, Part IIa, p 729. (5), Snell, *Metals I,* p 763. (7)
	Bathophenanthroline disulfonic acid	Fries/Getrost, p 191. (2), Snell, *Metals I,* p 772. (7)
	2,2′-Bipyridyl	Snell, *Metals I,* p 750. (7)
	Chrome Azurol S + Cetyltrimethylammonium bromide	Snell, *Metals I,* p 757. (7), *Coll. Czech. Chem. Comm., 45,* 2656, (1980).
	1,10-Phenanthroline	Fries/Getrost, p 199. (2), Marczenko, p 331. (3), Onishi, Part IIa, p 725. (5), Snell, *Metals I,* p 795. (7)
	1,10-Phenanthroline + Bromothymol Blue	*Zh. Anal. Khim., 25,* 1348, (1970).
	Ferrozine	Onishi, Part IIa, p 730. (5), Snell, *Metals I,* p 783. (7)
Lanthanum	Arsenazo III	Marczenko, p 468. (3), Snell, *Metals II,* p 1910. (8)

Determination	Reagents	Ref.
Lead	Dithizone	Fries/Getrost, p 207. (2), Onishi, Part IIa, p 824. (5), Snell, *Metals I,* p 2. (7), West, p 34. (10)
	Sodium diethyldithiocarbamate	Fries/Getrost, p 214. (2), Snell, *Metals I,* p 27. (7)
	4-(2-Pyridylazo)resorcinol	Fries/Getrost, p 220. (2), Marczenko, p 347. (3), Snell, *Metals I,* p 34. (7)
Lithium	Thoron	Onishi, Part IIa, p 863. (5), Snell, *Metals II,* p 1726. (8), T*alanta*, *30*, 587, (1983).
Magnesium	Eriochrome Black T	Fries/Getrost, p 226. (2), Marczenko, p 355. (3), Onishi, Part IIb, p 13. (6), Snell, *Metals II,* p 1932. (8)
	8-Hydroxyquinoline	Onishi, Part IIb, p 11. (6), Snell, *Metals II,* p 1938. (8)
	8-Hydroxyquinoline + Butylamine	Fries/Getrost, p 228. (2), Snell, *Metals II,* p 1938. (8)
	Titan Yellow	Fries/Getrost, p 234. (2), Marczenko, p 352. (3), Snell, *Metals II,* p 1945. (8)
	Xylidyl Blue	Fries/Getrost, p 231. (2), Onishi, Part IIb, p 14. (6), Snell, *Metals II,* p 1950. (8)
Manganese	Formaldoxime	Fries/Getrost, p 236. (2), Marczenko, p 364. (3), Onishi Part IIb, p 38. (6), Snell, *Metals II,* 1010. (8)
Mercury	Dithizone	Fries/Getrost, p 243. (2), Marczenko, p 373. (3), Onishi, Part IIb, p 66. (6), Snell, *Metals I,* p 107. (7), West, p 29. (10)
	Michler's thioketone	Marczenko, p 375. (3), Snell, *Metals I,* p 126. (7)
	Xylenol Orange	*Talanta*, *16*, 1023, (1969)
Molybdenum	Bromopyrogallol Red + Cetylpyridium chloride	West, p 58. (10)
	Phenylfluorone	Snell, *Metals II*, p 1311., *Microchem. J.*, *31*, 56, (1985).
	Toluene-3,4-dithiol	Fries/Getrost, p 251. (2), Marczenko, p 384. (3), Onishi, Part IIb, p 96. (6), Snell, *Metals II,* p 1301. (8)
Nickel	2-(5-Bromo-2-pyridylazo)-5-diethylaminophenol	Marczenko, p 397. (3), *Talanta 28,* 189, (1981).
	Dimethylglyoxime	Fries/Getrost, p 263. (2), Marczenko, p 393. (3), Onishi, Part IIb, p 125. (6), Snell, *Metals I,* p 887. (7)
	Dimethylglyoxime + Oxidant	Fries/Getrost, p 263. (2), Onishi, Part IIb, p 125. (6), Snell, *Metals I,* p 887. (7)
	2,2′-Furildioxime	Marczenko, p 396. (3), Snell, *Metals I,* p 904. (7)
	2-(2-Pyridylazo)-2-naphthol	Snell, *Metals I,* p 910. (7)
	4-(2-Pyridylazo)resorcinol	Snell, *Metals I,* p 911. (7), West, p 39. (10), *Anal. Chim. Acta, 82*, 431, (1976).
Niobium	*N*-Benzoyl-*N*-phenylhydroxylamine	Snell, *Metals II,* p 1425. (8)
	Pyrocatechol + EDTA or 2,2′Bipyridyl or 1-(2-thenoyl)-3,3,3,-trifluoroacetone	Snell, *Metals II,* p 1427. (8)
	Bromopyrogallol red	Marczenko, p 407. (3), Snell, *Metals II,* p 1426. (8)
	Bromopyrogallol red + Cetylpyridinium chloride	*Talanta*, *32*, 189, (1985).
	4-(2-Pyridylazo)resorcinol	Fries/Getrost, p 274. (2), Marczenko, p 406. (3), Onishi, Part IIb, p 160. (7), Snell, *Metals II,* p 1447. (8)

ORGANIC ANALYTICAL REAGENTS FOR THE DETERMINATION OF INORGANIC SUBSTANCES (continued)

Determination	Reagents	Ref.
	Sulfochlorophenol S	Onishi, Part IIb, p 161. (7), Snell, *Metals II,* p 1430. (8)
	Xylenol Orange	Onishi, Part IIb, p 164. (7)
Nitrate	Brucine	Boltz, p 227. (1), Fries/Getrost, p 280. (2), Snell, *Nonmetals,* p 546. (9)
	Chromotropic acid	Boltz, p 229. (1), Fries/Getrost, p 281. (2), Snell, *Nonmetals,* p 548. (9), Williams, p 132. (11), *Fres. Z. Anal. Chem., 320*, 490, (1985).
	Sulfanilamide + *N*-(1-Naphthyl)ethylenediamine dihydrochloride	Fries/Getrost, p 279. (2), Snell, *Nonmetals,* p 559. (9)
Nitrite	Sulfanilamide + *N*-(1-Naphthyl)ethylenediamine dihydrochlorine	Boltz, p 241. (1), Snell, N*onmetals, p* 585. (8), A*nalyst, 109,* 1281, (1984).
	Sulfanilic acid + 1-Naphthylamine	Boltz, p 237. (1), Fries/Getrost, p 285. (2), Marczenko, p 419. (3), Snell, *Nonmetals*, p 586. (9)
Osmium	1,5-Diphenylcarbazide	Marczenko, p 428. (3)
Palladium	2-(5 Bromo-2-pyridylazo)-5-diethylaminophenol	*Talanta*, *33*, 939, (1986).
	Dithizone	Marczenko, p 440. (3), Onishi, Part IIb, p 227. (6), Snell, *Metals II*, p 1577. (8)
	2-Nitroso-1-naphthol	Fries/Getrost, p 294. (2), Onishi, Part IIb, p 226. (6), Snell, *Metals II*, p 1581. (8)
	4-(2-Pyridylazo)resorcinol	Snell, *Metals II*, p 1583. (8) *Analyst, 107*, 708, (1982).
Phosphate	Rhodamine B + Molybdate	Snell, *Nonmetals*, p 103. (9)
	Malachite Green + Molybdate	Snell, *Nonmetals*, p 12. (9), Analyst, *108,* 361, (1983).
Platinum	Sulfochlorophenolazorhodamine	Onishi, Part IIb, p 253. (6), *Talanta*, *34*, 87, (1987).
	Dithizone	Fries/Getrost, p 300. (2), Onishi, Part IIb, p 253. (6), Snell, *Metals II,* p 1534. (8)
	2-Mercaptobenzothiazole	Fries/Getrost, p 302. (2), *Zh. Anal. Khim.*, *24*, 1172, (1969).
Rare Earths	Arsenazo I	Marczenko, p 470. (3), Onishi, Part IIa, p 785. (5), Snell, *Metals II,* p 1857. (8)
	Arsenazo III	Fries/Getrost, p 309. (2), Marczenko, p 468. (3), Onishi, Part IIa, p 786. (5), Snell, *Metals II,* p 1862. (8)
	Xylenol Orange	Onishi, Part IIa, p 787. (5), Snell, *Metals II,* p 1874. (8)
Rhenium	2,2′-Furildioxime	Fries/Getrost, p 310. (2), Marczenko, p 481. (3), Onishi, Part IIb, p 288. (6), Snell, *Metals II,* p 1659. (8)
Rhodium	1-(2-Pyridylazo)-2-naphthol	Fries/Getrost, p 311. (2), Snell, *Metals II,* p 1553. (8)
Ruthenium	1,10-Phenanthroline	Onishi, Part IIb, p 331. (6), Snell, *Metals II,* p 1623. (8)
	Thiourea	Fries/Getrost, p 318. (2), Onishi, Part IIb, 329. (6), Snell, *Metals II,* p 1626. (8)
	1,4-Diphenylthiosemicarbazide	Marczenko, p 493. (3), Onishi, Part IIb, p 330. (8)
Scandium	Alizarin red S	Fries/Getrost, p 319. (2), Onishi, Part IIb, p 360. (6), Snell, *Metals I,* p 536. (7)
	Arsenazo III	Onishi, Part IIb, p 359. (6), Snell, *Metals I,* p 539. (7)

ORGANIC ANALYTICAL REAGENTS FOR THE DETERMINATION OF INORGANIC SUBSTANCES (continued)

Determination	Reagents	Ref.
	Chrome Azurol S	Snell, Metals I, p 551. (7), *Anal. Chim. Acta, 159*, 309, (1984).
	Xylenol Orange	Marczenko, p 501. (3), Onishi, Part IIb, p 357. (6), Snell, *Metals I*, p 547. (7)
Selenium	3,3′-Diaminobenzidine	Boltz, p 391. (1), Fries/Getrost, p 323. (2), Marczenko, p 508. (3), Snell, *Nonmetals*, p 490. (9), West, p 4. (10).
	2,3-Diaminonaphthaline	Snell, *Nonmetals*, p 501. (9)
Silver	Dithizone	Fries/Getrost, p 328. (2), Marczenko, p 524. (3), Onishi, Part IIb, p 379. (6), Snell, *Metals I*, p 82. (7)
	Eosin + 1,10-Phenanthroline	Snell, *Metals I*, p 93. (7)
Sulfate	Methylthymol blue + Barium (II)	Snell, *Nonmetals*, p 457. (9)
Sulfide	*N,N*,-Dimethyl-1,4-phenylenediamine	Boltz, p 483. (1), Fries/Getrost, p 344. (2), Snell, *Nonmetals*, p 400. (9), Williams, p 578. (11)
Sulfite	Pararosaniline + Formaldehyde	Boltz, p 478. (1), Marczenko, p 540. (3), Snell, *Nonmetals*, p 430. (9), Williams, p 591. (11)
Tantalum	Methyl Violet	Marczenko, p 551. (3), Snell, *Metals II*, p 1485. (8)
	4-(2-Pyridylazo)resorcinol	Snell, *Metals II*, p 1488. (8)
	Phenylfluorone	Onishi, Part IIb, p 166. (6), Snell, *Metals II*, p 1486. (8)
Tellurium	Diethyldithiocarbamate	Boltz, p 402. (1), Fries/Getrost, p 348. (2), Snell, *Nonmetals*, p 533. (9), Williams, p 220. (10)
	Bismuthiol II	Boltz, p 401. (1), Marczenko, p 557. (3), Snell, *Nonmetals*, p 524. (9)
Thallium	Brilliant green	Fries/Getrost, p 352. (2), Marczenko, p 567. (3), Onishi, Part IIb, p 426. (6), Snell, *Metals I*, p 45. (7)
	Dithizone	Fries/Getrost, p 355. (2), Onishi, Part IIb, p 426. (6), Snell, *Metals I*, p 54. (7)
	Rhodamine B	Fries/Getrost, p 354. (2), Marczenko, p 566. (3), Onishi, Part IIb, p 424. (6), Snell, *Metals I*, p 63. (7)
Thorium	Arsenazo III	Fries/Getrost, p 360. (2), Marczenko, p 575. (3), Onishi, Part IIb, p 460. (6), Snell, *Metals II*, p 1820. (8)
	Thoron	Marczenko, p 574. (3), Onishi, Part IIb, p 463. (6), Snell, *Metals I*, p 1835. (7)
	Xylenol Orange	Snell, *Metals I*, p 1852. (7)
	Xylenol Orange + Cetyltrimethylammonium bromide	*Talanta, 26*, 499, (1979).
Tin	Pyrocatechol violet (and + Cetyltrimethylammonium bromide)	Marczenko, p 585. (3), Onishi, Part IIb, p 501. (6), Snell, M*etals I, p* 422. (7)
	Gallein	Onishi, Part IIb, p 507, 510. (6), Snell, *Metals I*, p 432. (7)
	Phenylfluorone	Fries/Getrost, p 368. (2), Marczenko, p 582. (3), Onishi, Part IIb, p 497. (6), Snell, *Metals I*, p 444. (7)
	Toluene-3,4-dithiol + Dispersant	Fries/Getrost, p 366. (2), Onishi, Part IIb, p 502. (6), Snell, *Metals I*, p 427. (7)
Titanium	Chromotropic acid	Marczenko, p 593. (3), Onishi, Part IIb, p 551. (6), Snell, *Metals II*, p 1080. (8)

ORGANIC ANALYTICAL REAGENTS FOR THE DETERMINATION OF INORGANIC SUBSTANCES (continued)

Determination	Reagents	Ref.
	Diantipyrinylmethane	Onishi, Part IIb, p 545. (6), Snell, *Metals II,* 1085. (8)
	Tiron	Fries/Getrost, p 376. (2), Onishi, Part IIb, p 549. (6), Snell, *Metals II,* p 1114. (8)
Tungsten	Pyrocatechol Violet	Snell, Metals II, p 1265. (8)
	Tetraphenylarsonium chloride + Thiocyanate	Onishi, Part IIb, p 596. (6), Snell, *Metals II,* p 1278. (8)
	Toluene-3,5-dithiol	Marczenko, p 605. (3), Onishi, Part IIb, p 590. (6), Snell, *Metals II,* p 1267. (8)
Uranium	Arsenazo III	Marczenko, p 611. (3), Onishi, Part IIb, p 627. (6), Snell, *Metals II,* p 1356. (8)
	2-(5-Bromo-2-pyridylazo)diethylaminophenol	Fries/Getrost, p 388. (2), Onishi, Part IIb, p 625. (6)
	Chlorophosphonazo III	Snell, Metals II, p 1367. (8), *Fres. Z. Anal. Chem., 306*, 110, (1981).
	1-(2-Pyridylazo)-2-naphthol	Fries/Getrost, p 386. (2), Onishi, Part IIb, p 625. (6), Snell, *Metals II,* p 1387. (8)
Vanadium	*N*-Benzoyl-*N*-phenylhydroxylamine	Fries/Getrost, p 395. (2), Marczenko, p 625. (3), Snell, *Metals II,* p 1196. (8)
	8-Hydroxyquinoline	Marczenko, p 623. (3), Snell, *Metals II,* p 1209. (8)
	4-(2-pyridylazo)resorcinol	Fries/Getrost, p 404. (23), Marczenko, p 628. (3), Onishi, Part IIb, p 625. (6), Snell, *Metals II,* p 1226. (8)
Yttrium	Alizarin Red S	Fries/Getrost, p 406. (2), Onishi, Part IIa, p 784. (5), Snell, *Metals II,* p 1919. (8)
	Arsenazo III	Marczenko, p 468. (3), Onishi, Part IIa, p 786. (5), Snell, *Metals II,* p 1921. (8)
	Xylenol Orange	Fries/Getrost, p 406. (2), Onishi, Part IIa, p 787. (5), Snell, *Metals II,* p 1923. (8)
Zinc	Dithizone	Fries/Getrost, p 408. (2), Marczenko, p 637. (3), Onishi, Part IIb, p 708. (6), Snell, *Metals II,* p 1042. (8)
	1-(2-Pyridylazo)-2-naphthol	Marczenko, p 639. (3), Onishi, Part IIb, p 719. (6), Snell, *Metals II,* p 1056. (8)
	Xylenol Orange	Fries/Getrost, p 417. (2), Snell, *Metals II,* p 1062. (8), Talanta, *26*, 693, (1979).
	Zircon	Fries/Getrost, p 412. (2), Onishi, Part IIb, p 719. (6), Snell, *Metals II,* p 1063. (8), West, p 23. (10)
Zirconium	Alizarin Red S	Fries/Getrost, p 421. (2), Marczenko, p 647. (3), Onishi, Part IIb, p 763. (6), Snell, *Metals II,* p 1136. (8)
	Arsenazo III	Fries/Getrost, p 421. (2), Onishi, Part IIb, p 770. (6), Snell, *Metals II,* p 1143. (8)
	Pyrocatechol Violet	Onishi, Part IIb, p 771. (6), Snell, *Metals I I,* p 1149. (8)
	Morin	Fries/Getrost, p 424. (2), Onishi, Part IIb, p 765. (6), Snell, *Metals II,* p 1158. (8)
	Xylenol Orange	Fries/Getrost, p 419. (2), Marczenko, p 648. (3), Onishi, Part IIb, p 767. (6), Snell, *Metals II,* p 1167. (8)

REVIEWS

Sommer, L, Ackermann, G., Thorburn Burns, D., and Savvin, S. B., *Pure and Applied Chem.,* 62, 2147, 1990.
Sommer, L., Ackermann, G., and Thorburn Burns, D., *Pure and Applied Chem.,* 62, 2323, 1990)
Sommer, L., Komarek, J., and Thorburn Burns, D., *Pure and Applied Chem., 64,* 213, 1992.
Savvin, S. B., *Crit. Rev. Anal. Chem.,* 8, 55, 1979.

MONOGRAPHS

1. Boltz, D. F., and Howell, J. A., *Colorimetric Determination of Nonmetals,* 2nd ed, Wiley, New York, 1978.
2. Fries, J. and Getrost, H., *Organic Reagents for Trace Analysis,* E Merck, Darmstadt, 1977.
3. Marczenko, Z., *Separation and Spectrophotometric Determination of Elements,* Ellis Horwood, Chichester, 1986.
4. Sandell, E. B. and Onishi, H., *Photometric Determination of Traces of Metals. General Aspects, Part I,* 4th ed, J. Wiley, New York, 1978.
5. Onishi, H., *Photometric Determination of Traces of Metals. Part IIa: Individual Metals, Aluminium to Lithium,* 4th ed, J. Wiley, New York, 1986.
6. Onishi, H., *Photometric Determination of Traces of Metals. Part IIb: Individual Metals, Magnesium to Zinc,* 4th ed, J. Wiley, New York, 1989.
7. Snell, F. D., *Photometric and Fluorimetric Methods of Analysis, Metals Part 1,* J. Wiley, New York, 1978.
8. Snell, F. D., *Photometric and Fluorimetric Methods of Analysis, Metals Part 2,* J. Wiley, New York, 1978.
9. Snell, F. D., *Photometric and Fluorimetric Methods of Analysis, Nonmetals,* J. Wiley, New York, 1981.
10. West, T. S. and Nürnberg, H. W., Eds., *The Determination of Trace Metals in Natural Waters,* Blackwell, Oxford, 1988.
11. Williams, W. J.,, *Handbook of Anion Determination,* Butterworth, London, 1979.
12. Townshend, A., Burns, D. T., Guilbault, G. G., Lobinski, R., Mavenzenko, Z., Newman, E., and Onishi, H., *Dictionary of Analytical Reagents*, Chapman & Hall, London, 1993.

ACID-BASE INDICATORS

A. K. Covington

The first part of this table lists some common acid-base indicators in alphabetical order along with the approximate pH range(s) at which a color change occurs. Following this is a table of the same indicators ordered by pH range, which includes the nature of the color change, instructions on preparation of the indicator solution, and the acid dissociation constant p*K*, when available. The color code is:

C = colorless A = amber B/G = blue-green Pk = pink Y = yellow V = violet R = red B = blue
P = purple O = orange

REFERENCE

Bishop, E., Ed., *Indicators*, Pergamon, Oxford, 1972.

Indicator	pH Range
Alizarin	5.6-7.2; 11.0-12.4
Alizarin Red S	4.6-6.0
Alizarin Yellow R	10.1-12.0
Benzopurpurine 4B	2.2-4.2
4,4'-Bis(2-amino-1-naphthylazo)-2,2'-stilbenedisulfonic acid	3.0-4.0
4,4'-Bis(4-amino-1-naphthylazo)-2,2'-stilbenedisulfonic acid	8.0-9.0
Brilliant Yellow	6.6-7.8
Bromocresol Green	3.8-5.4
Bromocresol Purple	5.2-6.8
Bromophenol Blue	3.0-4.6
Bromothymol Blue	6.0-7.6
Chlorophenol Red	5.2-6.8
Clayton Yellow	12.2-13.2
Congo Red	3.0-5.0
o-Cresolphthalein	8.2-9.8
Cresol Red	0.0-1.0; 7.0-8.8
Crystal Violet	0.0-1.8
Curcumin (Turmaric)	7.4-8.6
p-(2,4-Dihydroxyphenylazo) benzenesulfonic acid, sodium salt	11.4-12.6
p-Dimethylaminoazobenzene	2.8-4.4
4-(4-Dimethylamino-1-naphylazo)-3-methoxybenzenesulfonic acid	3.5-4.8
2-(*p*-Dimethylamino-phenylazo)pyridine	0.2-1.8; 4.4-5.6
N,N-Dimethyl-*p*-(*m*-tolylazo)aniline	2.6-4.8
2,4-Dinitrophenol	2.0-4.7
2-(2,4 Dinitrophenylazo)-1-naphthol-3,6-disulfonic acid, disodium salt	6.0-7.0
6,8-Dinitro-2,4-(1*H*)quinazolinedione	6.4-8.0
Erythrosin, disodium salt	2.2-3.6
4-(*p*-Ethoxyphenylazo)-*m*-phenylene-diamine monohydrochloride	4.4-5.8
Ethyl bis(2,4-dimethylphenyl) ethanoate	8.4-9.6
Ethyl Orange	3.4-4.8
Ethyl Red	4.0-5.8
Ethyl Violet	0.0-2.4
5,5'-Indigodisulfonic acid, disodium salt	11.4-13.0
Malachite Green	0.2-1.8
Metacresol Purple	1.2-2.8; 7.4-9.0
Metanil Yellow	1.2-2.4
Methyl Green	0.2-1.8
Methyl Orange	3.2-4.4
Methyl Red	4.8-6.0
Methyl Violet	0.0-1.6
p-Naphtholbenzein	8.2-10.0
Neutral Red	6.8-8.0
p-Nitrophenol	5.4-6.6
m-Nitrophenol	6.8-8.6
Orange IV	1.4-2.8
Paramethyl Red	1.0-3.0
Phenolphthalein	8.2-10.0
Phenol Red	6.6-8.0
4-Phenylazodiphenylamine	1.2-2.6
4-Phenylazo-1-naphthylamine	4.0-5.6
Propyl Red	4.8-6.6
Quinaldine Red	1.4-3.2
Resazurin	3.8-6.4
Resorcin Blue	4.4-6.2
Tetrabromophenolphthalein ethyl ester, potassium salt	3.0-4.2
Thymol Blue	1.2-2.8; 8.0-9.6
Thymolphthalein	9.4-10.6
4-*o*-Tolylazo-*o*-toluidine	1.4-2.8
1,3,5-Trinitrobenzene	12.0-14.0
2,4,6-Trinitrotoluene	11.5-13.0
Turmaric	7.4-8.6

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pH range	Color change	Indicator	p*K*	Preparation
0.0-1.0	R-Y	Cresol Red		0.1 g in 26.2 mL 0.01 M NaOH + 223.8 mL water
0.0-1.6	Y-B	Methyl Violet		0.01-0.05% in water
0.0-1.8	Y-B	Crystal Violet		0.02% in water
0.0-2.4	Y-B	Ethyl Violet		0.1 g in 50 mL 50% v/v methanol-water
0.2-1.8	Y-B/G	Malachite Green	1.3	water
0.2-1.8	Y-B	Methyl Green		0.1% in water
0.2-1.8	Y-R	2-(*p*-Dimethylaminophenylazo)pyridine		0.1% in ethanol
1.0-3.0	R-Y	Paramethyl Red		ethanol
1.2-2.4	R-Y	Metanil Yellow		0.01% in water
1.2-2.6	R-Y	4-Phenylazodiphenylamine		0.01 g in 1 mL 1 M HCl + 50 mL ethanol + 49 mL water
1.2-2.8	R-Y	Thymol Blue	1.65	0.1 g in 21.5 mL 0.01 M NaOH + 228.5 mL water
1.2-2.8	R-Y	Metacresol Purple	1.51	0.1 g in 26.2 mL 0.01 M NaOH + 223.8 mL water
1.4-2.8	R-Y	Orange IV		0.01% in water
1.4-2.8	O-Y	4-*o*-Tolylazo-*o*-toluidine		water
1.4-3.2	C-R	Quinaldine Red	2.63	1% in ethanol
2.0-4.7	C-Y	2,4-Dinitrophenol	3.96	sat. solution in water
2.2-3.6	O-R	Erythrosin, disodium salt		0.1% in water
2.2-4.2	V-R	Benzopurpurine 4B		0.1% in water
2.6-4.8	R-Y	*N,N*-Dimethyl-*p*-(*m*-tolylazo)aniline		0.1% in water
2.8-4.4	R-Y	*p*-Dimethylaminoazobenzene		0.1 g in 100 mL 90% v/v ethanol-water
3.0-4.0	P-R	4,4'-Bis(2-amino-1-naphthylazo)-2,2'-stilbenedisulfonic acid		0.1 g in 5.9 mL 0.05 M NaOH + 94.1 mL water
3.0-4.2	Y-B	Tetrabromophenolphthalein ethyl ester, potassium salt		0.1% in ethanol
3.0-4.6	Y-B	Bromophenol Blue	4.10	0.1 g in 14.9 mL 0.01 M NaOH + 235.1 mL water
3.0-5.0	B-R	Congo Red		0.1% in water
3.2-4.4	R-Y	Methyl Orange	3.46	0.1% in water
3.4-4.8	R-Y	Ethyl Orange	4.34	0.05-0.2% in water or aqueous ethanol
3.5-4.8	V-Y	4-(4-Dimethylamino-1-naphylazo)-3-methoxybenzenesulfonic acid		0.1% in 60% ethanol-water
3.8-5.4	Y-B	Bromocresol Green	4.90	0.1 g in 14.3 mL 0.01 M NaOH + 235.7 mL water
3.8-6.4	O-V	Resazurin		water
4.0-5.6	R-Y	4-Phenylazo-1-naphthylamine		0.1% in ethanol
4.0-5.8	C-R	Ethyl Red	5.42	0.1 g in 100 mL 50% v/v methanol-water
4.4-5.6	R-Y	2-(*p*-Dimethylaminophenylazo)pyridine		0.1% in ethanol
4.4-5.8	O-Y	4-(*p*-Ethoxyphenylazo)-*m*-phenylene-diamine monohydrochloride		0.1% in water
4.4-6.2	R-B	Resorcin Blue		0.2% in ethanol
4.6-6.0	Y-R	Alizarin Red S		water
4.8-6.0	R-Y	Methyl Red	5.00	0.02 g in 100 mL 60% v/v ethanol-water
4.8-6.6	R-Y	Propyl Red	5.48	ethanol
5.2-6.8	Y-P	Bromocresol Purple	6.40	0.1 g in 18.5 mL 0.01 M NaOH + 231.5 mL water
5.2-6.8	Y-R	Chlorophenol Red	6.25	0.1 g in 23.6 mL 0.01 M NaOH + 226.4 mL water
5.4-6.6	C-Y	*p*-Nitrophenol	7.15	0.1% in water
5.6-7.2	Y-R	Alizarin		0.1% in methanol
6.0-7.0	Y-B	2-(2,4-Dinitrophenylazo)-1-naphthol-3,6-disulfonic acid, disodium salt		0.1% in water
6.0-7.6	Y-B	Bromothymol Blue	7.30	0.1 g in 16 mL 0.01 M NaOH + 234 mL water
6.4-8.0	C-Y	6,8-Dinitro-2,4-(1*H*)quinazolinedione		25 g in 115 mL 1 M NaOH + 50 mL water at 100°C
6.6-7.8	Y-R	Brilliant Yellow		1% in water
6.6-8.0	Y-R	Phenol Red	8.00	0.1 g in 28.2 mL 0.01 M NaOH + 221.8 mL water
6.8-8.0	R-A	Neutral Red		0.01 g in 100 mL 50% v/v ethanol-water
6.8-8.6	C-Y	*m*-Nitrophenol	8.28	0.3% in water
7.0-8.8	Y-R	Cresol Red	8.46	0.1 g in 26.2 mL 0.01 M NaOH + 223.8 mL water
7.4-8.6	Y-R	Turmaric (Curcumin)		ethanol
7.4-9.0	Y-P	Metacresol Purple	8.3	0.1 g in 26.2 mL 0.01 M NaOH + 223.8 mL water

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ACID-BASE INDICATORS (continued)

pH range	Color change	Indicator	pK	Preparation
8.0-9.0	B-R	4,4'-Bis(4-amino-1-naphthylazo)-2,2'-stilbenedisulfonic acid		0.1 g in 5.9 mL 0.05 M NaOH + 94.1 mL water
8.0-9.6	Y-B	Thymol Blue	9.20	0.1 g in 21.5 mL 0.01 M NaOH + 228.5 mL water
8.2-10.0	O-B	*p*-Naphtholbenzein		1% in dil. alkali
8.2-10.0	C-Pk	Phenolphthalein	9.5	0.5 g in 100 mL 50% v/v ethanol-water
8.2-9.8	C-R	*o*-Cresolphthalein		0.04% in ethanol
8.4-9.6	C-B	Ethyl bis(2,4-dimethylphenyl)ethanoate		sat. solution in 50% acetone-ethanol
9.4-10.6	C-B	Thymolphthalein		0.04 g in 100 mL 50% v/v ethanol-water
10.1-12.0	Y-R	Alizarin Yellow R		0.01% in water
11.0-12.4	R-P	Alizarin		0.1% in methanol
11.4-12.6	Y-O	*p*-(2,4-Dihydroxyphenylazo) benzenesulfonic acid, sodium salt		0.1% in water
11.4-13.0	B-Y	5,5'-Indigodisulfonic acid, disodium salt		water
11.5-13.0	C-O	2,4,6-Trinitrotoluene		0.1-0.5% in ethanol
12.0-14.0	C-O	1,3,5-Trinitrobenzene		0.1-0.5% in ethanol
12.2-13.2	Y-A	Clayton Yellow		0.1% in water

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FLUORESCENT INDICATORS

Jack DeMent

Fluorescent indicators are substances which show definite changes in fluorescence with change in pH. Some fluorescent materials are not suitable for indicators since their change in fluorescence is too gradual. Fluorescent indicators find greatest utility in the titration of opaque, highly turbid or deeply colored solutions. A long wavelength ultraviolet ("black light") lamp in a dimly lighted room provides the best environment for titrations involving fluorescent indicators, although bright daylight is sometimes sufficient to evoke a response in the bright green, yellow and orange fluorescent indicators. Titrations are carried out in non-fluorescent glassware. One should check the glassware prior to use to make certain that it does not fluoresce due to the wavelengths of light involved in the titration. The meniscus of the liquid in the burette can be followed when a few particles of an insoluble fluorescent solid are dropped onto its surface.

In this table the indicators are arranged by approximate pH range covered. In the case of some of the dyestuffs the end point may vary slightly with the source or manufacturer.

pH 0 to 2

Indicator	C.I.	From pH	To pH
Benzoflavine	—	0.3, yellow fl.	1.7, green fl.
3,6-Dioxyphthalimide	—	0, blue fl.	2.4, green fl.
Eosine YS	768	0, yellow colored	3.0, yellow fl.
Erythrosine	772	0, yellow colored	3.6, yellow fl.
Esculin	—	1.5, colorless	2, blue fl.
4-Ethoxyacridone	—	1.2, green fl.	3.2, blue fl.
3,6-Tetramethyldiaminooxanthone	—	1.2, green fl.	3.4, blue fl.

pH 2 to 4

Indicator	C.I.	From pH	To pH
Chromotropic acid	—	3.5, colorless	4.5, blue fl.
Fluorescein	766	4, colorless	4.5, green fl.
Magdala Red	—	3.0, purple colored	4.0, fl.
α-Naphthylamine	—	3.4, colorless	4.8, blue fl.
β-Naphthylamine	—	2.8, colorless	4.4, violet fl.
Phloxine	774	3.4, colorless	5.0, bright yellow fl.
Salicylic acid	—	2.5, colorless	3.5, blue fl.

pH 4 to 6

Indicator	C.I.	From pH	To pH
Acridine	788	4.9, green fl.	5.1, violet colored
Dichlorofluorescein	—	4.0, colorless	5.0, green fl.
3,6-Dioxyxanthone	—	5.4, colorless	7.6, blue-violet fl.
Erythrosine	772	4.0, colorless	4.5, yellow-green fl.
β-Methylesculetin	—	4.0, colorless	6.2, blue fl.
Neville-Winther acid	—	6.0, colorless	6.5, blue fl.
Resorufin	—	4.4, yellow fl.	6.4, weak orange fl.
Quininic acid	—	4.0, yellow colored	5.0, blue fl.
Quinine [first end point]	—	5.0, blue fl.	6.1, violet fl.

pH 6 to 8

Indicator	C.I.	From pH	To pH
Acid R Phosphine	—	(claimed for range pH 6.0–7.0)	
Brilliant Diazol Yellow	—	6.5, colorless	7.5, violet fl.
Cleves acid	—	6.5, colorless	7.5, green fl.
Coumaric acid	—	7.2, colorless	9.0, green fl.
3,6-Dioxyphthalic dinitrile	—	5.8, blue fl.	8.2, green fl.
Magnesium 8-hydroxyquinolinate	—	6.5, colorless	7.5, golden fl.
β-Methylumbelliferone	—	7.0, colorless	7.5, blue fl.
1-Naphthol-4-sulfonic acid	—	6.0, colorless	6.5, blue fl.
Orcinaurine	—	6.5, colorless	8.0, green fl.
Patent Phosphine	789	(for the range pH 6.0–7.0, green-yellow fl.)	
Thioflavine	816	(for the region pH 6.5–7.0, yellow fl.)	
Umbelliferone	—	6.5, colorless	7.6, blue fl.

FLUORESCENT INDICATORS (Continued)

pH 8 to 10

Indicator	C.I.	From pH	To pH
Acridine Orange	788	8.4, orange colored	10.4, green fl.
Ethoxyphenylnaphthostilbazonium chloride	—	9, green fl.	11, non-fl.
G Salt	—	9.0, dull blue fl.	9.5, bright blue fl.
Naphthazol derivatives	—	8.2, colorless	10.0, yellow or green fl.
α-Naphthionic acid	—	9, blue fl.	11, green fl.
2-Naphthol-3,6-disulfonic acid	—	9.5, dark blue fl.	Light blue fl. at higher pH
β-Naphthol	—	8.6, colorless	Blue fl. at higher pH
α-Naphtholsulfonic acid	—	8.0, dark blue fl.	9.0, bright violet fl.
1,4-Naphtholsulfonic acid	—	8.2, dark blue fl.	Light blue fl. at higher pH
Orcinsulfonphthalein	—	8.6, yellow colored	10.0 fl.
Quinine [second end point]	—	9.5, violet fl.	10.0, colorless
R-Salt	—	9.0, dull blue fl.	9.5, bright blue fl.
Sodium 1-naphthol-2-sulfonate	—	9.0, dark blue fl.	10.0, bright violet fl.

pH 10 to 12

Indicator	C.I.	From pH	To pH
Coumarin	—	9.8, deep green fl.	12, light green fl.
Eosine BN	771	10.5, colorless	14.0, yellow fl.
Papaverine (permanganate oxidized)	—	9.5, yellow fl.	11.0, blue fl.
Schaffers Salt	—	5.0, violet fl.	11.0, green-blue fl.
SS-Acid (sodium salt)	—	10.0, violet fl.	12.0, yellow colored

pH 12 to 14

Indicator	C.I.	From pH	To pH
Cotarnine	—	12.0, yellow fl.	13.0, white fl.
α-Naphthionic acid	—	12, blue fl.	13, green fl.
β-Naphthionic acid	—	12, blue fl.	13, violet fl.

CONVERSION FORMULAS FOR CONCENTRATION OF SOLUTIONS

A	=	Weight per cent of solute	G	=	Molality
B	=	Molecular weight of solvent	M	=	Molarity
E	=	Molecular weight of solute	N	=	Mole fraction
F	=	Grams of solute per liter of solution	R	=	Density of solution in grams per milliliter

Concentration of solute—SOUGHT	Concentration of solute—GIVEN				
	A	N	G	M	F
A	—	$\frac{100N \times E}{N \times E + (1 - N)B}$	$\frac{100G \times E}{1000 + G \times E}$	$\frac{M \times E}{10R}$	$\frac{F}{10R}$
N	$\frac{\frac{A}{E}}{\frac{A}{E} + \frac{100 - A}{B}}$	—	$\frac{B \times G}{B \times G + 1000}$	$\frac{B \times M}{M(B - E) + 1000R}$	$\frac{B \times F}{F(B - E) + 1000R \times E}$
G	$\frac{1000A}{E(100 - A)}$	$\frac{1000N}{B - N \times B}$	—	$\frac{1000M}{1000R - (M \times E)}$	$\frac{1000F}{E(1000R - F)}$
M	$\frac{10R \times A}{E}$	$\frac{1000R \times N}{N \times E + (1 - N)B}$	$\frac{1000R \times G}{1000 + E \times G}$	—	$\frac{F}{E}$
F	$10AR$	$\frac{1000R \times N \times E}{N \times E + (1 - N)B}$	$\frac{1000R \times G \times E}{1000 + G \times E}$	$M \times E$	—

ELECTROCHEMICAL SERIES

Petr Vanýsek

There are three tables for this electrochemical series. Each table lists standard reduction potentials, *E*° values, at 298.15 K (25°C), and at a pressure of 101.325 kPa (1 atm). Table 1 is an alphabetical listing of the elements, according to the symbol of the elements. Thus, data for silver (Ag) precedes those for aluminum (Al). Table 2 lists only those reduction reactions which have *E*° values positive in respect to the standard hydrogen electrode. In Table 2, the reactions are listed in the order of increasing positive potential, and they range from 0.0000 V to + 3.4 V. Table 3 lists only those reduction potentials which have *E*° negative with respect to the standard hydrogen electrode. In Table 3, the reactions are listed in the order of decreasing potential and range from 0.0000 V to –4.10 V. The reliability of the potentials is not the same for all the data. Typically, the values with fewer significant figures have lower reliability. The values of reduction potentials, in particular those of less common reactions, are not definite; they are subject to occasional revisions.

Abbreviations: ac = acetate; bipy = 2,2′-dipyridine, or bipyridine; en = ethylenediamine; phen = 1,10-phenanthroline.

REFERENCES

1. G. Milazzo, S. Caroli, and V. K. Sharma, *Tables of Standard Electrode Potentials*, Wiley, Chichester, 1978.
2. A. J. Bard, R. Parsons, and J. Jordan, *Standard Potentials in Aqueous Solutions*, Marcel Dekker, New York, 1985.
3. S. G. Bratsch, *J. Phys. Chem. Ref. Data*, 18, 1—21, 1989.

TABLE 1
Alphabetical Listing

Reaction	*E*°/V
$Ac^{3+} + 3e \rightleftharpoons Ac$	–2.20
$Ag^+ + e \rightleftharpoons Ag$	0.7996
$Ag^{2+} + e \rightleftharpoons Ag^+$	1.980
$Ag(ac) + e \rightleftharpoons Ag + (ac)^-$	0.643
$AgBr + e \rightleftharpoons Ag + Br^-$	0.07133
$AgBrO_3 + e \rightleftharpoons Ag + BrO_3^-$	0.546
$Ag_2C_2O_4 + 2e \rightleftharpoons 2Ag + C_2O_4^{2-}$	0.4647
$AgCl + e \rightleftharpoons Ag + Cl^-$	0.22233
$AgCN + e \rightleftharpoons Ag + CN^-$	–0.017
$Ag_2CO_3 + 2e \rightleftharpoons 2Ag + CO_3^{2-}$	0.47
$Ag_2CrO_4 + 2e \rightleftharpoons 2Ag + CrO_4^{2-}$	0.4470
$AgF + e \rightleftharpoons Ag + F^-$	0.779
$Ag_4[Fe(CN)_6] + 4e \rightleftharpoons 4Ag + [Fe(CN)_6]^{4-}$	0.1478
$AgI + e \rightleftharpoons Ag + I^-$	–0.15224
$AgIO_3 + e \rightleftharpoons Ag + IO_3^-$	0.354
$Ag_2MoO_4 + 2e \rightleftharpoons 2Ag + MoO_4^{2-}$	0.4573
$AgNO_2 + e \rightleftharpoons Ag + 2NO_2^-$	0.564
$Ag_2O + H_2O + 2e \rightleftharpoons 2Ag + 2OH^-$	0.342
$Ag_2O_3 + H_2O + 2e \rightleftharpoons 2AgO + 2OH^-$	0.739
$Ag^{3+} + 2e \rightleftharpoons Ag^+$	1.9
$Ag^{3+} + e \rightleftharpoons Ag^{2+}$	1.8
$Ag_2O_2 + 4H^+ + e \rightleftharpoons 2Ag + 2H_2O$	1.802
$2AgO + H_2O + 2e \rightleftharpoons Ag_2O + 2OH^-$	0.607
$AgOCN + e \rightleftharpoons Ag + OCN^-$	0.41
$Ag_2S + 2e \rightleftharpoons 2Ag + S^{2-}$	–0.691
$Ag_2S + 2H^+ + 2e \rightleftharpoons 2Ag + H_2S$	–0.0366
$AgSCN + e \rightleftharpoons Ag + SCN^-$	0.08951
$Ag_2SeO_3 + 2e \rightleftharpoons 2Ag + SeO_4^{2-}$	0.3629
$Ag_2SO_4 + 2e \rightleftharpoons 2Ag + SO_4^{2-}$	0.654
$Ag_2WO_4 + 2e \rightleftharpoons 2Ag + WO_4^{2-}$	0.4660
$Al^{3+} + 3e \rightleftharpoons Al$	–1.662
$Al(OH)_3 + 3e \rightleftharpoons Al + 3OH^-$	–2.31
$Al(OH)_4^- + 3e \rightleftharpoons Al + 4OH^-$	–2.328
$H_2AlO_3^- + H_2O + 3e \rightleftharpoons Al + 4OH^-$	–2.33
$AlF_6^{3-} + 3e \rightleftharpoons Al + 6F^-$	–2.069
$Am^{4+} + e \rightleftharpoons Am^{3+}$	2.60
$Am^{2+} + 2e \rightleftharpoons Am$	–1.9
$Am^{3+} + 3e \rightleftharpoons Am$	–2.048
$Am^{3+} + e \rightleftharpoons Am^{2+}$	–2.3
$As + 3H^+ + 3e \rightleftharpoons AsH_3$	–0.608
$As_2O_3 + 6H^+ + 6e \rightleftharpoons 2As + 3H_2O$	0.234
$HAsO_2 + 3H^+ + 3e \rightleftharpoons As + 2H_2O$	0.248
$AsO_2^- + 2H_2O + 3e \rightleftharpoons As + 4OH^-$	–0.68
$H_3AsO_4 + 2H^+ + 2e^- \rightleftharpoons HAsO_2 + 2H_2O$	0.560
$AsO_4^{3-} + 2H_2O + 2e \rightleftharpoons AsO_2^- + 4OH^-$	–0.71
$At_2 + 2e \rightleftharpoons 2At^-$	0.3
$Au^+ + e \rightleftharpoons Au$	1.692
$Au^{3+} + 2e \rightleftharpoons Au^+$	1.401
$Au^{3+} + 3e \rightleftharpoons Au$	1.498
$Au^{2+} + e^- \rightleftharpoons Au^+$	1.8
$AuOH^{2+} + H^+ + 2e \rightleftharpoons Au^+ + H_2O$	1.32
$AuBr_2^- + e \rightleftharpoons Au + 2Br^-$	0.959
$AuBr_4^- + 3e \rightleftharpoons Au + 4Br^-$	0.854
$AuCl_4^- + 3e \rightleftharpoons Au + 4Cl^-$	1.002
$Au(OH)_3 + 3H^+ + 3e \rightleftharpoons Au + 3H_2O$	1.45
$H_2BO_3^- + 5H_2O + 8e \rightleftharpoons BH_4^- + 8OH^-$	–1.24
$H_2BO_3^- + H_2O + 3e \rightleftharpoons B + 4OH^-$	–1.79
$H_3BO_3 + 3H^+ + 3e \rightleftharpoons B + 3H_2O$	–0.8698
$B(OH)_3 + 7H^+ + 8e \rightleftharpoons BH_4^- + 3H_2O$	–0.481
$Ba^{2+} + 2e \rightleftharpoons Ba$	–2.912
$Ba^{2+} + 2e \rightleftharpoons Ba(Hg)$	–1.570
$Ba(OH)_2 + 2e \rightleftharpoons Ba + 2OH^-$	–2.99
$Be^{2+} + 2e \rightleftharpoons Be$	–1.847
$Be_2O_3^{2-} + 3H_2O + 4e \rightleftharpoons 2Be + 6OH^-$	–2.63

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TABLE 1
Alphabetical Listing (continued)

Reaction	*E*°/V
p–benzoquinone + 2 H^+ + 2 e $\rightleftharpoons$ hydroquinone	0.6992
Bi^+ + e $\rightleftharpoons$ Bi	0.5
Bi^{3+} + 3 e $\rightleftharpoons$ Bi	0.308
Bi^{3+} + 2 e $\rightleftharpoons$ Bi^+	0.2
Bi + 3 H^+ + 3 e $\rightleftharpoons$ BiH_3	–0.8
$BiCl_4^-$ + 3 e $\rightleftharpoons$ Bi + 4 Cl^-	0.16
Bi_2O_3 + 3 H_2O + 6 e $\rightleftharpoons$ 2 Bi + 6 OH^-	–0.46
Bi_2O_4 + 4 H^+ + 2 e $\rightleftharpoons$ 2 BiO^+ + 2 H_2O	1.593
BiO^+ + 2 H^+ + 3 e $\rightleftharpoons$ Bi + H_2O	0.320
BiOCl + 2 H^+ + 3 e $\rightleftharpoons$ Bi + Cl^- + H_2O	0.1583
Bk^{4+} + e $\rightleftharpoons$ Bk^{3+}	1.67
Bk^{2+} + 2 e $\rightleftharpoons$ Bk	–1.6
Bk^{3+} + e $\rightleftharpoons$ Bk^{2+}	–2.8
$Br_2(aq)$ + 2 e $\rightleftharpoons$ 2 Br^-	1.0873
$Br_2(l)$ + 2 e $\rightleftharpoons$ 2 Br^-	1.066
HBrO + H^+ + 2 e $\rightleftharpoons$ Br^- + H_2O	1.331
HBrO + H^+ + e $\rightleftharpoons$ 1/2 $Br_2(aq)$ + H_2O	1.574
HBrO + H^+ + e $\rightleftharpoons$ 1/2 $Br_2(l)$ + H_2O	1.596
BrO^- + H_2O + 2 e $\rightleftharpoons$ Br^- + 2 OH^-	0.761
BrO_3^- + 6 H^+ + 5 e $\rightleftharpoons$ 1/2 Br_2 + 3 H_2O	1.482
BrO_3^- + 6 H^+ + 6 e $\rightleftharpoons$ Br^- + 3 H_2O	1.423
BrO_3^- + 3 H_2O + 6 e $\rightleftharpoons$ Br^- + 6 OH^-	0.61
$(CN)_2$ + 2 H^+ + 2 e $\rightleftharpoons$ 2 HCN	0.373
2 HCNO + 2 H^+ + 2 e $\rightleftharpoons$ $(CN)_2$ + 2 H_2O	0.330
$(CNS)_2$ + 2 e $\rightleftharpoons$ 2 CNS^-	0.77
CO_2 + 2 H^+ + 2 e $\rightleftharpoons$ HCOOH	–0.199
Ca^+ + e $\rightleftharpoons$ Ca	–3.80
Ca^{2+} + 2 e $\rightleftharpoons$ Ca	–2.868
$Ca(OH)_2$ + 2 e $\rightleftharpoons$ Ca + 2 OH^-	–3.02
Calomel electrode, 1 molal KCl	0.2800
Calomel electrode, 1 molar KCl (NCE)	0.2801
Calomel electrode, 0.1 molar KCl	0.3337
Calomel electrode, saturated KCl (SCE)	0.2412
Calomel electrode, saturated NaCl (SSCE)	0.2360
Cd^{2+} + 2 e $\rightleftharpoons$ Cd	–0.4030
Cd^{2+} + 2 e $\rightleftharpoons$ Cd(Hg)	–0.3521
$Cd(OH)_2$ + 2 e $\rightleftharpoons$ Cd(Hg) + 2 OH^-	–0.809
$CdSO_4$ + 2 e $\rightleftharpoons$ Cd + SO_4^{2-}	–0.246
$Cd(OH)_4^{2-}$ + 2 e $\rightleftharpoons$ Cd + 4 OH^-	–0.658
CdO + H_2O + 2 e $\rightleftharpoons$ Cd + 2 OH^-	–0.783
Ce^{3+} + 3 e $\rightleftharpoons$ Ce	–2.336
Ce^{3+} + 3 e $\rightleftharpoons$ Ce(Hg)	–1.4373
Ce^{4+} + e $\rightleftharpoons$ Ce^{3+}	1.72
$CeOH^{3+}$ + H^+ + e $\rightleftharpoons$ Ce^{3+} + H_2O	1.715
Cf^{4+} + e $\rightleftharpoons$ Cf^{3+}	3.3
Cf^{3+} + e $\rightleftharpoons$ Cf^{2+}	–1.6
Cf^{3+} + 3 e $\rightleftharpoons$ Cf	–1.94
Cf^{2+} + 2 e $\rightleftharpoons$ Cf	–2.12
$Cl_2(g)$ + 2 e $\rightleftharpoons$ 2 Cl^-	1.35827
HClO + H^+ + e $\rightleftharpoons$ 1/2 Cl_2 + H_2O	1.611
HClO + H^+ + 2 e $\rightleftharpoons$ Cl^- + H_2O	1.482
ClO^- + H_2O + 2 e $\rightleftharpoons$ Cl^- + 2 OH^-	0.81
ClO_2 + H^+ + e $\rightleftharpoons$ $HClO_2$	1.277
$HClO_2$ + 2 H^+ + 2 e $\rightleftharpoons$ HClO + H_2O	1.645
$HClO_2$ + 3 H^+ + 3 e $\rightleftharpoons$ 1/2 Cl_2 + 2 H_2O	1.628
$HClO_2$ + 3 H^+ + 4 e $\rightleftharpoons$ Cl^- + 2 H_2O	1.570
ClO_2^- + H_2O + 2 e $\rightleftharpoons$ ClO^- + 2 OH^-	0.66
ClO_2^- + 2 H_2O + 4 e $\rightleftharpoons$ Cl^- + 4 OH^-	0.76
$ClO_2(aq)$ + e $\rightleftharpoons$ ClO_2^-	0.954
ClO_3^- + 2 H^+ + e $\rightleftharpoons$ ClO_2 + H_2O	1.152
ClO_3^- + 3 H^+ + 2 e $\rightleftharpoons$ $HClO_2$ + H_2O	1.214
ClO_3^- + 6 H^+ + 5 e $\rightleftharpoons$ 1/2 Cl_2 + 3 H_2O	1.47
ClO_3^- + 6 H^+ + 6 e $\rightleftharpoons$ Cl^- + 3 H_2O	1.451
ClO_3^- + H_2O + 2 e $\rightleftharpoons$ ClO_2^- + 2 OH^-	0.33
ClO_3^- + 3 H_2O + 6 e $\rightleftharpoons$ Cl^- + 6 OH^-	0.62
ClO_4^- + 2 H^+ + 2 e $\rightleftharpoons$ ClO_3^- H_2O	1.189
ClO_4^- + 8 H^+ + 7 e $\rightleftharpoons$ 1/2 Cl_2 + 4 H_2O	1.39
ClO_4^- + 8 H^+ + 8 e $\rightleftharpoons$ Cl^- + 4 H_2O	1.389
ClO_4^- + H_2O + 2 e $\rightleftharpoons$ ClO_3^- + 2 OH^-	0.36
Cm^{4+} + e $\rightleftharpoons$ Cm^{3+}	3.0
Cm^{3+} + 3 e $\rightleftharpoons$ Cm	–2.04
Co^{2+} + 2 e $\rightleftharpoons$ Co	–0.28
Co^{3+} + e $\rightleftharpoons$ Co^{2+}	1.92
$[Co(NH_3)_6]^{3+}$ + e $\rightleftharpoons$ $[Co(NH_3)_6]^{2+}$	0.108
$Co(OH)_2$ + 2 e $\rightleftharpoons$ Co + 2 OH^-	–0.73
$Co(OH)_3$ + e $\rightleftharpoons$ $Co(OH)_2$ + OH^-	0.17
Cr^{2+} + 2 e $\rightleftharpoons$ Cr	–0.913
Cr^{3+} + e $\rightleftharpoons$ Cr^{2+}	–0.407
Cr^{3+} + 3 e $\rightleftharpoons$ Cr	–0.744
$Cr_2O_7^{2-}$ + 14 H^+ + 6 e $\rightleftharpoons$ 2 Cr^{3+} + 7 H_2O	1.232
CrO_2^- + 2 H_2O + 3 e $\rightleftharpoons$ Cr + 4 OH^-	–1.2
$HCrO_4^-$ + 7 H^+ + 3 e $\rightleftharpoons$ Cr^{3+} + 4 H_2O	1.350
CrO_2 + 4 H^+ + e $\rightleftharpoons$ Cr^{3+} + $2H_2O$	1.48
Cr(V) + e $\rightleftharpoons$ Cr(IV)	1.34
CrO_4^{2-} + 4 H_2O + 3 e $\rightleftharpoons$ $Cr(OH)_3$ + 5 OH^-	–0.13
$Cr(OH)_3$ + 3 e $\rightleftharpoons$ Cr + 3 OH^-	–1.48
Cs^+ + e $\rightleftharpoons$ Cs	–3.026
Cu^+ + e $\rightleftharpoons$ Cu	0.521
Cu^{2+} + e $\rightleftharpoons$ Cu^+	0.153
Cu^{2+} + 2 e $\rightleftharpoons$ Cu	0.3419
Cu^{2+} + 2 e $\rightleftharpoons$ Cu(Hg)	0.345
Cu^{3+} + e $\rightleftharpoons$ Cu^{2+}	2.4
Cu_2O_3 + 6 H^+ + 2e $\rightleftharpoons$ $2Cu^{2+}$ + 3 H_2O	2.0
Cu^{2+} + 2 CN^- + e $\rightleftharpoons$ $[Cu(CN)_2]^-$	1.103
CuI_2^- + e $\rightleftharpoons$ Cu + 2 I^-	0.00
Cu_2O + H_2O + 2 e $\rightleftharpoons$ 2 Cu + 2 OH^-	–0.360
$Cu(OH)_2$ + 2 e $\rightleftharpoons$ Cu + 2 OH^-	–0.222
2 $Cu(OH)_2$ + 2 e $\rightleftharpoons$ Cu_2O + 2 OH^- + H_2O	–0.080
2 D^+ + 2 e $\rightleftharpoons$ D_2	–0.013
Dy^{2+} + 2 e $\rightleftharpoons$ Dy	–2.2
Dy^{3+} + 3 e $\rightleftharpoons$ Dy	–2.295
Dy^{3+} + e $\rightleftharpoons$ Dy^{2+}	–2.6
Er^{2+} + 2 e $\rightleftharpoons$ Er	–2.0
Er^{3+} + 3 e $\rightleftharpoons$ Er	–2.331
Er^{3+} + e $\rightleftharpoons$ Er^{2+}	–3.0
Es^{3+} + e $\rightleftharpoons$ Es^{2+}	–1.3
Es^{3+} + 3 e $\rightleftharpoons$ Es	–1.91
Es^{2+} + 2 e $\rightleftharpoons$ Es	–2.23
Eu^{2+} + 2 e $\rightleftharpoons$ Eu	–2.812
Eu^{3+} + 3 e $\rightleftharpoons$ Eu	–1.991

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TABLE 1
Alphabetical Listing (continued)

Reaction	$E°$/V
$Eu^{3+} + e \rightleftharpoons Eu^{2+}$	–0.36
$F_2 + 2\,H^+ + 2\,e \rightleftharpoons 2\,HF$	3.053
$F_2 + 2\,e \rightleftharpoons 2\,F^-$	2.866
$F_2O + 2\,H^+ + 4\,e \rightleftharpoons H_2O + 2\,F^-$	2.153
$Fe^{2+} + 2\,e \rightleftharpoons Fe$	–0.447
$Fe^{3+} + 3\,e \rightleftharpoons Fe$	–0.037
$Fe^{3+} + e \rightleftharpoons Fe^{2+}$	0.771
$2\,HFeO_4^- + 8\,H^+ + 6\,e \rightleftharpoons Fe_2O_3 + 5\,H_2O$	2.09
$HFeO_4^- + 4\,H^+ + 3\,e \rightleftharpoons FeOOH + 2\,H_2O$	2.08
$HFeO_4^- + 7\,H^+ + 3\,e \rightleftharpoons Fe^{3+} + 4\,H_2O$	2.07
$Fe_2O_3 + 4\,H^+ + 2\,e \rightleftharpoons 2\,FeOH^+ + H_2O$	0.16
$[Fe(CN)_6]^{3-} + e \rightleftharpoons [Fe(CN)_6]^{4-}$	0.358
$FeO_4^{2-} + 8\,H^+ + 3\,e \rightleftharpoons Fe^{3+} + 4\,H_2O$	2.20
$[Fe(bipy)_2]^{3+} + e \rightleftharpoons Fe(bipy)_2]^{2+}$	0.78
$[Fe(bipy)_3]^{3+} + e \rightleftharpoons Fe(bipy)_3]^{2+}$	1.03
$Fe(OH)_3 + e \rightleftharpoons Fe(OH)_2 + OH^-$	–0.56
$[Fe(phen)_3]^{3+} + e \rightleftharpoons [Fe(phen)_3]^{2+}$	1.147
$[Fe(phen)_3]^{3+} + e \rightleftharpoons [Fe(phen)_3]^{2+}$ (1 molar H_2SO_4)	1.06
$[Ferricinium]^+ + e \rightleftharpoons$ ferrocene	0.400
$Fm^{3+} + e \rightleftharpoons Fm^{2+}$	–1.1
$Fm^{3+} + 3\,e \rightleftharpoons Fm$	–1.89
$Fm^{2+} + 2\,e \rightleftharpoons Fm$	–2.30
$Fr^+ + e \rightleftharpoons Fr$	–2.9
$Ga^{3+} + 3\,e \rightleftharpoons Ga$	–0.549
$Ga^+ + e \rightleftharpoons Ga$	–0.2
$GaOH^{2+} + H^+ + 3\,e \rightleftharpoons Ga + H_2O$	–0.498
$H_2GaO^-_3 + H_2O + 3\,e \rightleftharpoons Ga + 4\,OH^-$	–1.219
$Gd^{3+} + 3\,e \rightleftharpoons Gd$	–2.279
$Ge^{2+} + 2\,e \rightleftharpoons Ge$	0.24
$Ge^{4+} + 4\,e \rightleftharpoons Ge$	0.124
$Ge^{4+} + 2\,e \rightleftharpoons Ge^{2+}$	0.00
$GeO_2 + 2\,H^+ + 2\,e \rightleftharpoons GeO + H_2O$	–0.118
$H_2GeO_3 + 4\,H^+ + 4\,e \rightleftharpoons Ge + 3\,H_2O$	–0.182
$2\,H^+ + 2\,e \rightleftharpoons H_2$	0.00000
$H_2 + 2\,e \rightleftharpoons 2\,H^-$	–2.23
$HO_2 + H^+ + e \rightleftharpoons H_2O_2$	1.495
$2\,H_2O + 2\,e \rightleftharpoons H_2 + 2\,OH^-$	–0.8277
$H_2O_2 + 2\,H^+ + 2\,e \rightleftharpoons 2\,H_2O$	1.776
$Hf^{4+} + 4\,e \rightleftharpoons Hf$	–1.55
$HfO^{2+} + 2\,H^+ + 4\,e \rightleftharpoons Hf + H_2O$	–1.724
$HfO_2 + 4\,H^+ + 4\,e \rightleftharpoons Hf + 2\,H_2O$	–1.505
$HfO(OH)_2 + H_2O + 4\,e \rightleftharpoons Hf + 4\,OH^-$	–2.50
$Hg^{2+} + 2\,e \rightleftharpoons Hg$	0.851
$2\,Hg^{2+} + 2\,e \rightleftharpoons Hg_2^{2+}$	0.920
$Hg_2^{2+} + 2\,e \rightleftharpoons 2\,Hg$	0.7973
$Hg_2(ac)_2 + 2\,e \rightleftharpoons 2\,Hg + 2(ac)^-$	0.51163
$Hg_2Br_2 + 2\,e \rightleftharpoons 2\,Hg + 2\,Br^-$	0.13923
$Hg_2Cl_2 + 2\,e \rightleftharpoons 2\,Hg + 2\,Cl^-$	0.26808
$Hg_2HPO_4 + 2\,e \rightleftharpoons 2\,Hg + HPO_4^{2-}$	0.6359
$Hg_2I_2 + 2\,e \rightleftharpoons 2\,Hg + 2\,I^-$	–0.0405
$Hg_2O + H_2O + 2\,e \rightleftharpoons 2\,Hg + 2\,OH^-$	0.123
$HgO + H_2O + 2\,e \rightleftharpoons Hg + 2\,OH^-$	0.0977
$Hg(OH)_2 + 2\,H^+ + 2\,e \rightleftharpoons Hg + 2\,H_2O$	1.034
$Hg_2SO_4 + 2\,e \rightleftharpoons 2\,Hg + SO_4^{2-}$	0.6125
$Ho^{2+} + 2\,e \rightleftharpoons Ho$	–2.1
$Ho^{3+} + 3\,e \rightleftharpoons Ho$	–2.33
$Ho^{3+} + e \rightleftharpoons Ho^{2+}$	–2.8
$I_2 + 2\,e \rightleftharpoons 2\,I^-$	0.5355
$I_3^- + 2\,e \rightleftharpoons 3\,I^-$	0.536
$H_3IO_6^{2-} + 2\,e \rightleftharpoons IO^-_3 + 3\,OH^-$	0.7
$H_5IO_6 + H^+ + 2\,e \rightleftharpoons IO_3^- + 3\,H_2O$	1.601
$2\,HIO + 2\,H^+ + 2\,e \rightleftharpoons I_2 + 2\,H_2O$	1.439
$HIO + H^+ + 2\,e \rightleftharpoons I^- + H_2O$	0.987
$IO^- + H_2O + 2\,e \rightleftharpoons I^- + 2\,OH^-$	0.485
$2\,IO_3^- + 12\,H^+ + 10\,e \rightleftharpoons I_2 + 6\,H_2O$	1.195
$IO_3^- + 6\,H^+ + 6\,e \rightleftharpoons I^- + 3\,H_2O$	1.085
$IO_3^- + 2\,H_2O + 4\,e \rightleftharpoons IO^- + 4\,OH^-$	0.15
$IO_3^- + 3\,H_2O + 6\,e \rightleftharpoons IO^- + 6\,OH^-$	0.26
$In^+ + e \rightleftharpoons In$	–0.14
$In^{2+} + e \rightleftharpoons In^+$	–0.40
$In^{3+} + e \rightleftharpoons In^{2+}$	–0.49
$In^{3+} + 2\,e \rightleftharpoons In^+$	–0.443
$In^{3+} + 3\,e \rightleftharpoons In$	–0.3382
$In(OH)_3 + 3\,e \rightleftharpoons In + 3\,OH^-$	–0.99
$In(OH)_4^- + 3\,e \rightleftharpoons In + 4\,OH^-$	–1.007
$In_2O_3 + 3\,H_2O + 6\,e \rightleftharpoons 2\,In + 6\,OH^-$	–1.034
$Ir^{3+} + 3\,e \rightleftharpoons Ir$	1.156
$[IrCl_6]^{2-} + e \rightleftharpoons [IrCl_6]^{3-}$	0.8665
$[IrCl_6]^{3-} + 3\,e \rightleftharpoons Ir + 6\,Cl^-$	0.77
$Ir_2O_3 + 3\,H_2O + 6\,e \rightleftharpoons 2\,Ir + 6\,OH^-$	0.098
$K^+ + e \rightleftharpoons K$	–2.931
$La^{3+} + 3\,e \rightleftharpoons La$	–2.379
$La(OH)_3 + 3\,e \rightleftharpoons La + 3\,OH^-$	–2.90
$Li^+ + e \rightleftharpoons Li$	–3.0401
$Lr^{3+} + 3\,e \rightleftharpoons Lr$	–1.96
$Lu^{3+} + 3\,e \rightleftharpoons Lu$	–2.28
$Md^{3+} + e \rightleftharpoons Md^{2+}$	–0.1
$Md^{3+} + 3\,e \rightleftharpoons Md$	–1.65
$Md^{2+} + 2\,e \rightleftharpoons Md$	–2.40
$Mg^+ + e \rightleftharpoons Mg$	–2.70
$Mg^{2+} + 2\,e \rightleftharpoons Mg$	–2.372
$Mg(OH)_2 + 2\,e \rightleftharpoons Mg + 2\,OH^-$	–2.690
$Mn^{2+} + 2\,e \rightleftharpoons Mn$	–1.185
$Mn^{3+} + 3e \rightleftharpoons Mn^{2+}$	1.5415
$MnO_2 + 4\,H^+ + 2\,e \rightleftharpoons Mn^{2+} + 2\,H_2O$	1.224
$MnO_4^- + e \rightleftharpoons MnO_4^{2-}$	0.558
$MnO_4^- + 4\,H^+ + 3\,e \rightleftharpoons MnO_2 + 2\,H_2O$	1.679
$MnO_4^- + 8\,H^+ + 5\,e \rightleftharpoons Mn^{2+} + 4\,H_2O$	1.507
$MnO_4^- + 2\,H_2O + 3\,e \rightleftharpoons MnO_2 + 4\,OH^-$	0.595
$MnO_4^{2-} + 2\,H_2O + 2\,e \rightleftharpoons MnO_2 + 4\,OH^-$	0.60
$Mn(OH)_2 + 2\,e \rightleftharpoons Mn + 2\,OH^-$	–1.56
$Mn(OH)_3 + e \rightleftharpoons Mn(OH)_2 + OH^-$	0.15
$Mn_2O_3 + 6\,H^+ + e \rightleftharpoons 2\,Mn^{2+} + 3\,H_2O$	1.485
$Mo^{3+} + 3\,e \rightleftharpoons Mo$	–0.200
$MoO_2 + 4\,H^+ + 4\,e \rightleftharpoons Mo + 4\,H_2O$	–0.152
$H_3Mo_7O_{24}^{3-} + 45\,H^+ + 42\,e \rightleftharpoons 7\,Mo + 24\,H_2O$	0.082
$MoO_3 + 6\,H^+ + 6\,e \rightleftharpoons Mo + 3\,H_2O$	0.075
$N_2 + 2\,H_2O + 6\,H^+ + 6\,e \rightleftharpoons 2\,NH_4OH$	0.092
$3\,N_2 + 2\,H^+ + 2\,e \rightleftharpoons 2\,HN_3$	–3.09
$N_5^+ + 3\,H^+ + 2\,e \rightleftharpoons 2\,NH_4^+$	1.275

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TABLE 1
Alphabetical Listing (continued)

Reaction	$E°$/V
$N_2O + 2\ H^+ + 2\ e \rightleftharpoons N_2 + H_2O$	1.766
$H_2N_2O_2 + 2\ H^+ + 2\ e \rightleftharpoons N_2 + 2\ H_2O$	2.65
$N_2O_4 + 2\ e \rightleftharpoons 2\ NO_2^-$	0.867
$N_2O_4 + 2\ H^+ + 2\ e \rightleftharpoons 2\ NHO_2$	1.065
$N_2O_4 + 4\ H^+ + 4\ e \rightleftharpoons 2\ NO + 2\ H_2O$	1.035
$2\ NH_3OH^+ + H^+ + 2\ e \rightleftharpoons N_2H_5^+ + 2\ H_2O$	1.42
$2\ NO + 2\ H^+ + 2\ e \rightleftharpoons N_2O + H_2O$	1.591
$2\ NO + H_2O + 2\ e \rightleftharpoons N_2O + 2\ OH^-$	0.76
$HNO_2 + H^+ + e \rightleftharpoons NO + H_2O$	0.983
$2\ HNO_2 + 4\ H^+ + 4\ e \rightleftharpoons H_2N_2O_2 + 2\ H_2O$	0.86
$2\ HNO_2 + 4\ H^+ + 4\ e \rightleftharpoons N_2O + 3\ H_2O$	1.297
$NO_2^- + H_2O + e \rightleftharpoons NO + 2\ OH^-$	–0.46
$2\ NO_2^- + 2\ H_2O + 4\ e \rightleftharpoons N_2O_2^{2-} + 4\ OH^-$	–0.18
$2\ NO_2^- + 3\ H_2O + 4\ e \rightleftharpoons N_2O + 6\ OH^-$	0.15
$NO_3^- + 3\ H^+ + 2\ e \rightleftharpoons HNO_2 + H_2O$	0.934
$NO_3^- + 4\ H^+ + 3\ e \rightleftharpoons NO + 2\ H_2O$	0.957
$2\ NO_3^- + 4\ H^+ + 2\ e \rightleftharpoons N_2O_4 + 2\ H_2O$	0.803
$NO_3^- + H_2O + 2\ e \rightleftharpoons NO_2^- + 2\ OH^-$	0.01
$2\ NO_3^- + 2\ H_2O + 2\ e \rightleftharpoons N_2O_4 + 4\ OH^-$	–0.85
$Na^+ + e \rightleftharpoons Na$	–2.71
$Nb^{3+} + 3\ e \rightleftharpoons Nb$	–1.099
$NbO_2 + 2\ H^+ + 2\ e \rightleftharpoons NbO + H_2O$	–0.646
$NbO_2 + 4\ H^+ + 4\ e \rightleftharpoons Nb + 2\ H_2O$	–0.690
$NbO + 2\ H^+ + 2\ e \rightleftharpoons Nb + H_2O$	–0.733
$Nb_2O_5 + 10\ H^+ + 10\ e \rightleftharpoons 2\ Nb + 5\ H_2O$	–0.644
$Nd^{3+} + 3\ e \rightleftharpoons Nd$	–2.323
$Nd^{2+} + 2\ e \rightleftharpoons Nd$	–2.1
$Nd^{3+} + e \rightleftharpoons Nd^{2+}$	–2.7
$Ni^{2+} + 2\ e \rightleftharpoons Ni$	–0.257
$Ni(OH)_2 + 2\ e \rightleftharpoons Ni + 2\ OH^-$	–0.72
$NiO_2 + 4\ H^+ + 2\ e \rightleftharpoons Ni^{2+} + 2\ H_2O$	1.678
$NiO_2 + 2\ H_2O + 2\ e \rightleftharpoons Ni(OH)_2 + 2\ OH^-$	–0.490
$No^{3+} + e \rightleftharpoons No^{2+}$	1.4
$No^{3+} + 3\ e \rightleftharpoons No$	–1.20
$No^{2+} + 2\ e \rightleftharpoons No$	–2.50
$Np^{3+} + 3\ e \rightleftharpoons Np$	–1.856
$Np^{4+} + e \rightleftharpoons Np^{3+}$	0.147
$NpO_2 + H_2O + H^+ + e \rightleftharpoons Np(OH)_3$	–0.962
$O_2 + 2\ H^+ + 2\ e \rightleftharpoons H_2O_2$	0.695
$O_2 + 4\ H^+ + 4\ e \rightleftharpoons 2\ H_2O$	1.229
$O_2 + H_2O + 2\ e \rightleftharpoons HO_2^- + OH^-$	–0.076
$O_2 + 2\ H_2O + 2\ e \rightleftharpoons H_2O_2 + 2\ OH^-$	–0.146
$O_2 + 2\ H_2O + 4\ e \rightleftharpoons 4\ OH^-$	0.401
$O_3 + 2\ H^+ + 2\ e \rightleftharpoons O_2 + H_2O$	2.076
$O_3 + H_2O + 2\ e \rightleftharpoons O_2 + 2\ OH^-$	1.24
$O(g) + 2\ H^+ + 2\ e \rightleftharpoons H_2O$	2.421
$OH + e \rightleftharpoons OH^-$	2.02
$HO_2^- + H_2O + 2\ e \rightleftharpoons 3\ OH^-$	0.878
$OsO_4 + 8\ H^+ + 8\ e \rightleftharpoons Os + 4\ H_2O$	0.838
$OsO_4 + 4\ H^+ + 4\ e \rightleftharpoons OsO_2 + 2\ H_2O$	1.02
$[Os(bipy)_2]^{3+} + e \rightleftharpoons [Os(bipy)_2]^{2+}$	0.81
$[Os(bipy)_3]^{3+} + e \rightleftharpoons [Os(bipy)_3]^{2+}$	0.80
$P(red) + 3\ H^+ + 3\ e \rightleftharpoons PH_3(g)$	–0.111
$P(white) + 3\ H^+ + 3\ e \rightleftharpoons PH_3(g)$	–0.063
$P + 3\ H_2O + 3\ e \rightleftharpoons PH_3(g) + 3\ OH^-$	–0.87
$H_2P_2^- + e \rightleftharpoons P + 2\ OH^-$	–1.82
$H_3PO_2 + H^+ + e \rightleftharpoons P + 2\ H_2O$	–0.508
$H_3PO_3 + 2\ H^+ + 2\ e \rightleftharpoons H_3PO_2 + H_2O$	–0.499
$H_3PO_3 + 3\ H^+ + 3\ e \rightleftharpoons P + 3\ H_2O$	–0.454
$HPO_3^{2-} + 2\ H_2O + 2\ e \rightleftharpoons H_2PO_2^- + 3\ OH^-$	–1.65
$HPO_3^{2-} + 2\ H_2O + 3\ e \rightleftharpoons P + 5\ OH^-$	–1.71
$H_3PO_4 + 2\ H^+ + 2\ e \rightleftharpoons H_3PO_3 + H_2O$	–0.276
$PO_4^{3-} + 2\ H_2O + 2\ e \rightleftharpoons HPO_3^{2-} + 3\ OH^-$	–1.05
$Pa^{3+} + 3\ e \rightleftharpoons Pa$	–1.34
$Pa^{4+} + 4\ e \rightleftharpoons Pa$	–1.49
$Pa^{4+} + e \rightleftharpoons Pa^{3+}$	–1.9
$Pb^{2+} + 2\ e \rightleftharpoons Pb$	–0.1262
$Pb^{2+} + 2\ e \rightleftharpoons Pb(Hg)$	–0.1205
$PbBr_2 + 2\ e \rightleftharpoons Pb + 2\ Br^-$	–0.284
$PbCl_2 + 2\ e \rightleftharpoons Pb + 2\ Cl^-$	–0.2675
$PbF_2 + 2\ e \rightleftharpoons Pb + 2\ F^-$	–0.3444
$PbHPO_4 + 2\ e \rightleftharpoons Pb + HPO_4^{2-}$	–0.465
$PbI_2 + 2\ e \rightleftharpoons Pb + 2\ I^-$	–0.365
$PbO + H_2O + 2\ e \rightleftharpoons Pb + 2\ OH^-$	–0.580
$PbO_2 + 4\ H^+ + 2\ e \rightleftharpoons Pb^{2+} + 2\ H_2O$	1.455
$HPbO_2^- + H_2O + 2\ e \rightleftharpoons Pb + 3\ OH^-$	–0.537
$PbO_2 + H_2O + 2\ e \rightleftharpoons PbO + 2\ OH^-$	0.247
$PbO_2 + SO_4^{2-} + 4\ H^+ + 2\ e \rightleftharpoons PbSO_4 + 2\ H_2O$	1.6913
$PbSO_4 + 2\ e \rightleftharpoons Pb + SO_4^{2-}$	–0.3588
$PbSO_4 + 2\ e \rightleftharpoons Pb(Hg) + SO_4^{2-}$	–0.3505
$Pd^{2+} + 2\ e \rightleftharpoons Pd$	0.951
$[PdCl_4]^{2-} + 2\ e \rightleftharpoons Pd + 4\ Cl^-$	0.591
$[PdCl_6]^{2-} + 2\ e \rightleftharpoons [PdCl_4]^{2-} + 2\ Cl^-$	1.288
$Pd(OH)_2 + 2\ e \rightleftharpoons Pd + 2\ OH^-$	0.07
$Pm^{2+} + 2\ e \rightleftharpoons Pm$	–2.2
$Pm^{3+} + 3\ e \rightleftharpoons Pm$	–2.30
$Pm^{3+} + e \rightleftharpoons Pm^{2+}$	–2.6
$Po^{4+} + 2\ e \rightleftharpoons Po^{2+}$	0.9
$Po^{4+} + 4\ e \rightleftharpoons Po$	0.76
$Pr^{4+} + e \rightleftharpoons Pr^{3+}$	3.2
$Pr^{2+} + 2\ e \rightleftharpoons Pr$	–2.0
$Pr^{3+} + 3\ e \rightleftharpoons Pr$	–2.353
$Pr^{3+} + e \rightleftharpoons Pr^{2+}$	–3.1
$Pt^{2+} + 2\ e \rightleftharpoons Pt$	1.18
$[PtCl_4]^{2-} + 2\ e \rightleftharpoons Pt + 4\ Cl^-$	0.755
$[PtCl_6]^{2-} + 2\ e \rightleftharpoons [PtCl_4]^{2-} + 2\ Cl^-$	0.68
$Pt(OH)_2 + 2\ e \rightleftharpoons Pt + 2\ OH^-$	0.14
$PtO_3 + 2\ H^+ + 2\ e \rightleftharpoons PtO_2 + H_2O$	1.7
$PtO_3 + 4\ H^+ + 2\ e \rightleftharpoons Pt(OH)_2^{2+} + H_2O$	1.5
$PtOH^+ + H^+ + 2\ e \rightleftharpoons Pt + H_2O$	1.2
$PtO_2 + 2\ H^+ + 2\ e \rightleftharpoons PtO + H_2O$	1.01
$PtO_2 + 4\ H^+ + 4\ e \rightleftharpoons Pt + 2\ H_2O$	1.00
$Pu^{3+} + 3\ e \rightleftharpoons Pu$	–2.031
$Pu^{4+} + e \rightleftharpoons Pu^{3+}$	1.006
$Pu^{5+} + e \rightleftharpoons Pu^{4+}$	1.099
$PuO_2(OH)_2 + 2\ H^+ + 2\ e \rightleftharpoons Pu(OH)_4$	1.325
$PuO_2(OH)_2 + H^+ + e \rightleftharpoons PuO_2OH + H_2O$	1.062
$Ra^{2+} + 2\ e \rightleftharpoons Ra$	–2.8
$Rb^+ + e \rightleftharpoons Rb$	–2.98
$Re^{3+} + 3\ e \rightleftharpoons Re$	0.300

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TABLE 1
Alphabetical Listing (continued)

Reaction	$E°$/V
$ReO_4^- + 4 H^+ + 3 e \rightleftharpoons ReO_2 + 2 H_2O$	0.510
$ReO_2 + 4 H^+ + 4 e \rightleftharpoons Re + 2 H_2O$	0.2513
$ReO_4^- + 2 H^+ + e \rightleftharpoons ReO_3 + H_2O$	0.768
$ReO_4^- + 4 H_2O + 7 e \rightleftharpoons Re + 8 OH^-$	–0.584
$ReO_4^- + 8 H^+ + 7 e \rightleftharpoons Re + 4 H_2O$	0.368
$Rh^+ + e \rightleftharpoons Rh$	0.600
$Rh^+ + 2e \rightleftharpoons Rh$	0.600
$Rh^{3+} + 3 e \rightleftharpoons Rh$	0.758
$[RhCl_6]^{3-} + 3 e \rightleftharpoons Rh + 6 Cl^-$	0.431
$RhOH^{2+} + H^+ + 3 e \rightleftharpoons Rh + H_2O$	0.83
$Ru^{2+} + 2 e \rightleftharpoons Ru$	0.455
$Ru^{3+} + e \rightleftharpoons Ru^{2+}$	0.2487
$RuO_2 + 4 H^+ + 2 e \rightleftharpoons Ru^{2+} + 2 H_2O$	1.120
$RuO_4^- + e \rightleftharpoons RuO_4^{2-}$	0.59
$RuO_4 + e \rightleftharpoons RuO_4^-$	1.00
$RuO_4 + 6 H^+ + 4 e \rightleftharpoons Ru(OH)_2^{2+} + 2 H_2O$	1.40
$RuO_4 + 8 H^+ + 8 e \rightleftharpoons Ru + 4 H_2O$	1.038
$[Ru(bipy)_3]^{3+} + e^- \rightleftharpoons [Ru(bipy)_3]^{2+}$	1.24
$[Ru(H_2O)_6]^{3+} + e^- \rightleftharpoons [Ru(H_2O)_6]^{2+}$	0.23
$[Ru(NH_3)_6]^{3+} + e^- \rightleftharpoons [Ru(NH_3)_6]^{2+}$	0.10
$[Ru(en)_3]^{3+} + e^- \rightleftharpoons [Ru(en)_3]^{2+}$	0.210
$[Ru(CN)_6]^{3-} + e^- \rightleftharpoons [Ru(CN)_6]^{4-}$	0.86
$S + 2 e \rightleftharpoons S^{2-}$	–0.47627
$S + 2H^+ + 2 e \rightleftharpoons H_2S(aq)$	0.142
$S + H_2O + 2 e \rightleftharpoons SH^- + OH^-$	–0.478
$2 S + 2 e \rightleftharpoons S_2^{2-}$	–0.42836
$S_2O_6^{2-} + 4 H^+ + 2 e \rightleftharpoons 2 H_2SO_3$	0.564
$S_2O_8^{2-} + 2 e \rightleftharpoons 2 SO_4^{2-}$	2.010
$S_2O_8^{2-} + 2 H^+ + 2 e \rightleftharpoons 2 HSO_4^-$	2.123
$S_4O_6^{2-} + 2 e \rightleftharpoons 2 S_2O_3^{2-}$	0.08
$2 H_2SO_3 + H^+ + 2 e \rightleftharpoons HS_2O_4^- + 2 H_2O$	–0.056
$H_2SO_3 + 4 H^+ + 4 e \rightleftharpoons S + 3 H_2O$	0.449
$2 SO_3^{2-} + 2 H_2O + 2 e \rightleftharpoons S_2O_4^{2-} + 4 OH^-$	–1.12
$2 SO_3^{2-} + 3 H_2O + 4 e \rightleftharpoons S_2O_3^{2-} + 6 OH^-$	–0.571
$SO_4^{2-} + 4 H^+ + 2 e \rightleftharpoons H_2SO_3 + H_2O$	0.172
$2 SO_4^{2-} + 4 H^+ + 2 e \rightleftharpoons S_2O_6^{2-} + H_2O$	–0.22
$SO_4^{2-} + H_2O + 2 e \rightleftharpoons SO_3^{2-} + 2 OH^-$	–0.93
$Sb + 3 H^+ + 3 e \rightleftharpoons SbH_3$	–0.510
$Sb_2O_3 + 6 H^+ + 6 e \rightleftharpoons 2 Sb + 3 H_2O$	0.152
Sb_2O_5 (senarmontite) $+ 4 H^+ + 4 e \rightleftharpoons Sb_2O_3 + 2 H_2O$	0.671
Sb_2O_5 (valentinite) $+ 4 H^+ + 4 e \rightleftharpoons Sb_2O_3 + 2 H_2O$	0.649
$Sb_2O_5 + 6 H^+ + 4 e \rightleftharpoons 2 SbO^+ + 3 H_2O$	0.581
$SbO^+ + 2 H^+ + 3 e \rightleftharpoons Sb + 2 H_2O$	0.212
$SbO_2^- + 2 H_2O + 3 e \rightleftharpoons Sb + 4 OH^-$	–0.66
$SbO_3^- + H_2O + 2 e \rightleftharpoons SbO_2^- + 2 OH^-$	–0.59
$Sc^{3+} + 3 e \rightleftharpoons Sc$	–2.077
$Se + 2 e \rightleftharpoons Se^{2-}$	–0.924
$Se + 2 H^+ + 2 e \rightleftharpoons H_2Se(aq)$	–0.399
$H_2SeO_3 + 4 H^+ + 4 e \rightleftharpoons Se + 3 H_2O$	0.74
$Se + 2 H^+ + 2 e \rightleftharpoons H_2Se$	–0.082
$SeO_3^{2-} + 3 H_2O + 4 e \rightleftharpoons Se + 6 OH^-$	–0.366
$SeO_4^{2-} + 4 H^+ + 2 e \rightleftharpoons H_2SeO_3 + H_2O$	1.151
$SeO_4^{2-} + H_2O + 2 e \rightleftharpoons SeO_3^{2-} + 2 OH^-$	0.05
$SiF_6^{2-} + 4 e \rightleftharpoons Si + 6 F^-$	–1.24
$SiO + 2 H^+ + 2 e \rightleftharpoons Si + H_2O$	–0.8

Reaction	$E°$/V
SiO_2 (quartz) $+ 4 H^+ + 4 e \rightleftharpoons Si + 2 H_2O$	0.857
$SiO_3^{2-} + 3 H_2O + 4 e \rightleftharpoons Si + 6 OH^-$	–1.697
$Sm^{3+} + e \rightleftharpoons Sm^{2+}$	–1.55
$Sm^{3+} + 3 e \rightleftharpoons Sm$	–2.304
$Sm^{2+} + 2 e \rightleftharpoons Sm$	–2.68
$Sn^{2+} + 2 e \rightleftharpoons Sn$	–0.1375
$Sn^{4+} + 2 e \rightleftharpoons Sn^{2+}$	0.151
$Sn(OH)_3^+ + 3 H^+ + 2 e \rightleftharpoons Sn^{2+} + 3 H_2O$	0.142
$SnO_2 + 4 H^+ + 2 e^- \rightleftharpoons Sn^{2+} + 2 H_2O$	–0.094
$SnO_2 + 4 H^+ + 4 e \rightleftharpoons Sn + 2 H_2O$	–0.117
$SnO_2 + 3 H^+ + 2 e \rightleftharpoons SnOH^+ + H_2O$	–0.194
$SnO_2 + 2 H_2O + 4 e \rightleftharpoons Sn + 4 OH^-$	–0.945
$HSnO_2^- + H_2O + 2 e \rightleftharpoons Sn + 3 OH^-$	–0.909
$Sn(OH)_6^{2-} + 2 e \rightleftharpoons HSnO_2^- + 3 OH^- + H_2O$	–0.93
$Sr^+ + e \rightleftharpoons Sr$	–4.10
$Sr^{2+} + 2 e \rightleftharpoons Sr$	–2.899
$Sr^{2+} + 2 e \rightleftharpoons Sr(Hg)$	–1.793
$Sr(OH)_2 + 2 e \rightleftharpoons Sr + 2 OH^-$	–2.88
$Ta_2O_5 + 10 H^+ + 10 e \rightleftharpoons 2 Ta + 5 H_2O$	–0.750
$Ta^{3+} + 3 e \rightleftharpoons Ta$	–0.6
$Tc^{2+} + 2 e \rightleftharpoons Tc$	0.400
$TcO_4^- + 4 H^+ + 3 e \rightleftharpoons TcO_2 + 2 H_2O$	0.782
$Tc^{3+} + e \rightleftharpoons Tc^{2+}$	0.3
$TcO_4^- + 8 H^+ + 7 e \rightleftharpoons Tc + 4 H_2O$	0.472
$Tb^{4+} + e \rightleftharpoons Tb^{3+}$	3.1
$Tb^{3+} + 3 e \rightleftharpoons Tb$	–2.28
$Te + 2 e \rightleftharpoons Te^{2-}$	–1.143
$Te + 2 H^+ + 2 e \rightleftharpoons H_2Te$	–0.793
$Te^{4+} + 4 e \rightleftharpoons Te$	0.568
$TeO_2 + 4 H^+ + 4 e \rightleftharpoons Te + 2 H_2O$	0.593
$TeO_3^{2-} + 3 H_2O + 4 e \rightleftharpoons Te + 6 OH^-$	–0.57
$TeO_4^- + 8 H^+ + 7 e \rightleftharpoons Te + 4 H_2O$	0.472
$H_6TeO_6 + 2 H^+ + 2 e \rightleftharpoons TeO_2 + 4 H_2O$	1.02
$Th^{4+} + 4 e \rightleftharpoons Th$	–1.899
$ThO_2 + 4 H^+ + 4 e \rightleftharpoons Th + 2 H_2O$	–1.789
$Th(OH)_4 + 4 e \rightleftharpoons Th + 4 OH^-$	–2.48
$Ti^{2+} + 2 e \rightleftharpoons Ti$	–1.630
$Ti^{3+} + e \rightleftharpoons Ti^{2+}$	–0.9
$TiO_2 + 4 H^+ + 2 e \rightleftharpoons Ti^{2+} + 2 H_2O$	–0.502
$Ti^{3+} + 3 e \rightleftharpoons Ti$	–1.37
$TiOH^{3+} + H^+ + e \rightleftharpoons Ti^{3+} + H_2O$	–0.055
$Tl^+ + e \rightleftharpoons Tl$	–0.336
$Tl^+ + e \rightleftharpoons Tl(Hg)$	–0.3338
$Tl^{3+} + 2 e \rightleftharpoons Tl^+$	1.252
$Tl^{3+} + 3 e \rightleftharpoons Tl$	0.741
$TlBr + e \rightleftharpoons Tl + Br^-$	–0.658
$TlCl + e \rightleftharpoons Tl + Cl^-$	–0.5568
$TlI + e \rightleftharpoons Tl + I^-$	–0.752
$Tl_2O_3 + 3 H_2O + 4 e \rightleftharpoons 2 Tl^+ + 6 OH^-$	0.02
$TlOH + e \rightleftharpoons Tl + OH^-$	–0.34
$Tl(OH)_3 + 2 e \rightleftharpoons TlOH + 2 OH^-$	–0.05
$Tl_2SO_4 + 2 e \rightleftharpoons Tl + SO_4^{2-}$	–0.4360
$Tm^{3+} + e \rightleftharpoons Tm^{2+}$	–2.2
$Tm^{3+} + 3 e \rightleftharpoons Tm$	–2.319
$Tm^{2+} + 2 e \rightleftharpoons Tm$	–2.4

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TABLE 1
Alphabetical Listing (continued)

Reaction	$E°$/V
$U^{3+} + 3e \rightleftharpoons U$	–1.798
$U^{4+} + e \rightleftharpoons U^{3+}$	–0.607
$UO_2^+ + 4H^+ + e \rightleftharpoons U^{4+} + 2H_2O$	0.612
$UO_2^{2+} + e \rightleftharpoons UO^+_2$	0.062
$UO_2^{2+} + 4H^+ + 2e \rightleftharpoons U^{4+} + 2H_2O$	0.327
$UO_2^{2+} + 4H^+ + 6e \rightleftharpoons U + 2H_2O$	–1.444
$V^{2+} + 2e \rightleftharpoons V$	–1.175
$V^{3+} + e \rightleftharpoons V^{2+}$	–0.255
$VO^{2+} + 2H^+ + e \rightleftharpoons V^{3+} + H_2O$	0.337
$VO_2^+ + 2H^+ + e \rightleftharpoons VO^{2+} + H_2O$	0.991
$V_2O_5 + 6H^+ + 2e \rightleftharpoons 2VO^{2+} + 3H_2O$	0.957
$V_2O_5 + 10H^+ + 10e \rightleftharpoons 2V + 5H_2O$	–0.242
$V(OH)_4^+ + 2H^+ + e \rightleftharpoons VO^{2+} + 3H_2O$	1.00
$V(OH)_4^+ + 4H^+ + 5e \rightleftharpoons V + 4H_2O$	–0.254
$[V(phen)_3]^{3+} + e \rightleftharpoons [V(phen)_3]^{2+}$	0.14
$W^{3+} + 3e \rightleftharpoons W$	0.1
$W_2O_5 + 2H^+ + 2e \rightleftharpoons 2WO_2 + H_2O$	–0.031
$WO_2 + 4H^+ + 4e \rightleftharpoons W + 2H_2O$	–0.119
$WO_3 + 6H^+ + 6e \rightleftharpoons W + 3H_2O$	–0.090
$WO_3 + 2H^+ + 2e \rightleftharpoons WO_2 + H_2O$	0.036
$2WO_3 + 2H^+ + 2e \rightleftharpoons W_2O_5 + H_2O$	–0.029
$H_4XeO_6 + 2H^+ + 2e \rightleftharpoons XeO_3 + 3H_2O$	2.42
$XeO_3 + 6H^+ + 6e \rightleftharpoons Xe + 3H_2O$	2.10
$XeF + e \rightleftharpoons Xe + F^-$	3.4
$Y^{3+} + 3e \rightleftharpoons Y$	–2.372
$Yb^{3+} + e \rightleftharpoons Yb^{2+}$	–1.05
$Yb^{3+} + 3e \rightleftharpoons Yb$	–2.19
$Yb^{2+} + 2e \rightleftharpoons Yb$	–2.76
$Zn^{2+} + 2e \rightleftharpoons Zn$	–0.7618
$Zn^{2+} + 2e \rightleftharpoons Zn(Hg)$	–0.7628
$ZnO_2^{2-} + 2H_2O + 2e \rightleftharpoons Zn + 4OH^-$	–1.215
$ZnSO_4 \cdot 7H_2O + 2e = Zn(Hg) + SO_4^{2-} + 7H_2O$ (Saturated $ZnSO_4$)	–0.7993
$ZnOH^+ + H^+ + 2e \rightleftharpoons Zn + H_2O$	–0.497
$Zn(OH)_4^{2-} + 2e \rightleftharpoons Zn + 4OH^-$	–1.199
$Zn(OH)_2 + 2e \rightleftharpoons Zn + 2OH^-$	–1.249
$ZnO + H_2O + 2e \rightleftharpoons Zn + 2OH^-$	–1.260
$ZrO_2 + 4H^+ + 4e \rightleftharpoons Zr + 2H_2O$	–1.553
$ZrO(OH)_2 + H_2O + 4e \rightleftharpoons Zr + 4OH^-$	–2.36
$Zr^{4+} + 4e \rightleftharpoons Zr$	–1.45

TABLE 2
Reduction Reactions Having $E°$ Values More Positive than that of the Standard Hydrogen Electrode

Reaction	$E°$/V
$2H^+ + 2e \rightleftharpoons H_2$	0.00000
$CuI_2^- + e \rightleftharpoons Cu + 2I^-$	0.00
$Ge^{4+} + 2e \rightleftharpoons Ge^{2+}$	0.00
$NO_3^- + H_2O + 2e \rightleftharpoons NO_2^- + 2OH^-$	0.01
$Tl_2O_3 + 3H_2O + 4e \rightleftharpoons 2Tl^+ + 6OH^-$	0.02
$SeO_4^{2-} + H_2O + 2e \rightleftharpoons SeO_3^{2-} + 2OH^-$	0.05
$WO_3 + 2H^+ + 2e \rightleftharpoons WO_2 + H_2O$	0.036
$UO_2^{2+} + e = UO_2^+$	0.062
$Pd(OH)_2 + 2e \rightleftharpoons Pd + 2OH^-$	0.07
$AgBr + e \rightleftharpoons Ag + Br^-$	0.07133
$MoO_3 + 6H^+ + 6e \rightleftharpoons Mo + 3H_2O$	0.075
$S_4O_6^{2-} + 2e \rightleftharpoons 2S_2O_3^{2-}$	0.08
$H_3Mo_7O_{24}^{3-} + 45H^+ + 42e \rightleftharpoons 7Mo + 24H_2O$	0.082
$AgSCN + e \rightleftharpoons Ag + SCN^-$	0.8951
$N_2 + 2H_2O + 6H^+ + 6e \rightleftharpoons 2NH_4OH$	0.092
$HgO + H_2O + 2e \rightleftharpoons Hg + 2OH^-$	0.0977
$Ir_2O_3 + 3H_2O + 6e \rightleftharpoons 2Ir + 6OH^-$	0.098
$2NO + 2e \rightleftharpoons N_2O_2^{2-}$	0.10
$[Ru(NH_3)_6]^{3+} + e \rightleftharpoons [Ru(NH_3)_6]^{2+}$	0.10
$W^{3+} + 3e \rightleftharpoons W$	0.1
$[Co(NH_3)_6]^{3+} + e \rightleftharpoons [Co(NH_3)_6]^{2+}$	0.108
$Hg_2O + H_2O + 2e \rightleftharpoons 2Hg + 2OH^-$	0.123
$Ge^{4+} + 4e \rightleftharpoons Ge$	0.124
$Hg_2Br_2 + 2e \rightleftharpoons 2Hg + 2Br^-$	0.13923
$Pt(OH)_2 + 2e \rightleftharpoons Pt + 2OH^-$	0.14
$[V(phen)_3]^{3+} + e \rightleftharpoons [V(phen)_3]^{2+}$	0.14
$S + 2H^+ + 2e \rightleftharpoons H_2S(aq)$	0.142
$Sn(OH)_3^+ + 3H^+ + 2e \rightleftharpoons Sn^{2+} + 3H_2O$	0.142
$Np^{4+} + e \rightleftharpoons Np^{3+}$	0.147
$Ag_4[Fe(CN)_6] + 4e \rightleftharpoons 4Ag + [Fe(CN)_6]^{4-}$	0.1478
$IO_3^- + 2H_2O + 4e \rightleftharpoons IO^- + 4OH^-$	0.15
$Mn(OH)_3 + e \rightleftharpoons Mn(OH)_2 + OH^-$	0.15
$2NO_2^- + 3H_2O + 4e \rightleftharpoons N_2O + 6OH^-$	0.15
$Sn^{4+} + 2e \rightleftharpoons Sn^{2+}$	0.151
$Sb_2O_3 + 6H^+ + 6e \rightleftharpoons 2Sb + 3H_2O$	0.152
$Cu^{2+} + e \rightleftharpoons Cu^+$	0.153
$BiOCl + 2H^+ + 3e \rightleftharpoons Bi + Cl^- + H_2O$	0.1583
$BiCl_4^- + 3e \rightleftharpoons Bi + 4Cl^-$	0.16
$Fe_2O_3 + 4H^+ + 2e \rightleftharpoons 2FeOH^+ + H_2O$	0.16
$Co(OH)_3 + e \rightleftharpoons Co(OH)_2 + OH^-$	0.17
$SO_4^{2-} + 4H^+ + 2e \rightleftharpoons H_2SO_3 + H_2O$	0.172
$Bi^{3+} + 2e \rightleftharpoons Bi^+$	0.2
$[Ru(en)_3]^{3+} + e \rightleftharpoons [Ru(en)_3]^{2+}$	0.210
$SbO^+ + 2H^+ + 3e \rightleftharpoons Sb + 2H_2O$	0.212
$AgCl + e \rightleftharpoons Ag + Cl^-$	0.22233
$[Ru(H_2O)_6]^{3+} + e \rightleftharpoons [Ru(H_2O)_6]^{2+}$	0.23
$As_2O_3 + 6H^+ + 6e \rightleftharpoons 2As + 3H_2O$	0.234
Calomel electrode, saturated NaCl (SSCE)	0.2360
$Ge^{2+} + 2e \rightleftharpoons Ge$	0.24
$Ru^{3+} + e \rightleftharpoons Ru^{2+}$	0.24
Calomel electrode, saturated KCl	0.2412
$PbO_2 + H_2O + 2e \rightleftharpoons PbO + 2OH^-$	0.247
$HAsO_2 + 3H^+ + 3e \rightleftharpoons As + 2H_2O$	0.248
$Ru^{3+} + e \rightleftharpoons Ru^{2+}$	0.2487

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TABLE 2
Reduction Reactions Having $E°$ Values More Positive than that of the Standard Hydrogen Electrode (continued)

Reaction	$E°$/V
$ReO_2 + 4 H^+ + 4 e \rightleftharpoons Re + 2 H_2O$	0.2513
$IO_3^- + 3 H_2O + 6 e \rightleftharpoons I^- + OH^-$	0.26
$Hg_2Cl_2 + 2 e \rightleftharpoons 2 Hg + 2 Cl^-$	0.26808
Calomel electrode, 1 molal KCl	0.2800
Calomel electrode, 1 molar KCl (NCE)	0.2801
$At_2 + 2 e \rightleftharpoons 2 At^-$	0.3
$Re^{3+} + 3 e \rightleftharpoons Re$	0.300
$Tc^{3+} + e \rightleftharpoons Tc^{2+}$	0.3
$Bi^{3+} + 3 e \rightleftharpoons Bi$	0.308
$BiO^+ + 2 H^+ + 3 e \rightleftharpoons Bi + H_2O$	0.320
$UO_2^{2+} + 4 H^+ + 2 e \rightleftharpoons U^{4+} + 2 H_2O$	0.327
$ClO_3^- + H_2O + 2 e \rightleftharpoons ClO_2^- + 2 OH^-$	0.33
$2 HCNO + 2 H^+ + 2 e \rightleftharpoons (CN)_2 + 2 H_2O$	0.330
Calomel electrode, 0.1 molar KCl	0.3337
$VO^{2+} + 2 H^+ + e \rightleftharpoons V^{3+} + H_2O$	0.337
$Cu^{2+} + 2 e \rightleftharpoons Cu$	0.3419
$Ag_2O + H_2O + 2 e \rightleftharpoons 2 Ag + 2 OH^-$	0.342
$Cu^{2+} + 2 e \rightleftharpoons Cu(Hg)$	0.345
$AgIO_3 + e \rightleftharpoons Ag + IO_3^-$	0.354
$[Fe(CN)_6]^{3-} + e \rightleftharpoons [Fe(CN)_6]^{4-}$	0.358
$ClO_4^- + H_2O + 2 e \rightleftharpoons ClO^-_3 + 2 OH^-$	0.36
$Ag_2SeO_3 + 2 e \rightleftharpoons 2 Ag + SeO_3^{2-}$	0.3629
$ReO_4^- + 8 H^+ + 7 e \rightleftharpoons Re + 4 H_2O$	0.368
$(CN)_2 + 2 H^+ + 2 e \rightleftharpoons 2 HCN$	0.373
$[Ferricinium]^+ + e \rightleftharpoons$ ferrocene	0.400
$Tc^{2+} + 2 e \rightleftharpoons Tc$	0.400
$O_2 + 2 H_2O + 4 e \rightleftharpoons 4 OH^-$	0.401
$AgOCN + e \rightleftharpoons Ag + OCN^-$	0.41
$[RhCl_6]^{3-} + 3 e \rightleftharpoons Rh + 6 Cl^-$	0.431
$Ag_2CrO_4 + 2 e \rightleftharpoons 2 Ag + CrO_4^{2-}$	0.4470
$H_2SO_3 + 4 H^+ + 4 e \rightleftharpoons S + 3 H_2O$	0.449
$Ru^{2+} + 2 e \rightleftharpoons Ru$	0.455
$Ag_2MoO_4 + 2 e \rightleftharpoons 2 Ag + MoO_4^{2-}$	0.4573
$Ag_2C_2O_4 + 2 e \rightleftharpoons 2 Ag + C_2O_4^{2-}$	0.4647
$Ag_2WO_4 + 2 e \rightleftharpoons 2 Ag + WO_4^{2-}$	0.4660
$Ag_2CO_3 + 2 e \rightleftharpoons 2 Ag + CO_3^{2-}$	0.47
$TcO_4^- + 8 H^+ + 7 e \rightleftharpoons Tc + 4 H_2O$	0.472
$TeO_4^- + 8 H^+ + 7 e \rightleftharpoons Te + 4 H_2O$	0.472
$IO^- + H_2O + 2 e \rightleftharpoons I^- + 2 OH^-$	0.485
$NiO_2 + 2 H_2O + 2 e \rightleftharpoons Ni(OH)_2 + 2 OH^-$	0.490
$Bi^+ + e \rightleftharpoons Bi$	0.5
$ReO_4^- + 4 H^+ + 3 e \rightleftharpoons ReO_2 + 2 H_2O$	0.510
$Hg_2(ac)_2 + 2 e \rightleftharpoons 2 Hg + 2(ac)^-$	0.51163
$Cu^+ + e \rightleftharpoons Cu$	0.521
$I_2 + 2 e \rightleftharpoons 2 I^-$	0.5355
$I_3^- + 2 e \rightleftharpoons 3 I^-$	0.536
$AgBrO_3 + e \rightleftharpoons Ag + BrO_3^-$	0.546
$MnO_4^- + e \rightleftharpoons MnO_2^-$	0.558
$H_3AsO_4 + 2 H^+ + 2 e \rightleftharpoons HAsO_2 + 2 H_2O$	0.560
$S_2O_6^{2-} + 4 H^+ + 2 e \rightleftharpoons 2 H_2SO_3$	0.564
$AgNO_2 + e \rightleftharpoons Ag + NO_2^-$	0.564
$Te^{4+} + 4 e \rightleftharpoons Te$	0.568
$Sb_2O_5 + 6 H^+ + 4 e \rightleftharpoons 2 SbO^+ + 3 H_2O$	0.581
$RuO_4^- + e \rightleftharpoons RuO_4^{2-}$	0.59
$[PdCl_4]^{2-} + 2 e \rightleftharpoons Pd + 4 Cl^-$	0.591
$TeO_2 + 4 H^+ + 4 e \rightleftharpoons Te + 2 H_2O$	0.593
$MnO_4^- + 2 H_2O + 3 e \rightleftharpoons MnO_2 + 4 OH^-$	0.595
$Rh^{2+} + 2 e \rightleftharpoons Rh$	0.600
$Rh^+ + e \rightleftharpoons Rh$	0.600
$MnO_4^{2-} + 2 H_2O + 2 e \rightleftharpoons MnO_2 + 4 OH^-$	0.60
$2 AgO + H_2O + 2 e \rightleftharpoons Ag_2O + 2 OH^-$	0.607
$BrO_3^- + 3 H_2O + 6 e \rightleftharpoons Br^- + 6 OH^-$	0.61
$UO_2^+ + 4 H^+ + e \rightleftharpoons U^{4+} + 2 H_2O$	0.612
$Hg_2SO_4 + 2 e \rightleftharpoons 2 Hg + SO_4^{2-}$	0.6125
$ClO_3^- + 3 H_2O + 6 e \rightleftharpoons Cl^- + 6 OH^-$	0.62
$Hg_2HPO_4 + 2 e \rightleftharpoons 2 Hg + HPO_4^{2-}$	0.6359
$Ag(ac) + e \rightleftharpoons Ag + (ac)^-$	0.643
Sb_2O_5(valentinite) $+ 4 H^+ + 4 e \rightleftharpoons Sb_2O_3 + 2 H_2O$	0.649
$Ag_2SO_4 + 2 e \rightleftharpoons 2 Ag + SO_4^{2-}$	0.654
$ClO_2^- + H_2O + 2 e \rightleftharpoons ClO^- + 2 OH^-$	0.66
Sb_2O_5(senarmontite) $+ 4 H^+ + 4 e \rightleftharpoons Sb_2O_5 + 2 H_2O$	0.671
$[PtCl_6]^{2-} + 2 e \rightleftharpoons [PtCl_4]^{2-} + 2 Cl^-$	0.68
$O_2 + 2 H^+ + 2 e \rightleftharpoons H_2O_2$	0.695
p–benzoquinone $+ 2 H^+ + 2 e \rightleftharpoons$ hydroquinone	0.6992
$H_3IO_6^{2-} + 2 e \rightleftharpoons IO_3^- + 3 OH^-$	0.7
$Ag_2O_3 + H_2O + 2 e \rightleftharpoons 2 AgO + 2 OH^-$	0.739
$Tl^{3+} + 3 e \rightleftharpoons Tl$	0.741
$[PtCl_4]^{2-} + 2 e \rightleftharpoons Pt + 4 Cl^-$	0.755
$Rh^{3+} + 3 e \rightleftharpoons Rh$	0.758
$ClO_2^- + 2 H_2O + 4 e \rightleftharpoons Cl^- + 4 OH^-$	0.76
$2 NO + H_2O + 2 e \rightleftharpoons N_2O + 2 OH^-$	0.76
$Po^{4+} + 4 e \rightleftharpoons Po$	0.76
$BrO^- + H_2O + 2 e \rightleftharpoons Br^- + 2 OH^-$	0.761
$ReO_4^- + 2 H^+ + e \rightleftharpoons ReO_3 + H_2O$	0.768
$(CNS)_2 + 2 e \rightleftharpoons 2 CNS^-$	0.77
$[IrCl_6]^{3-} + 3 e \rightleftharpoons Ir + 6 Cl^-$	0.77
$Fe^{3+} + e \rightleftharpoons Fe^{2+}$	0.771
$AgF + e \rightleftharpoons Ag + F^-$	0.779
$[Fe(bipy)_2]^{3+} + e \rightleftharpoons [Fe(bipy)_2]^{2+}$	0.78
$TcO_4^- + 4 H^+ + 3 e \rightleftharpoons TcO_2 + 2 H_2O$	0.782
$Hg_2^{2+} + 2 e \rightleftharpoons 2 Hg$	0.7973
$Ag^+ + e \rightleftharpoons Ag$	0.7996
$[Os(bipy)_3]^{3+} + e \rightleftharpoons [Os(bipy)_3]^{2+}$	0.80
$2 NO_3^- + 4 H^+ + 2 e \rightleftharpoons N_2O_4 + 2 H_2O$	0.803
$[Os(bipy)_2]^{3+} + e \rightleftharpoons [Os(bipy)_2]^{2+}$	0.81
$RhOH^{2+} + H + 3 e \rightleftharpoons Rh + H_2O$	0.83
$OsO_4 + 8 H^+ + 8 e \rightleftharpoons Os + 4 H_2O$	0.838
$ClO^- + H_2O + 2 e \rightleftharpoons Cl^- + 2 OH^-$	0.841
$Hg^{2+} + 2 e \rightleftharpoons Hg$	0.851
$AuBr_4^- + 3 e \rightleftharpoons Au + 4 Br^-$	0.854
SiO_2(quartz) $+ 4 H^+ + 4 e \rightleftharpoons Si + 2 H_2O$	0.857
$2 HNO_2 + 4 H^+ + 4 e \rightleftharpoons H_2N_2O_2 + H_2O$	0.86
$[Ru(CN)_6]^{3-} + e^- \rightleftharpoons [Ru(CN)_6]^{4-}$	0.86
$[IrCl_6]^{2-} + e \rightleftharpoons [IrCl_6]^{3-}$	0.8665
$N_2O_4 + 2 e \rightleftharpoons 2 NO_2^-$	0.867
$HO_2^- + H_2O + 2 e \rightleftharpoons 3 OH^-$	0.878
$Po^{4+} + 2 e \rightleftharpoons Po^{2+}$	0.9
$2 Hg^+ + 2 e \rightleftharpoons Hg_2^{2+}$	0.920

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TABLE 2
Reduction Reactions Having *E*° Values More Positive than that of the Standard Hydrogen Electrode (continued)

Reaction	*E*°/V
$NO_3^- + 3 H^+ + 2 e \rightleftharpoons HNO_2 + H_2O$	0.934
$Pd^{2+} + 2 e \rightleftharpoons Pd$	0.951
$ClO_2(aq) + e \rightleftharpoons ClO_2^-$	0.954
$NO_3^- + 4 H^+ + 3 e \rightleftharpoons NO + 2 H_2O$	0.957
$V_2O_5 + 6 H^+ + 2 e \rightleftharpoons 2 VO^{2+} + 3 H_2O$	0.957
$AuBr_2^- + e \rightleftharpoons Au + 2 Br^-$	0.959
$HNO_2 + H^+ + e \rightleftharpoons NO + H_2O$	0.983
$HIO + H^+ + 2 e \rightleftharpoons I^- + H_2O$	0.987
$VO_2^+ + 2 H^+ + e \rightleftharpoons VO^{2+} + H_2O$	0.991
$PtO_2 + 4 H^+ + 4 e \rightleftharpoons Pt + 2 H_2O$	1.00
$RuO_4 + e \rightleftharpoons RuO_4^-$	1.00
$V(OH)_4^+ + 2 H^+ + e \rightleftharpoons VO^{2+} + 3 H_2O$	1.00
$AuCl_4^- + 3 e \rightleftharpoons Au + 4 Cl^-$	1.002
$Pu^{4+} + e \rightleftharpoons Pu^{3+}$	1.006
$PtO_2 + 2 H^+ + 2 e \rightleftharpoons PtO + H_2O$	1.01
$OsO_4 + 4 H + 4 e \rightleftharpoons OsO_2 + 2 H_2O$	1.02
$H_6TeO_6 + 2 H^+ + 2 e \rightleftharpoons TeO_2 + 4 H_2O$	1.02
$[Fe(bipy)_3]^{3+} + e \rightleftharpoons [Fe(bipy)_3]^{2+}$	1.03
$Hg(OH)_2 + 2 H^+ + 2 e \rightleftharpoons Hg + 2 H_2O$	1.034
$N_2O_4 + 4 H^+ + 4 e \rightleftharpoons 2 NO + 2 H_2O$	1.035
$RuO_4 + 8 H^+ + 8 e \rightleftharpoons Ru + 4H_2O$	1.038
$[Fe(phen)_3]^{3+} + e \rightleftharpoons [Fe(phen)_3]^{2+}$ (1 molar H_2SO_4)	1.06
$PuO_2(OH)_2 + H^+ + e \rightleftharpoons PuO_2OH + H_2O$	1.062
$N_2O_4 + 2 H^+ + 2 e \rightleftharpoons 2 HNO_2$	1.065
$Br_2(l) + 2 e \rightleftharpoons 2Br^-$	1.066
$IO_3^- + 6 H^+ + 6 e \rightleftharpoons I^- + 3 H_2O$	1.085
$Br_2(aq) + 2 e \rightleftharpoons 2Br^-$	1.0873
$Pu^{5+} + e \rightleftharpoons Pu^{4+}$	1.099
$Cu^{2+} + 2 CN^- + e \rightleftharpoons [Cu(CN)_2]^-$	1.103
$RuO_2 + 4 H^+ + 2 e \rightleftharpoons Ru^{2+} + 2 H_2O$	1.120
$[Fe(phen)_3]^{3+} + e \rightleftharpoons [Fe(phen)_3]^{2+}$	1.147
$SeO_4^{2-} + 4 H^+ + 2 e \rightleftharpoons H_2SeO_3 + H_2O$	1.151
$ClO_3^- + 2 H^+ + e \rightleftharpoons ClO_2 + H_2O$	1.152
$Ir^{3+} + 3 e \rightleftharpoons Ir$	1.156
$Pt^{2+} + 2 e \rightleftharpoons Pt$	1.18
$ClO_4^- + 2 H^+ + 2 e \rightleftharpoons ClO_3^- + H_2O$	1.189
$2 IO_3^- + 12 H^+ + 10 e \rightleftharpoons I_2 + 6 H_2O$	1.195
$PtOH^+ + H^+ + 2 e \rightleftharpoons Pt + H_2O$	1.2
$ClO_3^- + 3 H^+ + 2 e \rightleftharpoons HClO_2 + H_2O$	1.214
$MnO_2 + 4 H^+ + 2 e \rightleftharpoons Mn^{2+} + 2 H_2O$	1.224
$O_2 + 4 H^+ + 4 e \rightleftharpoons 2 H_2O$	1.229
$Cr_2O_7^{2-} + 14 H^+ + 6 e \rightleftharpoons 2 Cr^{3+} + 7 H_2O$	1.232
$O_3 + H_2O + 2 e \rightleftharpoons O_2 + 2 OH^-$	1.24
$[Ru(bipy)_3]^{3+} + e \rightleftharpoons [Ru(bipy)_3]^{2+}$	1.24
$Tl^{3+} + 2 e \rightleftharpoons Tl^+$	1.252
$N_2H_5^+ + 3 H^+ + 2 e \rightleftharpoons 2 NH_4^+$	1.275
$ClO_2 + H^+ + e \rightleftharpoons HClO_2$	1.277
$[PdCl_6]^{2-} + 2 e \rightleftharpoons [PdCl_4]^{2-} + 2 Cl^-$	1.288
$2 HNO_2 + 4 H^+ + 4 e \rightleftharpoons N_2O + 3 H_2O$	1.297
$AuOH^{2+} + H^+ + 2 e \rightleftharpoons Au^+ + H_2O$	1.32
$PuO_2(OH)_2 + 2 H^- + 2 e \rightleftharpoons Pu(OH)_4$	1.325
$HBrO + H^+ + 2 e \rightleftharpoons Br^- + H_2O$	1.331
$Cr(V) + e \rightleftharpoons Cr(IV)$	1.34
$HCrO_4^- + 7 H^+ + 3 e \rightleftharpoons Cr^{3+} + 4 H_2O$	1.350
$Cl_2(g) + 2 e \rightleftharpoons 2Cl^-$	1.35827
$ClO_4^- + 8 H^+ + 8 e \rightleftharpoons Cl^- + 4 H_2O$	1.389
$ClO_4^- + 8 H^+ + 7 e \rightleftharpoons 1/2 Cl_2 + 4 H_2O$	1.39
$No^{3+} + e \rightleftharpoons No^{2+}$	1.4
$RuO_4 + 6 H^+ + 4 e \rightleftharpoons Ru(OH)_2^{2+} + 2 H_2O$	1.40
$Au^{3+} + 2 e \rightleftharpoons Au^+$	1.401
$2 NH_3OH^+ + H^+ + 2 e \rightleftharpoons N_2H_5^+ + 2 H_2O$	1.42
$BrO_3^- + 6 H^+ + 6 e \rightleftharpoons Br^- + 3 H_2O$	1.423
$2 HIO + 2 H^+ + 2 e \rightleftharpoons I_2 + 2 H_2O$	1.439
$Au(OH)_3 + 3 H^+ + 3 e \rightleftharpoons Au^- + 3 H_2O$	1.45
$3IO_3^- + 6 H^+ + 6 e \rightleftharpoons Cl^- + 3 H_2O$	1.451
$PbO_2 + 4 H^+ + 2 e \rightleftharpoons Pb^{2+} + 2 H_2O$	1.455
$ClO_3^- + 6 H^+ + 5 e \rightleftharpoons 1/2 Cl_2 + 3 H_2O$	1.47
$CrO_2 + 4 H^+ + e \rightleftharpoons Cr^{3+} + 2 H_2O$	1.48
$BrO_3^- + 6 H^+ + 5 e \rightleftharpoons 1/2 Br_2 + 3 H_2O$	1.482
$HClO + H^+ + 2 e \rightleftharpoons Cl^- + H_2O$	1.482
$Mn_2O_3 + 6 H^+ + e \rightleftharpoons 2 Mn^{2+} + 3 H_2O$	1.485
$HO_2 + H^+ + e \rightleftharpoons H_2O_2$	1.495
$Au^{3+} + 3 e \rightleftharpoons Au$	1.498
$PtO_3 + 4 H^+ + 2 e \rightleftharpoons Pt(OH)_2^{2+} + H_2O$	1.5
$MnO_4^- + 8 H^+ + 5 e \rightleftharpoons Mn^{2+} + 4 H_2O$	1.507
$Mn^{3+} + e \rightleftharpoons Mn^{2-}$	1.5415
$HClO_2 + 3 H^+ + 4 e \rightleftharpoons Cl^- + 2 H_2O$	1.570
$HBrO + H^+ + e \rightleftharpoons 1/2 Br_2(aq) + H_2O$	1.574
$2 NO + 2 H^+ + 2 e \rightleftharpoons N_2O + H_2O$	1.591
$Bi_2O_4 + 4 H^+ + 2 e \rightleftharpoons 2 BiO^+ + 2 H_2O$	1.593
$HBrO + H^+ + e \rightleftharpoons 1/2 Br_2(l) + H_2O$	1.596
$H_5IO_6 + H^+ + 2 e \rightleftharpoons IO_3^- + 3 H_2O$	1.601
$HClO + H^+ + e \rightleftharpoons 1/2 Cl_2 + H_2O$	1.611
$HClO_2 + 3 H^+ + 3 e \rightleftharpoons 1/2 Cl_2 + 2 H_2O$	1.628
$HClO_2 + 2 H^+ + 2 e \rightleftharpoons HClO + H_2O$	1.645
$Bk^{4+} + e \rightleftharpoons Bk^{3+}$	1.67
$NiO_2 + 4 H^+ + 2 e \rightleftharpoons Ni^{2+} + 2 H_2O$	1.678
$MnO_4^- + 4 H^+ + 3 e \rightleftharpoons MnO_2 + 2 H_2O$	1.679
$PbO_2 + SO_4^{2-} + 4 H^+ + 2 e \rightleftharpoons PbSO_4 + 2 H_2O$	1.6913
$Au^+ + e \rightleftharpoons Au$	1.692
$PtO_3 + 2 H^+ + 2 e \rightleftharpoons PtO_2 + H_2O$	1.7
$CeOH^{3+} + H^+ + e \rightleftharpoons Ce^{3+} + H_2O$	1.715
$Ce^{4+} + e \rightleftharpoons Ce^{3+}$	1.72
$N_2O + 2 H^+ + 2 e \rightleftharpoons N_2 + H_2O$	1.766
$H_2O_2 + 2 H^+ + 2 e \rightleftharpoons 2 H_2O$	1.776
$Ag^{3+} + e \rightleftharpoons Ag^{2+}$	1.8
$Au^{2+} + e^- \rightleftharpoons Au^+$	1.8
$Ag_2O_2 + 4 H^+ + e \rightleftharpoons 2 Ag + 2 H_2O$	1.802
$Co^{3+} + e \rightleftharpoons Co^{2-}$(2 molar H_2SO_4)	1.83
$Ag^{3+} + 2 e \rightleftharpoons Ag^+$	1.9
$Co^{3+} + e \rightleftharpoons Co^{2+}$	1.92
$Ag^{2+} + e \rightleftharpoons Ag^+$	1.980
$Cu_2O_3 + 6 H^+ + 2 e \rightleftharpoons 2 Cu^{2+} + 3 H_2O$	2.0
$S_2O_8^{2-} + 2 e \rightleftharpoons 2 SO_4^{2-}$	2.010
$OH + e \rightleftharpoons OH^-$	2.02
$HFeO_4^- + 7 H^+ + 3 e \rightleftharpoons Fe^{3+} + 4 H_2O$	2.07
$O_3 + 2 H^+ + 2 e \rightleftharpoons O_2 + H_2O$	2.076
$HFeO_4^- + 4 H^+ + 3 e \rightleftharpoons FeOOH + 2 H_2O$	2.08

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TABLE 2
Reduction Reactions Having $E°$ Values More Positive than that of the Standard Hydrogen Electrode (continued)

Reaction	$E°$/V	Reaction	$E°$/V
$2\ HFeO_4^- + 8\ H^+ + 6\ e \rightleftharpoons Fe_2O_3 + 5\ H_2O$	2.09	$H_2N_2O_2 + 2\ H^+ + 2\ e \rightleftharpoons N_2 + 2\ H_2O$	2.65
$XeO_3 + 6\ H^+ + 6\ e \rightleftharpoons Xe + 3\ H_2O$	2.10	$F_2 + 2\ e \rightleftharpoons 2\ F^-$	2.866
$S_2O_8^{2-} + 2\ H^+ + 2\ e \rightleftharpoons 2\ HSO_4^-$	2.123	$Cm^{4+} + e \rightleftharpoons Cm^{3+}$	3.0
$F_2O + 2\ H^+ + 4\ e \rightleftharpoons H_2O + 2\ F^-$	2.153	$F_2 + 2\ H^+ + 2\ e \rightleftharpoons 2\ HF$	3.053
$FeO_4^{2-} + 8\ H^+ + 3\ e \rightleftharpoons Fe^{3+} + 4\ H_2O$	2.20	$Tb^{4+} + e \rightleftharpoons Tb^{3+}$	3.1
$Cu^{3+} + e \rightleftharpoons Cu^{2+}$	2.4	$Pr^{4+} + e \rightleftharpoons Pr^{3+}$	3.2
$H_4XeO_6 + 2\ H^+ + 2\ e \rightleftharpoons XeO_3 + 3\ H_2O$	2.42	$Cf^{4+} + e \rightleftharpoons Cf^{3+}$	3.3
$O(g) + 2\ H^+ + 2\ e \rightleftharpoons H_2O$	2.421	$XeF + e \rightleftharpoons Xe + F^-$	3.4
$Am^{4+} + e \rightleftharpoons Am^{3+}$	2.60		

TABLE 3
Reduction Reactions Having $E°$ Values More Negative than that of the Standard Hydrogen Electrode

Reaction	$E°$/V	Reaction	$E°$/V
$2\ H^+ + 2\ e \rightleftharpoons H_2$	0.00000	$Cu(OH)_2 + 2\ e \rightleftharpoons Cu + 2\ OH^-$	–0.222
$2\ D^+ + 2\ e \rightleftharpoons D_2$	–0.013	$V_2O_5 + 10\ H^+ + 10\ e \rightleftharpoons 2\ V + 5\ H_2O$	–0.242
$AgCN + e \rightleftharpoons Ag + CN^-$	–0.017	$CdSO_4 + 2\ e \rightleftharpoons Cd + SO_4^{2-}$	–0.246
$2\ WO_3 + 2\ H^+ + 2\ e \rightleftharpoons W_2O_5 + H_2O$	–0.029	$V(OH)_4^+ + 4\ H^+ + 5\ e \rightleftharpoons V + 4\ H_2O$	–0.254
$W_2O_5 + 2\ H^+ + 2\ e \rightleftharpoons 2\ WO_2 + H_2O$	–0.031	$V^{3+} + e \rightleftharpoons V^{2+}$	–0.255
$Ag_2S + 2\ H^+ + 2\ e \rightleftharpoons 2\ Ag + H_2S$	–0.0366	$Ni^{2+} + 2\ e \rightleftharpoons Ni$	–0.257
$Fe^{3+} + 3\ e \rightleftharpoons Fe$	–0.037	$PbCl_2 + 2\ e \rightleftharpoons Pb + 2\ Cl^-$	–0.2675
$Hg_2I_2 + 2\ e \rightleftharpoons 2\ Hg + 2\ I^-$	–0.0405	$H_3PO_4 + 2\ H^+ + 2\ e \rightleftharpoons H_3PO_3 + H_2O$	–0.276
$Tl(OH)_3 + 2\ e \rightleftharpoons TlOH + 2\ OH^-$	–0.05	$Co^{2+} + 2\ e \rightleftharpoons Co$	–0.28
$TiOH^{3+} + H^+ + e \rightleftharpoons Ti^{3+} + H_2O$	–0.055	$PbBr_2 + 2\ e \rightleftharpoons Pb + 2\ Br^-$	–0.284
$2\ H_2SO_3 + H^+ + 2\ e \rightleftharpoons HS_2O_4^- + 2\ H_2O$	–0.056	$Tl^+ + e \rightleftharpoons Tl(Hg)$	–0.3338
$P(white) + 3\ H^+ + 3\ e \rightleftharpoons PH_3(g)$	–0.063	$Tl^+ + e \rightleftharpoons Tl$	–0.336
$O_2 + H_2O + 2\ e \rightleftharpoons HO_2^- + OH^-$	–0.076	$In^{3+} + 3\ e \rightleftharpoons In$	–0.3382
$2\ Cu(OH)_2 + 2\ e \rightleftharpoons Cu_2O + 2\ OH^- + H_2O$	–0.080	$TlOH + e \rightleftharpoons Tl + OH^-$	–0.34
$Se + 2\ H^+ + 2\ e \rightleftharpoons H_2Se$	–0.082	$PbF_2 + 2\ e \rightleftharpoons Pb + 2\ F^-$	–0.3444
$WO_3 + 6\ H^+ + 6\ e \rightleftharpoons W + 3\ H_2O$	–0.090	$PbSO_4 + 2\ e \rightleftharpoons Pb(Hg) + SO_4^{2-}$	–0.3505
$SnO_2 + 4\ H^+ + 2\ e \rightleftharpoons Sn^{2+} + 2\ H_2O$	–0.094	$Cd^{2+} + 2\ e \rightleftharpoons Cd(Hg)$	–0.3521
$Md^{3+} + e \rightleftharpoons Md^{2+}$	–0.1	$PbSO_4 + 2\ e \rightleftharpoons Pb + SO_4^{2-}$	–0.3588
$P(red) + 3\ H^+ + 3\ e \rightleftharpoons PH_3(g)$	–0.111	$Cu_2O + H_2O + 2\ e \rightleftharpoons 2\ Cu + 2\ OH^-$	–0.360
$SnO_2 + 4\ H^+ + 4\ e \rightleftharpoons Sn + 2\ H_2O$	–0.117	$Eu^{3+} + e \rightleftharpoons Eu^{2+}$	–0.36
$GeO_2 + 2\ H^+ + 2\ e \rightleftharpoons GeO + H_2O$	–0.118	$PbI_2 + 2\ e \rightleftharpoons Pb + 2\ I^-$	–0.365
$WO_2 + 4\ H^+ + 4\ e \rightleftharpoons W + 2\ H_2O$	–0.119	$SeO_3^{2-} + 3\ H_2O + 4\ e \rightleftharpoons Se + 6\ OH^-$	–0.366
$Pb^{2+} + 2\ e \rightleftharpoons Pb(Hg)$	–0.1205	$Se + 2\ H^+ + 2\ e \rightleftharpoons H_2Se(aq)$	–0.399
$Pb^{2+} + 2\ e \rightleftharpoons Pb$	–0.1262	$In^{2+} + e \rightleftharpoons In^+$	–0.40
$CrO_4^{2-} + 4\ H_2O + 3\ e \rightleftharpoons Cr(OH)_3 + 5\ OH^-$	–0.13	$Cd^{2+} + 2\ e \rightleftharpoons Cd$	–0.4030
$Sn^{2-} + 2\ e \rightleftharpoons Sn$	–0.1375	$Cr^{3+} + e \rightleftharpoons Cr^{2+}$	–0.407
$In^+ + e \rightleftharpoons In$	–0.14	$2\ S + 2\ e \rightleftharpoons S_2^{2-}$	–0.42836
$O_2 + 2\ H_2O + 2\ e \rightleftharpoons H_2O_2 + 2\ OH^-$	–0.146	$Tl_2SO_4 + 2\ e \rightleftharpoons Tl + SO_4^{2-}$	–0.4360
$MoO_2 + 4\ H^+ + 4\ e \rightleftharpoons Mo + 4\ H_2O$	–0.152	$In^{3+} + 2\ e \rightleftharpoons In^+$	–0.443
$AgI + e \rightleftharpoons Ag + I^-$	–0.15224	$Fe^{2+} + 2\ e \rightleftharpoons Fe$	–0.447
$2\ NO_2^- + 2\ H_2O + 4\ e \rightleftharpoons N_2O_2^{2-} + 4\ OH^-$	–0.18	$H_3PO_3 + 3\ H^+ + 3\ e \rightleftharpoons P + 3\ H_2O$	–0.454
$H_2GeO_3 + 4\ H^+ + 4\ e \rightleftharpoons Ge + 3\ H_2O$	–0.182	$Bi_2O_3 + 3\ H_2O + 6\ e \rightleftharpoons 2\ Bi + 6\ OH^-$	–0.46
$SnO_2 + 3\ H^+ + 2\ e \rightleftharpoons SnOH^+ + H_2O$	–0.194	$NO_2^- + H_2O + e \rightleftharpoons NO + 2\ OH$	–0.46
$CO_2 + 2\ H^+ + 2\ e \rightleftharpoons HCOOH$	–0.199	$PbHPO_4 + 2\ e \rightleftharpoons Pb + HPO_4^{2-}$	–0.465
$Mo^{3+} + 3\ e \rightleftharpoons Mo$	–0.200	$S + 2\ e \rightleftharpoons S^{2-}$	–0.47627
$Ga^+ + e \rightleftharpoons Ga$	–0.2	$S + H_2O + 2\ e \rightleftharpoons HS^- + OH^-$	–0.478
$2\ SO_2^{2-} + 4\ H^+ + 2\ e \rightleftharpoons S_2O_6^{2-} + H_2O$	–0.22	$B(OH)_3 + 7\ H^+ + 8\ e \rightleftharpoons BH_4^- + 3\ H_2O$	–0.481

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TABLE 3
Reduction Reactions Having *E*° Values More Negative than that of the Standard Hydrogen Electrode (continued)

Reaction	*E*°/V
$In^{3+} + e \rightleftharpoons In^{2+}$	–0.49
$ZnOH^{+} + H^{+} + 2 e \rightleftharpoons Zn + H_2O$	–0.497
$GaOH^{2+} + H^{+} + 3 e \rightleftharpoons Ga + H_2O$	–0.498
$H_3PO_3 + 2 H^{+} + 2 e \rightleftharpoons H_3PO_2 + H_2O$	–0.499
$TiO_2 + 4 H^{+} + 2 e \rightleftharpoons Ti^{2+} + 2 H_2O$	–0.502
$H_3PO_2 + H^{+} + e \rightleftharpoons P + 2 H_2O$	–0.508
$Sb + 3 H^{+} + 3 e \rightleftharpoons SbH_3$	–0.510
$HPbO_2^{-} + H_2O + 2 e \rightleftharpoons Pb + 3 OH^{-}$	–0.537
$Ga^{3+} + 3 e \rightleftharpoons Ga$	–0.549
$TlCl + e \rightleftharpoons Tl + Cl^{-}$	–0.5568
$Fe(OH)_3 + e \rightleftharpoons Fe(OH)_2 + OH^{-}$	–0.56
$TeO_3^{2-} + 3 H_2O + 4 e \rightleftharpoons Te + 6 OH^{-}$	–0.57
$2 SO_3^{2-} + 3 H_2O + 4 e \rightleftharpoons S_2O_3^{2-} + 6 OH^{-}$	–0.571
$PbO + H_2O + 2 e \rightleftharpoons Pb + 2 OH^{-}$	–0.580
$ReO_2^{-} + 4 H_2O + 7 e \rightleftharpoons Re + 8 OH^{-}$	–0.584
$SbO_3^{-} + H_2O + 2 e \rightleftharpoons SbO_2^{-} + 2 OH^{-}$	–0.59
$Ta^{3+} + 3 e \rightleftharpoons Ta$	–0.6
$U^{4+} + e \rightleftharpoons U^{3+}$	–0.607
$As + 3 H^{+} + 3 e \rightleftharpoons AsH_3$	–0.608
$Nb_2O_5 + 10 H^{+} + 10 e \rightleftharpoons 2 Nb + 5 H_2O$	–0.644
$NbO_2 + 2 H^{+} + 2 e \rightleftharpoons NbO + H_2O$	–0.646
$Cd(OH)_4^{2-} + 2 e \rightleftharpoons Cd + 4 OH^{-}$	–0.658
$TlBr + e \rightleftharpoons Tl + Br^{-}$	–0.658
$SbO_2^{-} + 2 H_2O + 3 e \rightleftharpoons Sb + 4 OH^{-}$	–0.66
$AsO_2^{-} + 2 H_2O + 3 e \rightleftharpoons As + 4 OH^{-}$	–0.68
$NbO_2 + 4 H^{+} + 4 e \rightleftharpoons Nb + 2 H_2O$	–0.690
$Ag_2S + 2 e \rightleftharpoons 2 Ag + S^{2-}$	–0.691
$AsO_4^{3-} + 2 H_2O + 2 e \rightleftharpoons AsO_2^{-} + 4 OH^{-}$	–0.71
$Ni(OH)_2 + 2 e \rightleftharpoons Ni + 2 OH^{-}$	–0.72
$Co(OH)_2 + 2 e \rightleftharpoons Co + 2 OH^{-}$	–0.73
$NbO + 2 H^{+} + 2 e \rightleftharpoons Nb + H_2O$	–0.733
$H_2SeO_3 + 4 H^{+} + 4 e \rightleftharpoons Se + 3 H_2O$	–0.74
$Cr^{3+} + 3 e \rightleftharpoons Cr$	–0.744
$Ta_2O_5 + 10 H^{+} + 10 e \rightleftharpoons 2 Ta + 5 H_2O$	–0.750
$TlI + e \rightleftharpoons Tl + I^{-}$	–0.752
$Zn^{2+} + 2 e \rightleftharpoons Zn$	–0.7618
$Zn^{2+} + 2 e \rightleftharpoons Zn(Hg)$	–0.7628
$CdO + H_2O + 2 e \rightleftharpoons Cd + 2 OH^{-}$	–0.783
$Te + 2 H^{+} + 2 e \rightleftharpoons H_2Te$	–0.793
$ZnSO_4 \cdot 7H_2O + 2 e \rightleftharpoons Zn(Hg) + SO_4^{2-} + 7 H_2O$ (Saturated $ZnSO_4$)	–0.7993
$Bi + 3 H^{+} + 3 e \rightleftharpoons BiH_3$	–0.8
$SiO + 2 H^{+} + 2 e \rightleftharpoons Si + H_2O$	–0.8
$Cd(OH)_2 + 2 e \rightleftharpoons Cd(Hg) + 2 OH^{-}$	–0.809
$2 H_2O + 2 e \rightleftharpoons H_2 + 2 OH^{-}$	–0.8277
$2 NO^{-}_3 + 2 H_2O + 2 e \rightleftharpoons N_2O_4 + 4 OH^{-}$	–0.85
$H_3BO_3 + 3 H^{+} + 3 e \rightleftharpoons B + 3 H_2O$	–0.8698
$P + 3 H_2O + 3 e \rightleftharpoons PH_3(g) + 3 OH^{-}$	–0.87
$Ti^{3+} + e \rightleftharpoons Ti^{2+}$	–0.9
$HSnO_2^{-} + H_2O + 2 e \rightleftharpoons Sn + 3 OH^{-}$	–0.909
$Cr^{2+} + 2 e \rightleftharpoons Cr$	–0.913
$Se + 2 e \rightleftharpoons Se^{2-}$	–0.924
$SO_4^{2-} + H_2O + 2 e \rightleftharpoons SO_3^{2-} + 2 OH^{-}$	–0.93
$Sn(OH)_6^{2-} + 2 e \rightleftharpoons HSnO_2^{-} + 3 OH^{-} + H_2O$	–0.93
$SnO_2 + 2 H_2O + 4 e \rightleftharpoons Sn + 4 OH^{-}$	–0.945
$In(OH)_3 + 3 e \rightleftharpoons In + 3 OH^{-}$	–0.99
$NpO_2 + H_2O + H^{+} + e \rightleftharpoons Np(OH)_3$	–0.962
$In(OH)_4^{-} + 3 e \rightleftharpoons In + 4 OH^{-}$	–1.007
$In_2O_3 + 3 H_2O + 6 e \rightleftharpoons 2 In + 6 OH^{-}$	–1.034
$PO_4^{3-} + 2 H_2O + 2 e \rightleftharpoons HPO_3^{2-} + 3 OH^{-}$	–1.05
$Yb^{3+} + e \rightleftharpoons Yb^{2+}$	–1.05
$Nb^{3+} + 3 e \rightleftharpoons Nb$	–1.099
$Fm^{3+} + e \rightleftharpoons Fm^{2+}$	–1.1
$2 SO_3^{2-} + 2 H_2O + 2 e \rightleftharpoons S_2O_4^{2-} + 4 OH^{-}$	–1.12
$Te + 2 e \rightleftharpoons Te^{2-}$	–1.143
$V^{2+} + 2 e \rightleftharpoons V$	–1.175
$Mn^{2+} + 2 e \rightleftharpoons Mn$	–1.185
$Zn(OH)_4^{2-} + 2 e \rightleftharpoons Zn + 4 OH^{-}$	–1.199
$CrO_2 + 2 H_2O + 3 e \rightleftharpoons Cr + 4 OH^{-}$	–1.2
$No^{3+} + 3 e \rightleftharpoons No$	–1.20
$ZnO_2^{-} + 2 H_2O + 2 e \rightleftharpoons Zn + 4 OH^{-}$	–1.215
$H_2GaO_3^{-} + H_2O + 3 e \rightleftharpoons Ga + 4 OH^{-}$	–1.219
$H_2BO_3^{-} + 5 H_2O + 8 e \rightleftharpoons BH_4^{-} + 8 OH^{-}$	–1.24
$SiF_6^{2-} + 4 e \rightleftharpoons Si + 6 F^{-}$	–1.24
$Zn(OH)_2 + 2 e \rightleftharpoons Zn + 2 OH^{-}$	–1.249
$ZnO + H_2O + 2 e \rightleftharpoons Zn + 2 OH^{-}$	–1.260
$Es^{3+} + e \rightleftharpoons Es^{2+}$	–1.3
$Pa^{3+} + 3 e \rightleftharpoons Pa$	–1.34
$Ti^{3+} + 3 e \rightleftharpoons Ti$	–1.37
$Ce^{3+} + 3 e \rightleftharpoons Ce(Hg)$	–1.4373
$UO_2^{2+} + 4 H^{+} + 6 e \rightleftharpoons U + 2 H_2O$	–1.444
$Zr^{4+} + 4 e \rightleftharpoons Zr$	–1.45
$Cr(OH)_3 + 3 e \rightleftharpoons Cr + 3 OH^{-}$	–1.48
$Pa^{4+} + 4 e \rightleftharpoons Pa$	–1.49
$HfO_2 + 4 H^{+} + 4 e \rightleftharpoons Hf + 2 H_2O$	–1.505
$Hf^{4+} + 4 e \rightleftharpoons Hf$	–1.55
$Sm^{3+} + e \rightleftharpoons Sm^{2+}$	–1.55
$ZrO_2 + 4 H^{+} + 4 e \rightleftharpoons Zr + 2 H_2O$	–1.553
$Mn(OH)_2 + 2 e \rightleftharpoons Mn + 2 OH^{-}$	–1.56
$Ba^{2+} + 2 e \rightleftharpoons Ba(Hg)$	–1.570
$Bk^{2+} + 2 e \rightleftharpoons Bk$	–1.6
$Cf^{3+} + e \rightleftharpoons Cf^{2+}$	–1.6
$Ti^{2+} + 2 e \rightleftharpoons Ti$	–1.630
$Md^{3+} + 3 e \rightleftharpoons Md$	–1.65
$HPO_3^{2-} + 2 H_2O + 2 e \rightleftharpoons H_2PO_2^{-} + 3 OH^{-}$	–1.65
$Al^{3+} + 3 e \rightleftharpoons Al$	–1.662
$SiO_3^{2-} + H_2O + 4 e \rightleftharpoons Si + 6 OH^{-}$	–1.697
$HPO_3^{2-} + 2 H_2O + 3 e \rightleftharpoons P + 5 OH^{-}$	–1.71
$HfO^{2+} + 2 H^{+} + 4 e \rightleftharpoons Hf + H_2O$	–1.724
$ThO_2 + 4 H^{+} + 4 e \rightleftharpoons Th + 2 H_2O$	–1.789
$H_2BO_3^{-} + H_2O + 3 e \rightleftharpoons B + 4 OH^{-}$	–1.79
$Sr^{2+} + 2 e \rightleftharpoons Sr(Hg)$	–1.793
$U^{3+} + 3 e \rightleftharpoons U$	–1.798
$H_2PO^{-}_2 + e \rightleftharpoons P + 2 OH^{-}$	–1.82
$Be^{2+} + 2 e \rightleftharpoons Be$	–1.847
$Np^{3+} + 3 e \rightleftharpoons Np$	–1.856
$Fm^{3+} + 3 e \rightleftharpoons Fm$	–1.89
$Th^{4+} + 4 e \rightleftharpoons Th$	–1.899

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TABLE 3
Reduction Reactions Having *E*° Values More Negative than that of the Standard Hydrogen Electrode (continued)

Reaction	*E*°/V
$Am^{2+} + 2 e \rightleftharpoons Am$	–1.9
$Pa^{4+} + e \rightleftharpoons Pa^{3+}$	–1.9
$Es^{3+} + 3 e \rightleftharpoons Es$	–1.91
$Cf^{3+} + 3 e \rightleftharpoons Cf$	–1.94
$Lr^{3+} + 3 e \rightleftharpoons Lr$	–1.96
$Eu^{3+} + 3 e \rightleftharpoons Eu$	–1.991
$Er^{2+} + 2 e \rightleftharpoons Er$	–2.0
$Pr^{2+} + 2 e \rightleftharpoons Pr$	–2.0
$Pu^{3+} + 3 e \rightleftharpoons Pu$	–2.031
$Cm^{3+} + 3 e \rightleftharpoons Cm$	–2.04
$Am^{3+} + 3 e \rightleftharpoons Am$	–2.048
$AlF_6^{3-} + 3 e \rightleftharpoons Al + 6 F^-$	–2.069
$Sc^{3+} + 3 e \rightleftharpoons Sc$	–2.077
$Ho^{2+} + 2 e \rightleftharpoons Ho$	–2.1
$Nd^{2+} + 2 e \rightleftharpoons Nd$	–2.1
$Cf^{2+} + 2 e \rightleftharpoons Cf$	–2.12
$Yb^{3+} + 3 e \rightleftharpoons Yb$	–2.19
$Ac^{3+} + 3 e \rightleftharpoons Ac$	–2.20
$Dy^{2+} + 2 e \rightleftharpoons Dy$	–2.2
$Tm^{3+} + e \rightleftharpoons Tm^{2+}$	–2.2
$Pm^{2+} + 2 e \rightleftharpoons Pm$	–2.2
$Es^{2+} + 2 e \rightleftharpoons Es$	–2.23
$H_2 + 2 e \rightleftharpoons 2 H^-$	–2.23
$Gd^{3+} + 3 e \rightleftharpoons Gd$	–2.279
$Tb^{3+} + 3 e \rightleftharpoons Tb$	–2.28
$Lu^{3+} + 3 e \rightleftharpoons Lu$	–2.28
$Dy^{3+} + 3 e \rightleftharpoons Dy$	–2.295
$Am^{3+} + e \rightleftharpoons Am^{2+}$	–2.3
$Fm^{2+} + 2 e \rightleftharpoons Fm$	–2.30
$Pm^{3+} + 3 e \rightleftharpoons Pm$	–2.30
$Sm^{3+} + 3 e \rightleftharpoons Sm$	–2.304
$Al(OH)_3 + 3 e \rightleftharpoons Al + 3 OH^-$	–2.31
$Tm^{3+} + 3 e \rightleftharpoons Tm$	–2.319
$Nd^{3+} + 3 e \rightleftharpoons Nd$	–2.323
$Al(OH)^- + 3 e \rightleftharpoons Al + 4 OH^-$	–2.328
$H_2AlO_3^- + H_2O + 3 e \rightleftharpoons Al + 4 OH^-$	–2.33
$Ho^{3+} + 3 e \rightleftharpoons Ho$	–2.33
$Er^{3+} + 3 e \rightleftharpoons Er$	–2.331
$Ce^{3+} + 3 e \rightleftharpoons Ce$	–2.336
$Pr^{3+} + 3 e \rightleftharpoons Pr$	–2.353

Reaction	*E*°/V
$ZrO(OH)_2 + H_2O + 4 e \rightleftharpoons Zr + 4 OH^-$	–2.36
$Mg^{2+} + 2 e \rightleftharpoons Mg$	–2.372
$Y^{3+} + 3 e \rightleftharpoons Y$	–2.372
$La^{3+} + 3 e \rightleftharpoons La$	–2.379
$Tm^{2+} + 2 e \rightleftharpoons Tm$	–2.4
$Md^{2+} + 2 e \rightleftharpoons Md$	–2.40
$Th(OH)_4 + 4 e \rightleftharpoons Th + 4 OH^-$	–2.48
$HfO(OH)_2 + H_2O + 4 e \rightleftharpoons Hf + 4 OH^-$	–2.50
$No^{2+} + 2 e \rightleftharpoons No$	–2.50
$Dy^{3+} + e \rightleftharpoons Dy^{2+}$	–2.6
$Pm^{3+} + e \rightleftharpoons Pm^{2+}$	–2.6
$Be_2O_3^{2-} + 3 H_2O + 4 e \rightleftharpoons 2 Be + 6 OH^-$	–2.63
$Sm^{2+} + 2 e \rightleftharpoons Sm$	–2.68
$Mg(OH)_2 + 2 e \rightleftharpoons Mg + 2 OH^-$	–2.690
$Nd^{3+} + e \rightleftharpoons Nd^{2+}$	–2.7
$Mg^+ + e \rightleftharpoons Mg$	–2.70
$Na^+ + e \rightleftharpoons Na$	–2.71
$Yb^{2+} + 2 e \rightleftharpoons Yb$	–2.76
$Bk^{3+} + e \rightleftharpoons Bk^{2+}$	–2.8
$Ho^{3+} + e \rightleftharpoons Ho^{2+}$	–2.8
$Ra^{2+} + 2 e \rightleftharpoons Ra$	–2.8
$Eu^{2+} + 2 e \rightleftharpoons Eu$	–2.812
$Ca^{2+} + 2 e \rightleftharpoons Ca$	–2.868
$Sr(OH)_2 + 2 e \rightleftharpoons Sr + 2 OH^-$	–2.88
$Sr^{2+} + 2 e \rightleftharpoons Sr$	–2.89
$Fr^+ + e \rightleftharpoons Fr$	–2.9
$La(OH)_3 + 3 e \rightleftharpoons La + 3 OH^-$	–2.90
$Ba^{2+} + 2 e \rightleftharpoons Ba$	–2.912
$K^+ + e \rightleftharpoons K$	–2.931
$Rb^+ + e \rightleftharpoons Rb$	–2.98
$Ba(OH)_2 + 2 e \rightleftharpoons Ba + 2 OH^-$	–2.99
$Er^{3+} + e \rightleftharpoons Er^{2+}$	–3.0
$Ca(OH)_2 + 2 e \rightleftharpoons Ca + 2 OH^-$	–3.02
$Cs^+ + e \rightleftharpoons Cs$	–3.026
$Li^+ + e \rightleftharpoons Li$	–3.0401
$3 N_2 + 2 H^+ + 2 e \rightleftharpoons 2 HN_3$	–3.09
$Pr^{3+} + e \rightleftharpoons Pr^{2+}$	–3.1
$Ca^+ + e \rightleftharpoons Ca$	–3.80
$Sr^+ + e \rightleftharpoons Sr$	–4.10

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REDUCTION AND OXIDATION POTENTIALS FOR CERTAIN ION RADICALS

Petr Vanýsek

There are two tables for ion radicals. The first table lists reduction potentials for organic compounds which produce anion radicals during reduction, a process described as $A + e^- \rightleftharpoons A^{-}\cdot$. The second table lists oxidation potentials for organic compounds which produce cation radicals during oxidation, a process described as $A \rightleftharpoons A^{+}\cdot + e^-$. To obtain reduction potential for a reverse reaction, the sign for the potential is changed.

Unlike the table of the Electrochemical Series, which lists *standard* potentials, values for radicals are experimental values with experimental conditions given in the second column. Since the measurements leading to potentials for ion radicals are very dependent on conditions, an attempt to report standard potentials for radicals would serve no useful purpose. For the same reason, the potentials are also reported as experimental values, usually a half-wave potential ($E_{1/2}$ in polarography) or a peak potential (E_p in cyclic voltammetry). Unless otherwise stated, the values are reported vs. SCE (saturated calomel electrode). To obtain a value vs. normal hydrogen electrode, 0.241 V has to be added to the SCE values. All the ion radicals chosen for inclusion in the tables result from electrochemically reversible reactions. More detailed data on ion radicals can be found in the *Encyclopedia of Electrochemistry of Elements,* (A. J. Bard, Ed.), Vol. XI and XII in particular, Marcel Dekker, New York, 1978.

Abbreviations are: CV — cyclic voltammetry; DMF — *N,N*-Dimethylformamide; *E* swp — potential sweep; $E°$ — standard potential; E_p — peak potential; $E_{p/2}$ — half-peak potential; $E_{1/2}$ — half wave potential; *M* — mol/L; MeCN — acetonitrile; pol — polarography; rot Pt dsk — rotated Pt disk; SCE — saturated calomel electrode; $TBABF_4$ — tetrabutylammonium tetrafluoroborate; TBAI — tetrabutylammonium iodide; TBAP — tetrabutylammonium perchlorate; TEABr — tetraethylammonium bromide; TEAP — tetraethylammonium perchlorate; THF — tetrahydrofuran; $TPACF_3SO_3$ — tetrapropylammonium trifluoromethanesulfite; TPAP — tetrapropylammonium perchlorate; and wr — wire.

Reduction Potentials (Products are Anion Radicals)

Substance	Conditions/electrode/technique	Potential V (vs. SCE)
Acetone	DMF, 0.1 *M* TEABr/Hg/pol	$E_{1/2} = -2.84$
1-Naphthyphenylacetylene	DMF, 0.03 *M* TBAI/Hg/pol	$E_{1/2} = -1.91$
1-Naphthalenecarboxyaldehyde	-/Hg/pol	$E_{1/2} = -0.91$
2-Naphthalenecarboxyaldehyde	-/Hg/pol	$E_{1/2} = -0.96$
2-Phenanthrenecarboxaldehyde	-/Hg/pol	$E_{1/2} = -1.00$
3-Phenanthrenecarboxaldehyde	-/Hg/pol	$E_{1/2} = -0.94$
9-Phenanthrenecarboxaldehyde	-/Hg/pol	$E_{1/2} = -0.83$
1-Anthracenecarboxaldehyde	-/Hg/pol	$E_{1/2} = -0.75$
1-Pyrenecarboxaldehyde	-/Hg/pol	$E_{1/2} = -0.76$
2-Pyrenecarboxaldehyde	-/Hg/pol	$E_{1/2} = -1.00$
Anthracene	DMF, 0.1 *M* TBAP/Pt dsk/CV	$E_p = -2.00$
	DMF, 0.5 *M* $TBABF_4$/Hg/CV	$E_{1/2} = -1.93$
	MeCN, 0.1 *M* TEAP/Hg/CV	$E_{1/2} = -2.07$
	DMF, 0.1 *M* TBAI/Hg/pol	$E_{1/2} = -1.92$
9,10-Dimethylanthracene	DMF, 0.1 *M* TBAP/Pt/CV	$E_p = -2.08$
	MeCN, 0.1 *M* TBAP/Pt/CV	$E_p = -2.10$
1-Phenylanthracene	DMF, 0.5 *M* $TBABF_2$/Hg/CV	$E_{1/2} = -1.91$
	DMF, 0.1 *M* TBAI/Hg/pol	$E_{1/2} = -1.878$
2-Phenylanthracene	DMF, 0.1 *M* TBAI/Hg/pol	$E_{1/2} = -1.875$
8-Phenylanthracene	DMF, 0.5 *M* $TBABF_4$/Hg/CV	$E_{1/2} = -1.91$
9-Phenylanthracene	DMF, 0.5 *M* $TBABF_4$/Hg/CV	$E_{1/2} = -1.93$
	DMF, 0.1 *M* TBAI/Hg/pol	$E_{1/2} = -1.863$
1,8-Diphenylanthracene	DMF, 0.5 *M* $TBABF_4$/Hg/CV	$E_{1/2} = -1.88$
1,9-Diphenylanthracene	DMF, 0.1 *M* TBAI/Hg/pol	$E_{1/2} = -1.846$
1,10-Diphenylanthracene	DMF, 0.1 *M* TBAI/Hg/pol	$E_{1/2} = -1.786$
8,9-Diphenylanthracene	DMF, 0.5 *M* $TBABF_4$/Hg/CV	$E_{1/2} = -1.90$
9,10-Diphenylanthracene	MeCN, 0.1 *M* TBAP/rot Pt/E swp	$E_{1/2} = -1.83$
	DMF, 0.1 *M* TBAI/Hg/pol	$E_{1/2} = -1.835$
1,8,9-Triphenylanthracene	DMF, 0.5 *M* $TBABF_4$/Hg/CV	$E_{1/2} = -1.85$
1,8,10-Triphenylanthracene	DMF, 0.5 *M* $TBABF_4$/Hg/CV	$E_{1/2} = -1.81$
9,10-Dibiphenylanthracene	MeCN, 0.1 *M* TBAP/rot Pt/E swp	$E_{1/2} = -1.94$
Benz(a)anthracene	MeCN, 0.1 *M* TEAP/Hg/CV	$E_{1/2} = -2.11$
	MeCN, 0.1 *M* TEAP/Hg/pol	$E_{1/2} = -2.40$[a]
Azulene	DMF, 0.1 *M* TBAI/Hg/pol	$E_{1/2} = -1.10$[c]
Annulene	DMF, 0.5 *M* TBAP 0°C/Hg/pol	$E_{1/2} = -1.23$
Benzaldehyde	DMF, 0.1 *M* TBAP/Hg/pol	$E_{1/2} = -1.67$
Benzil	DMSO, 0.1 *M* TBAP/Hg/pol	$E_{1/2} = -1.04$

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Reduction Potentials (Products are Anion Radicals) (continued)

Substance	Conditions/electrode/technique	Potential V (vs. SCE)
Benzophenone	-/Hg/pol	$E_{1/2}$ = –1.80
	DMF/Pt dsk/CV	$E°$ = –1.72
Chrysene	MeCN, 0.1 *M* TEAP/Hg/pol	$E_{1/2}$ = –2.73[a]
Fluoranthrene	DMF, 0.1 *M* TBAP/Pt dsk/CV	E_p = –1.76
Cyclohexanone	DMF, 0.1 *M* TEABr/Hg/pol	$E_{1/2}$ = –2.79
5,5-Dimethyl-3-phenyl-2-cyclohexen-1-one	DMF, 0.5 *M*/Hg/pol	$E_{1/2}$ = –1.71
1,2,3-Indanetrione hydrate (ninhydrin)	DMF, 0.2 *M* $NaNO_3$/Hg/pol	$E_{1/2}$ = –0.039
Naphthacene	DMF, 0.1 *M* TBAI/Hg/pol	$E_{1/2}$ = –1.53
Naphthalene	DMF, 0.1 *M* TBAP/Pt dsk/CV	E_p = –2.55
	DMF, 0.5 *M* $TBABF_4$/Hg/CV	$E_{1/2}$ = –2.56
	DMF, MeCN, 0.1 *M* TEAP/Hg/CV	$E_{1/2}$ = –2.63
	DMF, 0.1 *M* TBAI/Hg/pol	$E_{1/2}$ = –2.50
1-Phenylnaphthalene	DMF, 0.5 *M* $TBABF_4$/Hg/CV	$E_{1/2}$ = –2.36
1,2-Diphenylnaphthalene	DMF, 0.5 *M* $TBABF_4$/Hg/CV	$E_{1/2}$ = –2.25
Cyclopentanone	DMF, 0.1 *M* TEABr/Hg/pol	$E_{1/2}$ = –2.82
Phenanthrene	MeCN, 0.1 *M* TBAP/Pt wr/CV	$E_{1/2}$ = –2.47
	MeCN, 0.1 *M* TEAP/Hg/pol	$E_{1/2}$ = –2.88[a]
Pentacene	THF, 0.1 *M* TBAP/rot Pt dsk/E swp	$E_{1/2}$ = –1.40
Perylene	MeCN, 0.1 *M* TEAP/Hg/CV	$E_{1/2}$ = –1.73
1,3-Diphenyl-1,3-propanedione	DMSO, 0.2 *M* TBAP/Hg/CV	$E_{1/2}$ = –1.42
2,2-Dimethyl-1,3-diphenyl-1,3 propanedione	DMSO, TBAP/Hg/CV	$E_{1/2}$ = –1.80
Pyrene	DMF, 0.1 *M* TBAP/Pt/CV	E_p = –2.14
	MeCN, 0.1 *M* TEAP/Hg/pol	$E_{1/2}$ = –2.49[a]
Diphenylsulfone	DMF, TEABr	$E_{1/2}$ = –2.16
Triphenylene	MeCN, 0.1 *M* TEAP/Hg/pol	$E_{1/2}$ = –2.87[a]
9,10-Anthraquinone	DMF, 0.5 *M* TBAP, 20°/Pt dsk/CV	$E_{1/2}$ = –1.01
1,4-Benzoquinone	MeCN, 0.1 *M* TEAP/Pt/CV	E_p = –0.54
1,4-Naphthohydroquinone, dipotassium salt	DMF, 0.5 *M* TBAP, 20°/Pt dsk/CV	$E_{1/2}$ = –1.55
Rubrene	DMF, 0.1 *M* TBAP/Pt dsk/CV	E_p = –1.48
	DMF, 0.1 *M* TBAI/Hg/pol	$E_{1/2}$ = –1.410
Benzocyclooctatetraene	THF, 0.1 *M* TBAP/Hg/pol	$E_{1/2}$ = –2.13
sym-Dibenzocyclooctatetraene	THF, 0.1 *M* TBAP/Hg/pol	$E_{1/2}$ = –2.29
Ubiquinone-6	MeCN, 0.1 *M* TEAP/Pt/CV	E_p = –1.05[e]
(9-Phenyl-fluorenyl)$^+$	10.2 *M* H_2SO_4/Hg/CV	E_p = –0.01[b]
(Triphenylcyclopropenyl)$^+$	MeCN, 0.1 *M* TEAP/Hg/CV	E_p = –1.87
(Triphenylmethyl)$^+$	MeCN, 0.1 *M* TBAP/Hg/pol	$E_{1/2}$ = 0.27
	H_2SO_4, 10.2 *M*/Hg/CV	E_p = –0.58[b]
(Tribiphenylmethyl)$^+$	MeCN, 0.1 *M* TBAP/Hg/pol	$E_{1/2}$ = 0.19
(Tri-4-*t*-butyl-5-phenylmethyl)$^+$	MeCN, 0.1 *M* TBAP/Hg/pol	$E_{1/2}$ = 0.13
(Tri-4-isopropylphenylmethyl)$^+$	MeCN, 0.1 *M* TBAP/Hg/pol	$E_{1/2}$ = 0.07
(Tri-4-methylphenylmethyl)$^+$	MeCN, 0.1 *M* TBAP/Hg/pol	$E_{1/2}$ = 0.05
(Tri-4-cyclopropylphenylmethyl)$^+$	MeCN, 0.1 *M* TBAP/Hg/pol	$E_{1/2}$ = 0.01
(Tropylium)$^+$	MeCN, 0.1 *M* TBAP/Hg/pol	$E_{1/2}$ = –0.17
	DMF, 0.15 *M* TBAI/Hg/pol	$E_{1/2}$ = –1.55
	DMF, 0.15 *M* TBAI/Hg/pol	$E_{1/2}$ = –1.55
	DMF, 0.15 *M* TBAI/Hg/pol	$E_{1/2}$ = –1.57
	DMF, 0.15 *M* TBAI/Hg/pol	$E_{1/2}$ = –1.60
	DMF, 0.15 *M* TBAI/Hg/pol	$E_{1/2}$ = –1.87
	DMF, 0.15 *M* TBAI/Hg/pol	$E_{1/2}$ = –1.96
	DMF, 0.15 *M* TBAI/Hg/pol	$E_{1/2}$ = –2.05

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Oxidation Potentials (Products are Cation Radicals)

Substance	Conditions/electrode/technique	Potential V (vs. SCE)
Anthracene	CH_2Cl_2, 0.2 *M* $TBABF_4$, –70°C/Pt dsk/CV	$E_p = +0.73$[d]
9,10-Dimethylanthracene	MeCN, 0.1 *M* $LiClO_4$/Pt wr/CV	$E_p = +1.0$
9,10-Dipropylanthracene	MeCN, 0.1 *M* TEAP/Pt/CV	$E_p = +1.08$
1,8-Diphenylanthracene	CH_2Cl_2, 0.2 *M* $TPrACF_3SO_3$/rot Pt wr/E swp	$E_{1/2} = +1.34$
8,9-Diphenylanthracene	CH_2Cl_2, 0.2 *M* $TPrACF_3SO_3$/rot Pt wr/E swp	$E_{1/2} = +1.30$
9,10-Diphenylanthracene	MeCN/Pt/CV	$E_p = +1.22$
Perylene	MeCN, 0.1 *M* TBAP/Pt/CV	$E_p = +1.34$
Pyrene	DMF, 0.1 *M* TBAP/Pt dsk/CV	$E_p = +1.25$
Rubrene	DMF, 0.1 *M* TBAP/Pt dsk/CV	$E_p = +1.10$
Tetracene	CH_2Cl_2, 0.2 *M* $TBABF_4$, –70°C/Pt wr/CV	$E_p = +0.35$[d]
1,4-Dithiabenzene	MeCN, 0.1 *M* TEAP/Pt dsk/rot	$E_{1/2} = +0.69$
1,4-Dithianaphthalene	MeCN, 0.1 *M* TEAP/Pt dsk/rot	$E_{1/2} = +0.80$
Thianthrene	0.1 *M* TPAP/Pt/CV	$E_{1/2} = +1.28$

[a] vs 0.01 *M* $Ag/AgClO_4$
[b] vs. Hg/Hg_2SO_4, 17 *M* H_2SO_4
[c] vs Hg pool
[d] vs Ag/saturated $AgNO_3$
[e] vs Ag/0.01 *M* Ag^+

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pH SCALE FOR AQUEOUS SOLUTIONS

A. K. Covington

The pH value is the negative decadic logarithm of the (relative) ion activity of the hydrogen ion in the solution.

$$\mathrm{pH} = -\log a_H \tag{1}$$

This is only a notional definition since Equation 1 involves a single ion activity, which is immeasurable, and has to be attained through a nonthermodynamic assumption such as that described in Equation 5 below. In terms of substance concentration, molarity, Equation 1 may be rewritten

$$\mathrm{pH} = -\log (c_H y_H / c^o) \tag{2}$$

where c^o is an arbitrary constant representing the standard state condition and equal to 1 mol dm^{-3}, c_H is the concentration of hydrogen ion and y_H is the single ion activity of the hydrogen ion. In terms of molality, Equation 1 may be rewritten

$$\mathrm{pH} = -\log (m_H \gamma_H / m^o) \tag{3}$$

where m^o is an arbitrary constant representing the standard state condition and equal to 1 mol kg^{-1}, m_H is the concentration of hydrogen ion and γ_H is the single ion activity of the hydrogen ion. For most purposes the difference between these two scales can be ignored for dilute aqueous solutions; the difference is 0.001 at 25° C and 0.02 at 100° C. Arising from the nonexperimental determinability of single ion activities, the definition and determination of pH have an operational basis, and depend on the assignment of pH values to a standard solution (or solutions) together with the determination of pH difference by a cell with liquid junction called the operational cell.

The Operational Definition of pH Difference[1,2]

The electromotive force, EMF, *E*(X) of the cell with liquid junction:

Reference electrode | KCl (aq., concentrated) || Solution X | H_2 | Pt (I)

is measured, and likewise that, *E*(S), of the cell:

Reference electrode | KCl (aq., concentrated) || Solution S | H_2 | Pt (II)

The temperature of both cells (I and II) must be equal and uniform throughout, and the hydrogen gas pressures identical. The two bridge solutions may be any molality of KCl not less than 3.5 mol kg^{-1} provided they are the same.

The pH of the solution X, pH(X), is then related to the assigned pH of the solution S, pH(S) by the definition:

$$\mathrm{pH(X)} = \mathrm{pH(S)} + [E(\mathrm{S}) - E(\mathrm{X})]/[(RT/F) \ln 10] \tag{4}$$

where *R* is the gas constant, *T* the thermodynamic temperature, *F* the Faraday constant. The quantity $k = (RT/F) \ln 10$ is called the slope factor whose values are given as a function of temperature in Table 1. As a consequence of this definition any difference in liquid junction potential between cells I and II is subsumed into the value of pH(X).

The pH Scale

The pH scale at a particular temperature is defined by Equation 4 as a straight line, on the plot of pH against *E*(X), having a slope of *k* drawn through the pH value assigned to the Reference Value Standard (RVS) solution (as given in Table 2) and the value of *E*(S) for cell II when it contains the Reference Value Standard solution. The solution chosen for the RVS is 0.05 mol kg^{-1} aqueous potassium hydrogen phthalate. The procedure by which pH(RVS) values have been assigned to the Reference Value Standard (RVS) is the cell III without transference:[1,3]

Pt(Pd) | H_2 (g, *p*=1 atm = 101 325 Pa) | RVS, Cl^- | AgCl | Ag (III)

The palladised-platinum hydrogen electrode is used to reduce the catalytised chemical reduction of the phthalate by hydrogen gas. The calculation involves a non-thermodynamic assumption, the Bates-Guggenheim Convention, for the single ion activity of the chloride ion[1,2] as

$$\log (\gamma_{Cl})^o = -A(I/m^o)^{1/2}/[1 + 1.5\,(I/m^o)^{1/2}] \tag{5}$$

where I is the ionic strength $= (1/2)\Sigma m_i z_i^2 = 0.0534$ mol kg^{-1} for the RVS solution and *A* is a known function of temperature (Table 1).

To prepare the RVS solution, dry the sample at 110° C for 2 h before use. The water should have a conductivity of less than 0.1 mS m^{-1}. The required solution contains 10.211 g kg^{-1} water. It can be prepared on a volume basis by dissolving 10.138 g potassium hydrogen phthalate in water and making up to 1 L at 20° C. This solution is 0.04964 mol/L with a density of 1.00300 g/L at 20° C.

Primary Standards[2]

pH values may be assigned by the cell without transference method (cell III) to six other buffer solutions which meet certain criteria of reproducibility of preparation and properties. These solutions are called primary pH standards (PS), and details and the pH(PS) values assigned to them are given in Table 3. When these PS solutions are used in the operational cell I, the experimental value of the slope will not be in accord with the slope factor values of Table 1, and, moreover, the experimental value could change if additional primary solutions were to be defined. Hence the pH value determined for an unknown solution can be slightly dependent (±0.02) on the choice of primary standard.[2,4,5] Some useful data for standard buffers are given in Table 5.

Operational Standards[2,6]

Operational standards (OS) are also defined which are traceable to the Reference Value Standard (RVS). Values are assigned by means of the operational cells I and II where the liquid junctions are the free diffusion type reproducibly formed in 1 mm vertical capillary tubes. These operational standards are not restricted in number provided certain preparation criteria are met, and pH(OS) values for 16 solutions are given in Table 4.[2] These OS represent an alternative procedure and are in no way to be regarded as inferior to the primary standards. As a consequence of their definition, all pH(OS) values fall on the line with slope given by the slope factor value for the appropriate temperature in Table 1. Any difference in liquid junction potential between the solutions of cells I and II and KCl is subsumed into the assigned value of pH(OS).

Measurement of pH. Choice of Standard Reference Solution

1a. If pH is not required to better than ±0.05 any standard reference solution may be selected.

1b. If pH is required to ±0.002 and interpretation in terms of hydrogen ion concentration or activity is desired, choose a standard reference solution, pH(PS) or pH(OS), to match X as closely as possible in terms of pH, composition and ionic strength.

2. Alternatively, a bracketting procedure may be adopted whereby two standard reference solutions are chosen whose pH values, pH(S1), pH(S2) are on either side of pH(X). Then if the corresponding potential difference measurements are E(S1), E(S2), E(X), then pH(X) is obtained from

$$\mathrm{pH(X)} = \mathrm{pH(S1)} + [E(\mathrm{X}) - E(\mathrm{S1})]/\ \%k$$

where $\%k = 100[E(\mathrm{S2}) - E(\mathrm{S1})]/[\mathrm{pH(S2)} - \mathrm{pH(S1)}]$ is the apparent percentage slope. This procedure is very easily done on some pH meters simply by adjusting downwards the slope factor control with the electrodes in S2. The purpose of the bracketting procedure is to compensate for deficiencies in the electrodes and measuring system.

Information to be Given about the Measurement of pH(X)

The standard solutions selected for calibration of the pH meter system should be reported with the measurement as follows,

1.System calibrated with pH(RVS) = ... at ...K.
2.System calibrated with two primary standards pH(PS1) = ... and pH(PS2) = ... at ... K.
3.System calibrated with two operational standards pH(OS1) =..... and pH(OS2) = ... at .... K.

Interpretation of pH(X) in Terms of Hydrogen Ion Concentration

The operationally defined pH has no simple interpretation in terms of hydrogen ion concentration but the mean ionic activity coefficient of a typical 1:1 electrolyte can be substituted into equation 2 or 3 to obtain hydrogen ion concentration subject to an uncertainty of 3.9% in concentration corresponding to 0.02 in pH.

REFERENCES

1. R. G. Bates, *Measurement of pH. Theory and Practice*, 2nd ed., John Wiley & Sons,, New York, 1973.
2. A. K. Covington, R. G. Bates, and R. A. Durst, *Pure Appl. Chem.*, 57, 531, 1985.
3. H. P. Butikofer and A. K. Covington, *Anal. Chim. Acta*, 108, 179, 1979.
4. R. G. Bates, *Crit. Rev. Anal. Chem.*, 10, 247, 1981.
5. A. K. Covington, *Anal. Chim. Acta*, 127, 1, 1981.
6. A. K. Covington and M. J. Rebelo, *Anal. Chim. Acta.*, 200, 245, 1987.
7. V. E. Bower and R. G. Bates, *J. Res. Natl. Bur. Stand.*, 39, 263, 1954.

TABLE 1
Standard EMF, Slope Factor and Debye-Huckel Constant *A* (Unit Weight of Solvent) as Functions of Temperature

Temperature/°C	*E*°/mV[7]	Slope Factor *k*/mV	*A*[1]
0	236.55	54.199	0.4918
5	234.13	55.191	0.4952
10	231.42	56.183	0.4988
15	228.57	57.175	0.5026
20	225.57	58.167	0.5066
25	222.34	59.159	0.5108
30	219.04	60.152	0.5150
35	215.65	61.144	0.5196
40	212.08	62.136	0.5242
45	208.35	63.128	0.5291
50	204.49	64.120	0.5341
55	200.56	65.112	0.5393
60	196.49	66.104	0.5448
70	187.82	68.088	0.5562
80	178.73	70.073	0.5685
90	169.52	72.057	0.5817
95	165.11	73.049	0.5886

TABLE 2
Values of pH(RVS) for the Reference Value Standard of 0.05 mol kg^{-1} Potassium Hydrogen Phthalate at Various Temperatures

t/°C	pH(RVS)	*t*/°C	pH(RVS)	*t*/°C	pH(RVS)
0	4.000	35	4.018	65	4.097
5	3.998	37	4.022	70	4.116
10	3.997	40	4.027	75	4.137
15	3.998	45	4.038	80	4.159
20	4.001	50	4.050	85	4.183
25	4.005	55	4.064	90	4.21
30	4.011	60	4.080	95	4.24

TABLE 3
Values of pH(PS) for Primary Standard Reference Solutions

Primary ref. standard	t/°C 0	5	10	15	20	25	30	35	37	40	50	60	70	80	90	95
Saturated (at 25° C) Potassium hydrogen tartrate	—	—	—	—	—	3.557	3.552	3.549	3.548	3.547	3.549	3.560	3.580	3.610	3.650	3.674
0.1 mol/kg Potassium dihydrogen citrate	3.863	3.840	3.820	3.802	3.788	3.776	3.766	3.759	3.756	3.754	3.749	—	—	—	—	—
0.025 mol/kg Disodium hydrogen phosphate +0.025 mol/kg Potassium dihydrogen phosphate	6.984	6.951	6.923	6.900	6.881	6.865	6.853	6.844	6.841	6.838	6.833	6.836	6.845	6.859	6.876	6.886
0.03043 mol/kg Disodium hydrogen phosphate +0.008695 mol/kg Potassium dihydrogen phosphate	7.534	7.500	7.472	7.448	7.429	7.413	7.400	7.389	7.386	7.380	7.367	—	—	—	—	—
0.01 mol/kg Disodium tetraborate	9.464	9.395	9.332	9.276	9.225	9.180	9.139	9.102	9.088	9.068	9.011	8.962	8.921	8.884	8.850	8.833
0.025 mol/kg Sodium hydrogen carbonate +0.025 mol/kg sodium carbonate	10.317	10.245	10.179	10.118	10.062	10.012	9.966	9.926	9.910	9.889	9.828	—	—	—	—	—

Note: Based on an uncertainty of ±0.2 mV in determined (E-E^{θ}), the uncertainty is ±0.003 in pH in the range 0—50° C.

pH SCALE FOR AQUEOUS SOLUTIONS (continued)

TABLE 4
pH (OS) Values for Operational Reference Solutions

Operational standard ref. solution	t/°C 0	5	10	15	20	25	30	37	40	50	60	70	80	90	95
0.1 mol/kg Potassium tetroxalate[a]	—	—	—	—	1.475	1.479	1.483	1.490	1.493	1.503	1.513	1.52	1.53	1.53	1.53
0.05 mol/kg potassium tetroxalate[a]	—	—	1.638	1.642	1.644	1.646	1.648	1.649	1.650	1.653	1.660	1.671	1.689	1.72	1.73
0.05 mol/kg sodium hydrogen diglycolate[b]	—	3.466	3.470	3.476	3.484	3.492	3.502	3.519	3.527	3.558	3.595	—	—	—	—
Saturated (at 25° C) potassium hydrogen tartrate	—	—	—	—	—	3.556	3.549	3.544	3.542	3.544	3.553	3.570	3.596	3.627	3.649
0.05 mol/kg Potassium hydrogen phthalate (RVS)	4.000	3.998	3.997	3.998	4.000	4.005	4.011	4.022	4.027	4.050	4.080	4.115	4.159	4.21	4.24
0.1 mol/dm^3 Acetic acid + 0.1 mol/dm^3 sodium acetate	4.664	4.657	4.652	4.647	4.645	4.644	4.643	4.647	4.650	4.663	4.684	4.713	4.75	4.80	4.83
0.01 mol/dm^3 Acetic acid + 0.1 mol/dm^3 sodium acetate	4.729	4.722	4.717	4.714	4.712	4.713	4.715	4.722	4.726	4.743	4.768	4.800	4.839	4.88	4.91
0.02 mol/kg Piperazine phosphate[c]	—	6.477	6.419	6.364	6.310	6.259	6.209	6.143	6.116	6.030	5.952	—	—	—	—
0.025 mol/kg Disodium hydrogen phosphate + 0.025 mol/kg potassium dihydrogen phosphate	6.961	6.935	6.912	6.891	6.873	6.857	6.843	6.828	6.823	6.814	6.817	6.830	6.85	6.90	6.92
0.03043 mol/kg Disodium hydrogen phosphate + 0.008695 mol/kg potassium disodium phosphate	7.506	7.482	7.460	7.441	7.423	7.406	7.390	7.369	—	—	—	—	—	—	—
0.04 mol/kg Disodium hydrogen phosphate + 0.01 mol/kg potassium dihydrogen phosphate	—	7.512	7.488	7.466	7.445	7.428	7.414	7.404	—	—	—	—	—	—	—
0.05 mol/kg Tris hydrochloride + 0.01667 mol/kg Tris[d]	8.399	8.238	8.083	7.933	7.788	7.648	7.513	7.332	7.257	7.018	6.794	—	—	—	—
0.05 mol/kg Disodium tetraborate ($Na_2B_4O_7$)	9.475	9.409	9.347	9.288	9.233	9.182	9.134	9.074	9.051	8.983	8.932	8.898	8.88	8.84	8.89
0.01 mol/kg Disodium tetraborate ($Na_2B_4O_7$)	9.451	9.388	9.329	9.275	9.225	9.179	9.138	9.086	9.066	9.009	8.965	8.932	8.91	8.90	8.89

TABLE 4
pH(OS) Values for Operational Standard Reference Solutions (continued)

Operational standard ref. solution	t/°C 0	5	10	15	20	25	30	37	40	50	60	70	80	90	95
0.025 mol/kg Sodium hydrogen carbonate + 0.025 mol/kg sodium carbonate	10.273	10.212	10.154	10.098	10.045	9.995	9.948	9.889	9.866	9.800	9.753	9.728	9.725	9.75	9.77
Saturated (at 20° C) calcium hydroxide	13.360	13.159	12.965	12.780	12.602	12.431	12.267	12.049	11.959	11.678	11.423	11.192	10.984	10.80	10.71

Note: Uncertainty is ±0.003 in pH between 0 and 60° C rising to ±0.01 above 70° C.

[a] Potassium trihydrogen dioxalate ($KH_3C_4O_8$).
[b] Sodium hydrogen 2,2′-oxydiethanoate.
[c] $C_4H_{10}N_2 \cdot H_3PO_4$.
[d] 2-Amino-2-(hydroxymethyl)-1,3 propanediol or tris(hydroxymethyl)aminomethane.

TABLE 5
Useful Data on Some Standard Buffer Solutions

	Molecular formula	Molality (mol/kg)	Relative molar mass	Density at 20° C (g/cm³)	Molarity at at 20° C (mol/L)	Mass of 1 L at 20° C (g)	Mass tolerance for ±0.001 pH[a] (g)	Mass tolerance expressed as a percentage (%)
Potassium tetraoxalate	$KH_3C_4O_8 \cdot 2H_2O$	0.1	254.1913	1.0091	0.09875	25.1017	0.07	0.27
Potassium tetraoxalate	$KH_3C_4O_8 \cdot 2H_2O$	0.05	254.1913	1.0038	0.04965	12.6202	0.034	0.26
Disodium hydrogen orthophosphate	Na_2HPO_4	0.025	141.9588	1.0038 (both)	0.02492 (both)	3.5379	0.02	0.56
Potassium dihydrogen orthophosphate	KH_2PO_4	0.025	136.0852			3.3912	0.02	0.58
Disodium tetraborate	$Na_2B_4O_7 \cdot 10H_2O$	0.05	381.367	1.0075	0.04985	19.0117	0.9	4.73
Disodium tetraborate	$Na_2B_4O_7 \cdot 10H_2O$	0.01	381.367	1.0001	0.009981	3.8064	0.19	0.49
Sodium carbonate	Na_2CO_3	0.025	105.9887	1.0021 (both)	0.02494 (both)	2.6428	0.017	0.064
Sodium hydrogen carbonate	$NaHCO_3$	0.025	84.0069			2.0947	0.013	0.62

a Calculated from known dilution value of solution.

PRACTICAL pH MEASUREMENTS ON NATURAL WATERS

A. K. Covington and W. Davison

(1) Dilute solutions and freshwater including 'acid-rain' samples ($I < 0.02$ mol kg^{-1})

Major problems could be encountered due to errors associated with the liquid junction. It is recommended that either a free diffusion junction is used or it is verified that the junction is working correctly using dilute solutions as follows. For commercial electrodes calibrated with IUPAC aqueous RVS or PS standards, the pH(X) of dilute solutions should be within ±0.02 of those given in Table 1. The difference in determined pH(X) between a stirred and unstirred dilute solution should be < 0.02. The characteristics of glass electrodes are such that below pH 5 the readings should be stable within 2 min, but for pH 5 to 8, 8 or so minutes may be necessary to attain stability. Interpretation of pH(X) measured in this way in terms of activity of hydrogen ion, a_{H+} is subject[1] to an uncertainty of ±0.02 in pH.

(2) Seawater

Measurements made by calibration of electrodes with IUPAC aqueous RVS or PS standards to obtain pH(X) are perfectly valid. However, the interpretation of pH(X) in terms of the activity of hydrogen ion is complicated by the non zero residual liquid junction potential as well as by systematic differences between electrode pairs, principally attributable to the reference electrode. For 35‰ salinity seawater ($S = 0.035$) a_{H+} calculated from pH(X) is typically 12% too low. Special seawater pH scales have been devised to overcome this problem:
(i) The total hydrogen ion scale, pH_T, is defined in terms of the sum of free and complexed (total) hydrogen ion concentrations, where

$${}^{T}C_H = [H^+] + [HSO_4^-] + [HF].$$

$$\text{So, } pH_T = -\log {}^{T}C_H$$

Calibration of the electrodes with a buffer having a composition similar to that of seawater, to which pH_T has been assigned, results in values of pHT(X) (Tables 2, 3) which are accurately interpretable in terms of ${}^{T}C_H$.
(ii) The free hydrogen ion scale, pH_F, is defined, and fully interpretable, in terms of the concentration of free hydrogen ions.

$$pH_F = -\log [H^+]$$

Values of pH_F as a function of temperature have been assigned to the same set of pH_T seawater buffers,and so alternatively can be used for calibration (Tables 2, 3) [2,3]

(3) Estuarine water

Prescriptions for seawater scale buffers are available for a range of salinities. Reliable estuarine pH measurements can be made by calibrating with a buffer of the same salinity as the sample. However, these buffers are difficult to prepare and their use presumes prior knowledge of salinity of the sample. Interpretable measurements of estuarine pH can be made by calibration with IUPAC aqueous RVS or PS standards if the electrode pair is additionally calibrated using a 20‰ salinity seawater buffer.[4] The difference between the assigned pH_{SWS} of the seawater buffer and its measured pH(X) value using RVS or PS standards is

$$\Delta pH = pH_{SWS} - pH(X)$$

Values of ΔpH should be in the range of 0.08 to 0.18. It empirically corrects for differences between the two pH scales and for measurement errors associated with the electrode pair. The pH(X) of samples measured using IUPAC aqueous buffers, can be converted to pH_T or pH_F using the appropriate measured ΔpH:

$$pH_T = pH(X) - \Delta pH$$
$$\text{or } pH_F = pH(X) - \Delta pH$$

This simple procedure is appropriate to pH measurement at salinities from 2‰ to 35‰. For salinities lower than 2‰ the procedures for freshwaters should be adopted.

REFERENCES

1. Davison, W. and Harbinson,T. R., *Analyst*, 113, 709, 1988.
2. Culberson, C. H., in *Marine Electrochemistry*, Whitfield, M. and Jagner,D., Eds., Wiley, 1981.
3. Millero, F. J., *Limnol. Oceanogr.*, 31, 839, 1986.
4. Covington, A. K., Whalley, P. D., Davison, W., and Whitfield, M., in *The Determination of Trace Metals in Natural Waters*, West, T. S. and Nurnberg, H. W., Eds., Blackwell, Oxford, 1988.
5. Koch, W. F., Marinenko, G., and Paule, R. C., *J. Res. NBS*, 91, 33, 1986.

Table 1
pH of Dilute Solutions at 25°C, Degassed and Equilibrated with Air, Suitable as Quality Control Standards

	Ionic strength mmol kg^{-1}	Concentration(x) mmol kg^{-1}	pH p_{CO_2}= 0	pH p_{CO_2}= air
Potassium hydrogen phthalate	10.7	10	4.12	4.12
	1.1	1	4.33	4.33
$x KH_2PO_4 + x Na_2HPO_4$	9.9	2.5	7.07	7.05
$x KH_2PO_4 + 3.5 x Na_2HPO_4$	10	0.87	7.61	7.58
$Na_2B_4O_7 \cdot 10H_2O$	10	5	9.20	—
HCl	0.1	0.1	4.03	4.03
SRM2694-I[a]	—	—	4.30	—
SRM2694-II[a]	—	—	3.59	—

Note: The pH of solutions near to pH 4 is virtually independent of temperature over the range of 5 to 30°C.

[a] Simulated rainwater samples are available (Reference 5) from NIST containing sulfate, nitrate, chloride, fluoride, sodium, potassium, calcium and magnesium

Table 2
Composition of Seawater Buffer of Salinity *S* = 35‰ at 25°C (Reference 3)

Solute	mol dm^{-3}	mol kg^{-1}	g kg^{-1}	g dm^{-3}
NaCl	0.3666	0.3493	20.416	20.946
Na_2SO_4	0.02926	0.02788	3.96	4.063
KCl	0.01058	0.01008	0.752	0.772
$CaCl_2$	0.01077	0.01026	1.139	1.169
$MgCl_2$	0.05518	0.05258	5.006	5.139
Tris	0.06	0.05717	6.926	7.106
Tris · HCl	0.06	0.05717	9.010	9.244

Tris = tris(hydroxymethyl)aminomethane $(HOCH_2)_3CNH_2$.
A 20‰ buffer is made by diluting the 35‰ in the ratio 20:35.

Table 3
Assigned Values of 20‰ and 35‰ Buffers on Free and Total Hydrogen Ion Scales. Calculated from Equations Provided by Millero (Reference 3)

Temp (°C)	pH_T *S* = 20‰	pH_T *S* = 35‰	pH_F *S* = 20‰	pH_F *S* = 35‰
5	8.683	8.718	8.759	8.81
10	8.513	8.542	8.597	8.647
15	8.351	8.374	8.442	8.491
20	8.195	8.212	8.292	8.341
25	8.045	8.057	8.149	8.197
30	7.901	7.908	8.011	8.059
35	7.762	7.764	7.879	7.926

BUFFER SOLUTIONS GIVING ROUND VALUES OF pH AT 25°C

A		B		C		D		E	
pH	***x***	**pH**	***x***	**pH**	***x***	**pH**	***x***	**pH**	***x***
1.00	67.0	2.20	49.5	4.10	1.3	5.80	3.6	7.00	46.6
1.10	52.8	2.30	45.8	4.20	3.0	5.90	4.6	7.10	45.7
1.20	42.5	2.40	42.2	4.30	4.7	6.00	5.6	7.20	44.7
1.30	33.6	2.50	38.8	4.40	6.6	6.10	6.8	7.30	43.4
1.40	26.6	2.60	35.4	4.50	8.7	6.20	8.1	7.40	42.0
1.50	20.7	2.70	32.1	4.60	11.1	6.30	9.7	7.50	40.3
1.60	16.2	2.80	28.9	4.70	13.6	6.40	11.6	7.60	38.5
1.70	13.0	2.90	25.7	4.80	16.5	6.50	13.9	7.70	36.6
1.80	10.2	3.00	22.3	4.90	19.4	6.60	16.4	7.80	34.5
1.90	8.1	3.10	18.8	5.00	22.6	6.70	19.3	7.90	32.0
2.00	6.5	3.20	15.7	5.10	25.5	6.80	22.4	8.00	29.2
2.10	5.10	3.30	12.9	5.20	28.8	6.90	25.9	8.10	26.2
2.20	3.9	3.40	10.4	5.30	31.6	7.00	29.1	8.20	22.9
		3.50	8.2	5.40	34.1	7.10	32.1	8.30	19.9
		3.60	6.3	5.50	36.6	7.20	34.7	8.40	17.2
		3.70	4.5	5.60	38.8	7.30	37.0	8.50	14.7
		3.80	2.9	5.70	40.6	7.40	39.1	8.60	12.2
		3.90	1.4	5.80	42.3	7.50	40.9	8.70	10.3
		4.00	0.1	5.90	43.7	7.60	42.4	8.80	8.5
						7.70	43.5	8.90	7.0
						7.80	44.5	9.00	5.7
						7.90	45.3		
						8.00	46.1		

F		G		H		I		J	
pH	***x***	**pH**	***x***	**pH**	***x***	**pH**	***x***	**pH**	***x***
8.00	20.5	9.20	0.9	9.60	5.0	10.90	3.3	12.00	6.0
8.10	19.7	9.30	3.6	9.70	6.2	11.00	4.1	12.10	8.0
8.20	18.8	9.40	6.2	9.80	7.6	11.10	5.1	12.20	10.2
8.30	17.7	9.50	8.8	9.90	9.1	11.20	6.3	12.30	12.8
8.40	16.6	9.60	11.1	10.00	10.7	11.30	7.6	12.40	16.2
8.50	15.2	9.70	13.1	10.10	12.2	11.40	9.1	12.50	20.4
8.60	13.5	9.80	15.0	10.20	13.8	11.50	11.1	12.60	25.6
8.70	11.6	9.90	16.7	10.30	15.2	11.60	13.5	12.70	32.2
8.80	9.6	10.00	18.3	10.40	16.5	11.70	16.2	12.80	41.2
8.90	7.1	10.10	19.5	10.50	17.8	11.80	19.4	12.90	53.0
9.00	4.6	10.20	20.5	10.60	19.1	11.90	23.0	13.00	66.0
9.10	2.0	10.30	21.3	10.70	20.2	12.00	26.9		
		10.40	22.1	10.80	21.2				
		10.50	22.7	10.90	22.0				
		10.60	23.3	11.00	22.7				
		10.70	23.8						
		10.80	24.25						

A. 25 ml of 0.2 molar KCl + *x* ml of 0.2 molar HCl.
B. 50 ml of 0.1 molar potassium hydrogen phthalate + *x* ml of 0.1 molar HCl.
C. 50 ml of 0.1 molar potassium hydrogen phthalate + *x* ml of 0.1 molar NaOH.
D. 50 ml of 0.1 molar potassium dihydrogen phosphate + *x* ml of 0.1 molar NaOH.
E. 50 ml of 0.1 molar tris(hydroxymethyl)aminomethane + *x* ml of 0.1 M HCl.
F. 50 ml of 0.025 molar borax + *x* ml of 0.1 molar HCl.
G. 50 ml of 0.025 molar borax + *x* ml of 0.1 molar NaOH.
H. 50 ml of 0.05 molar sodium bicarbonate + *x* ml of 0.1 molar NaOH.
I. 50 ml of 0.05 molar disodium hydrogen phosphate + *x* ml of 0.1 molar NaOH.
J. 25 ml of 0.2 molar KCl + *x* ml of 0.2 molar NaOH.

Final volume of mixtures = 100 ml.

REFERENCES

1. Bower, V.E., and Bates, R.G., *J. Res. Natl. Bur. Stand.*, 55, 197, 1955 (A–D).
2. Bates, R.G., and Bower, V.E., *Anal. Chem.*, 28, 1322, 1956 (E–J).

DISSOCIATION CONSTANTS OF INORGANIC ACIDS AND BASES

The data in this table are presented as values of pK_a, defined as the negative logarithm of the acid dissociation constant K_a for the reaction

$$BH \rightleftharpoons B^- + H^+$$

Thus pK_a = –log K_a , and the hydrogen ion concentration [H^+] can be calculated from

$$K_a = \frac{[H^+][B^-]}{[BH]}$$

In the case of bases, the entry in the table is for the conjugate acid; e.g., ammonium ion for ammonia. The OH^- concentration in the system

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

can be calculated from the equation

$$K_b = K_{water} / K_a = \frac{[OH^-][NH_4^+]}{[NH_3]}$$

where $K_{water} = 1.01 \times 10^{-14}$ at 25 °C. Note that pK_a + pK_b = pK_{water}.

All values refer to dilute aqueous solutions at zero ionic strength at the temperature indicated. The table is arranged alphabetically by compound name.

REFERENCE

1. Perrin, D. D., *Ionization Constants of Inorganic Acids and Bases in Aqueous Solution, Second Edition,* Pergamon, Oxford, 1982.

Name	Formula	Step	t/°C	pK_a
Aluminum(III) ion	Al^{+3}		25	5.0
Ammonia	NH_3		25	9.25
Arsenic acid	H_3AsO_4	1	25	2.26
		2	25	6.76
		3	25	11.29
Arsenious acid	H_2AsO_3		25	9.29
Barium(II) ion	Ba^{+2}		25	13.4
Boric acid	H_3BO_3	1	20	9.27
		2	20	>14
Calcium(II) ion	Ca^{+2}		25	12.6
Carbonic acid	H_2CO_3	1	25	6.35
		2	25	10.33
Chlorous acid	$HClO_2$		25	1.94
Chromic acid	H_2CrO_4	1	25	0.74
		2	25	6.49
Cyanic acid	HCNO		25	3.46
Germanic acid	H_2GeO_3	1	25	9.01
		2	25	12.3
Hydrazine	N_2H_4		25	8.1
Hydrazoic acid	HN_3		25	4.6
Hydrocyanic acid	HCN		25	9.21
Hydrofluoric acid	HF		25	3.20
Hydrogen peroxide	H_2O_2		25	11.62
Hydrogen selenide	H_2Se	1	25	3.89
		2	25	11.0
Hydrogen sulfide	H_2S	1	25	7.05
		2	25	19
Hydrogen telluride	H_2Te	1	18	2.6
		2	25	11
Hydroxylamine	NH_2OH		25	5.94
Hypobromous acid	HBrO		25	8.55

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DISSOCIATION CONSTANTS OF INORGANIC ACIDS AND BASES (continued)

Name	Formula	Step	t/°C	pK_a
Hypochlorous acid	$HClO$		25	7.40
Hypoiodous acid	HIO		25	10.5
Iodic acid	HIO_3		25	0.78
Lithium ion	Li^+		25	13.8
Magnesium(II) ion	Mg^{+2}		25	11.4
Nitrous acid	HNO_2		25	3.25
Perchloric acid	$HClO_4$		20	-1.6
Periodic acid	HIO_4		25	1.64
Phosphoric acid	H_3PO_4	1	25	2.16
		2	25	7.21
		3	25	12.32
Phosphorous acid	H_3PO_3	1	20	1.3
		2	20	6.70
Pyrophosphoric acid	$H_4P_2O_7$	1	25	0.91
		2	25	2.10
		3	25	6.70
		4	25	9.32
Selenic acid	H_2SeO_4	2	25	1.7
Selenious acid	H_2SeO_3	1	25	2.62
		2	25	8.32
Silicic acid	H_4SiO_4	1	30	9.9
		2	30	11.8
		3	30	12
		4	30	12
Sodium ion	Na^+		25	14.8
Strontium(II) ion	Sr^{+2}		25	13.2
Sulfamic acid	NH_2SO_3H		25	1.05
Sulfuric acid	H_2SO_4	2	25	1.99
Sulfurous acid	H_2SO_3	1	25	1.85
		2	25	7.2
Telluric acid	H_2TeO_4	1	18	7.68
		2	18	11.0
Tellurous acid	H_2TeO_3	1	25	6.27
		2	25	8.43
Tetrafluoroboric acid	HBF_4		25	0.5
Thiocyanic acid	$HSCN$		25	-1.8
Water	H_2O		25	13.995

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DISSOCIATION CONSTANTS OF ORGANIC ACIDS AND BASES

This table lists the dissociation (ionization) constants of over 1070 organic acids, bases, and amphoteric compounds. All data apply to dilute aqueous solutions and are presented as values of pK_a, which is defined as the negative of the logarithm of the equilibrium constant K_a for the reaction

$$HA \rightleftharpoons H^+ + A^-$$

i.e.,

$$K_a = [H^+][A^-]/[HA]$$

where $[H^+]$, etc. represent the concentrations of the respective species in mol/L. It follows that pK_a = pH + log[HA] - log[A^-], so that a solution with 50% dissociation has pH equal to the pK_a of the acid.

Data for bases are presented as pK_a values for the conjugate acid, i.e., for the reaction

$$BH^+ \rightleftharpoons H^+ + B$$

In older literature, an ionization constant K_b was used for the reaction $B + H_2O \rightleftharpoons BH^+ + OH^-$. This is related to K_a by

$$pK_a + pK_b = pK_{water} = 14.00 \quad (\text{at } 25°C)$$

Compounds are listed by molecular formula in Hill order.

REFERENCES

1. Perrin, D.D., *Dissociation Constants of Organic Bases in Aqueous Solution*, Butterworths, London, 1965; Supplement, 1972.
2. Serjeant, E.P., and Dempsey, B., *Ionization Constants of Organic Acids in Aqueous Solution*, Pergamon, Oxford, 1979.
3. Albert, A., “Ionization Constants of Heterocyclic Substances”, in Katritzky, A.R., Ed., *Physical Methods in Heterocyclic Chemistry*, Academic Press, New York, 1963.
4. Sober, H.A., Ed., *CRC Handbook of Biochemistry*, CRC Press, Boca Raton, FL, 1968.
5. Perrin, D.D., Dempsey, B., and Serjeant, E.P., pK_a *Prediction for Organic Acids and Bases*, Chapman and Hall, London, 1981.
6. Albert, A., and Serjeant, E. P., *The Determination of Ionization Constants, Third Edition*, Chapman and Hall, London, 1984.
7. Budavari, S., Editor, *The Merck Index, Twelth Edition*, Merck & Co., Whitehouse Station, NJ, 1996.

Mol. Form.	Name	Step	t/°C	pK_a
$CHNO$	Cyanic acid		25	3.7
CH_2N_2	Cyanamide		29	1.1
CH_2O	Formaldehyde		25	13.27
CH_2O_2	Formic acid		25	3.75
CH_3NO_2	Nitromethane		25	10.21
CH_3NS_2	Carbamodithioic acid		25	2.95
CH_4N_2O	Urea		25	0.10
CH_4N_2S	Thiourea		25	-1
CH_4O	Methanol		25	15.5
CH_4S	Methanethiol		25	10.33
CH_5N	Methylamine		25	10.66
CH_5NO	*O*-Methylhydroxylamine			12.5
CH_5N_3	Guanidine		25	13.6
C_2HCl_3O	Trichloroacetaldehyde		25	10.04
$C_2HCl_3O_2$	Trichloroacetic acid		20	0.66
$C_2HF_3O_2$	Trifluoroacetic acid		25	0.52
$C_2H_2Cl_2O_2$	Dichloroacetic acid		25	1.35
$C_2H_2O_3$	Glyoxylic acid		25	3.18
$C_2H_2O_4$	Oxalic acid	1	25	1.25
		2	25	3.81
$C_2H_3BrO_2$	Bromoacetic acid		25	2.90
$C_2H_3ClO_2$	Chloroacetic acid		25	2.87
$C_2H_3Cl_3O$	2,2,2-Trichloroethanol		25	12.24
$C_2H_3FO_2$	Fluoroacetic acid		25	2.59
$C_2H_3F_3O$	2,2,2-Trifluoroethanol		25	12.37
$C_2H_3IO_2$	Iodoacetic acid		25	3.18
$C_2H_3NO_4$	Nitroacetic acid		24	1.48
$C_2H_3N_3$	1H-1,2,3-Triazole		20	1.17
$C_2H_3N_3$	1H-1,2,4-Triazole		20	2.27
$C_2H_4N_2$	Aminoacetonitrile		25	5.34
C_2H_4O	Acetaldehyde		25	13.57
C_2H_4OS	Thioacetic acid		25	3.33
$C_2H_4O_2$	Acetic acid		25	4.756
$C_2H_4O_2S$	Thioglycolic acid		25	3.68
$C_2H_4O_3$	Glycolic acid		25	3.83
C_2H_5N	Ethyleneimine		25	8.04
C_2H_5NO	Acetamide		25	15.1
$C_2H_5NO_2$	Acetohydroxamic acid			8.70
$C_2H_5NO_2$	Nitroethane		25	8.46
$C_2H_5NO_2$	Glycine	1	25	2.35
		2	25	9.78
$C_2H_6N_2$	Ethanimidamide		25	12.1
C_2H_6O	Ethanol		25	15.5
C_2H_6OS	2-Mercaptoethanol		25	9.72
$C_2H_6O_2$	Ethyleneglycol		25	15.1
$C_2H_7AsO_2$	Dimethylarsinic acid	1	25	1.57
		2	25	6.27
C_2H_7N	Ethylamine		25	10.65
C_2H_7N	Dimethylamine		25	10.73
C_2H_7NO	Ethanolamine		25	9.50
$C_2H_7NO_3S$	2-Aminoethanesulfonic	1	25	1.5
	acid	2	25	9.06
C_2H_7NS	Cysteamine	1	25	8.27
		2	25	10.53
$C_2H_7N_5$	Biguanide	1		11.52
		2		2.93
$C_2H_8N_2$	1,2-Ethanediamine	1	25	9.92
		2	25	6.86

Mol. Form.	Name	Step	t/°C	pKa
$C_2H_8O_7P_2$	1-Hydroxy-1,1-diphosphonoethane	1		1.35
		2		2.87
		3		7.03
		4		11.3
$C_3H_2O_2$	2-Propynoic acid		25	1.84
C_3H_3NO	Oxazole		33	0.8
C_3H_3NO	Isoxazole		25	-2.0
$C_3H_3NO_2$	Cyanoacetic acid		25	2.47
C_3H_3NS	Thiazole		25	2.52
$C_3H_3N_3O_3$	Cyanuric acid	1		6.88
		2		11.40
		3		13.5
$C_3H_4N_2$	1*H*-Pyrazole		25	2.49
$C_3H_4N_2$	Imidazole		25	6.99
$C_3H_4N_2S$	2-Thiazolamine		20	5.36
C_3H_4O	Propargyl alcohol		25	13.6
$C_3H_4O_2$	Acrylic acid		25	4.25
$C_3H_4O_3$	Pyruvic acid		25	2.39
$C_3H_4O_4$	Malonic acid	1	25	2.85
		2	25	5.70
$C_3H_4O_5$	Hydroxypropanedioic acid	1		2.42
		2		4.54
$C_3H_5BrO_2$	3-Bromopropanoic acid		25	4.00
$C_3H_5ClO_2$	2-Chloropropanoic acid		25	2.83
$C_3H_5ClO_2$	3-Chloropropanoic acid		25	3.98
$C_3H_6N_2$	3-Aminopropanenitrile		20	7.80
$C_3H_6N_6$	1,3,5-Triazine-2,4,6-triamine		25	5.00
C_3H_6O	Allyl alcohol		25	15.5
$C_3H_6O_2$	Propanoic acid		25	4.87
$C_3H_6O_2S$	(Methylthio)acetic acid		25	3.66
$C_3H_6O_3$	Lactic acid		25	3.86
$C_3H_6O_3$	3-Hydroxypropanoic acid		25	4.51
$C_3H_6O_4$	Glyceric acid		25	3.52
C_3H_7N	Allylamine		25	9.49
C_3H_7N	Azetidine		25	11.29
C_3H_7NO	2-Propanone oxime		25	12.42
$C_3H_7NO_2$	*L*-Alanine	1	25	2.34
		2	25	9.87
$C_3H_7NO_2$	β-Alanine	1	25	3.55
		2	25	10.24
$C_3H_7NO_2$	Sarcosine	1	25	2.21
		2	25	10.1
$C_3H_7NO_2S$	*L*-Cysteine	1	25	1.5
		2	25	8.7
		3	25	10.2
$C_3H_7NO_3$	*L*-Serine	1	25	2.19
		2	25	9.21
$C_3H_7NO_5S$	*DL*-Cysteic acid	1	25	1.3
		2	25	1.9
		3	25	8.70
$C_3H_7N_3O_2$	Glycocyamine		25	2.82
$C_3H_8O_2$	Ethylene glycol monomethyl ether		25	14.8
$C_3H_8O_3$	Glycerol		25	14.15
C_3H_9N	Propylamine		25	10.54
C_3H_9N	Isopropylamine		25	10.63
C_3H_9N	Trimethylamine		25	9.80
C_3H_9NO	2-Methoxyethylamine		25	9.40
C_3H_9NO	Trimethylamine oxide		20	4.65
$C_3H_{10}N_2$	1,2-Propanediamine, (±)	1	25	9.82
		2	25	6.61
$C_3H_{10}N_2$	1,3-Propanediamine	1	25	10.55
		2	25	8.88
$C_3H_{10}N_2O$	1,3-Diamino-2-propanol	1	20	9.69
		2	20	7.93
$C_3H_{11}N_3$	1,2,3-Triaminopropane	1	20	9.59
		2	20	7.95
$C_4H_4FN_3O$	Flucytosine			3.26
$C_4H_4N_2$	Pyrazine		20	0.65
$C_4H_4N_2$	Pyrimidine		20	1.23
$C_4H_4N_2$	Pyridazine		20	2.24
$C_4H_4N_2O_2$	Uracil		25	9.45
$C_4H_4N_2O_3$	Barbituric acid		25	4.01
$C_4H_4N_2O_5$	Alloxanic acid		25	6.64
$C_4H_4N_4O_2$	5-Nitropyrimidinamine		20	0.35
$C_4H_4O_2$	2-Butynoic acid		25	2.62
$C_4H_4O_4$	Maleic acid	1	25	1.92
		2	25	6.23
$C_4H_4O_4$	Fumaric acid	1	25	3.02
		2	25	4.38
$C_4H_4O_5$	Oxaloacetic acid	1	25	2.55
		2	25	4.37
		3	25	13.03
C_4H_5N	Pyrrole		25	-3.8
$C_4H_5NO_2$	Succinimide		25	9.62
$C_4H_5N_3$	2-Pyrimidinamine		20	3.45
$C_4H_5N_3$	4-Pyrimidinamine		20	5.71
$C_4H_5N_3O$	Cytosine	1		4.60
		2		12.16
$C_4H_5N_3O_2$	6-Methyl-1,2,4-triazine-3,5(2H,4H)-dione			7.6
$C_4H_6N_2$	1-Methylimidazol		25	6.95
$C_4H_6N_4O_3$	Allantoin		25	8.96
$C_4H_6N_4O_3S_2$	Acetazolamide			7.2
$C_4H_6O_2$	*trans*-Crotonic acid		25	4.69
$C_4H_6O_2$	3-Butenoic acid		25	4.34
$C_4H_6O_2$	Cyclopropanecarboxylic acid		25	4.83
$C_4H_6O_3$	2-Oxobutanoic acid		25	2.50
$C_4H_6O_3$	Acetoacetic acid		25	3.6
$C_4H_6O_4$	Succinic acid	1	25	4.21
		2	25	5.64
$C_4H_6O_4$	Methylmalonic acid	1	25	3.07
		2	25	5.76
$C_4H_6O_5$	Malic acid	1	25	3.40
		2	25	5.11
$C_4H_6O_6$	*DL*-Tartaric acid	1	25	3.03
		2	25	4.37
$C_4H_6O_6$	*meso*-Tartaric acid	1	25	3.17
		2	25	4.91
$C_4H_6O_6$	*L*-Tartaric acid	1	25	2.98
		2	25	4.34
$C_4H_6O_8$	Dihydroxytartaric acid		25	1.92
$C_4H_7ClO_2$	2-Chlorobutanoic acid			2.86
$C_4H_7ClO_2$	3-Chlorobutanoic acid			4.05
$C_4H_7ClO_2$	4-Chlorobutanoic acid			4.52

Mol. Form.	Name	Step	t/°C	pK_a
$C_4H_7NO_2$	4-Cyanobutanoic acid		25	2.42
$C_4H_7NO_3$	*N*-Acetylglycine		25	3.67
$C_4H_7NO_4$	Iminodiacetic acid	1		2.98
		2		9.89
$C_4H_7NO_4$	*L*-Aspartic acid	1	25	1.99
		2	25	3.90
		3	25	9.90
$C_4H_7N_3O$	Creatinine	1	25	4.8
		2		9.2
$C_4H_7N_5$	2,4,6-Pyrimidinetriamine		20	6.84
$C_4H_8N_2O_3$	*L*-Asparagine	1	20	2.1
		2	20	8.80
$C_4H_8N_2O_3$	*N*-Glycylglycine	1	25	3.14
		2		8.17
$C_4H_8O_2$	Butanoic acid		25	4.83
$C_4H_8O_2$	2-Methylpropanoic acid		20	4.84
$C_4H_8O_3$	3-Hydroxybutanoic acid, (±)		25	4.70
$C_4H_8O_3$	4-Hydroxybutanoic acid		25	4.72
$C_4H_8O_3$	Ethoxyacetic acid		18	3.65
C_4H_9N	Pyrrolidine		25	11.31
C_4H_9NO	Morpholine		25	8.50
$C_4H_9NO_2$	2-Methylalanine	1	25	2.36
		2	25	10.21
$C_4H_9NO_2$	*N,N*-Dimethylglycine		25	9.89
$C_4H_9NO_2$	*DL*-2-Aminobutanoic acid	1	25	2.29
		2	25	9.83
$C_4H_9NO_2$	4-Aminobutanoic acid	1	25	4.031
		2	25	10.556
$C_4H_9NO_2S$	*DL*-Homocysteine	1	25	2.22
		2	25	8.87
		3	25	10.86
$C_4H_9NO_3$	*L*-Threonine	1	25	2.09
		2	25	9.10
$C_4H_9NO_3$	*L*-Homoserine	1	25	2.71
		2	25	9.62
$C_4H_9N_3O_2$	Creatine	1	25	2.63
		2	25	14.3
$C_4H_{10}N_2$	Piperazine	1	25	9.73
		2	25	5.33
$C_4H_{10}N_2O_2$	2,4-Diaminobutanoic acid	1	25	1.85
		2	25	8.24
		3	25	10.44
$C_4H_{10}O_4$	1,2,3,4-Butanetetrol			13.9
$C_4H_{11}N$	Butylamine		25	10.60
$C_4H_{11}N$	*sec*-Butylamine		25	10.56
$C_4H_{11}N$	*tert*-Butylamine		25	10.68
$C_4H_{11}N$	Diethylamine		25	10.84
$C_4H_{11}NO_3$	Tris(hydroxymethyl) methylamine		20	8.3
$C_4H_{12}N_2$	1,4-Butanediamine	1	25	10.80
		2	25	9.63
C_5H_4BrN	3-Bromopyridine		25	2.84
C_5H_4ClN	2-Chloropyridine		25	0.49
C_5H_4ClN	3-Chloropyridine		25	2.81
C_5H_4ClN	4-Chloropyridine		25	3.83
C_5H_4FN	2-Fluoropyridine		25	-0.44
$C_5H_4N_2O_2$	4-Nitropyridine		25	1.61
$C_5H_4N_4$	1*H*-Purine	1	20	2.30
		2	20	8.96
$C_5H_4N_4O$	Hypoxanthine		25	8.7
$C_5H_4N_4O$	Allopurinol			10.2
$C_5H_4N_4O_3$	Uric acid		12	3.89
$C_5H_4N_4S$	1,7-Dihydro-6H-	1		7.77
	purine-6-thione	2		11.17
$C_5H_4O_2S$	2-Thiophenecarboxylic acid		25	3.49
$C_5H_4O_2S$	3-Thiophenecarboxylic acid		25	4.1
$C_5H_4O_3$	2-Furancarboxylic acid		25	3.16
$C_5H_4O_3$	3-Furancarboxylic acid		25	3.9
C_5H_5N	Pyridine		25	5.23
C_5H_5NO	2-Pyridinol	1	20	0.75
		2	20	11.65
C_5H_5NO	3-Pyridinol	1	20	4.79
		2	20	8.75
C_5H_5NO	4-Pyridinol	1	20	3.20
		2	20	11.12
C_5H_5NO	2(1H)-Pyridinone	1	20	0.75
		2	20	11.65
C_5H_5NO	Pyridine-1-oxide		24	0.79
$C_5H_5NO_2$	1*H*-Pyrrole-2-carboxylic acid		20	4.45
$C_5H_5NO_2$	1*H*-Pyrrole-3-carboxylic acid		20	5.00
$C_5H_5N_3O$	Pyrazinecarboxamide			0.5
$C_5H_5N_5$	Adenine	1		4.3
		2		9.83
$C_5H_5N_5O$	Guanine		40	9.92
$C_5H_6N_2$	2-Pyridinamine		20	6.82
$C_5H_6N_2$	3-Pyridinamine		25	6.04
$C_5H_6N_2$	4-Pyridinamine		25	9.11
$C_5H_6N_2$	2-Methylpyrazine		27	1.45
$C_5H_6N_2O_2$	Thymine		25	9.94
$C_5H_6O_4$	1,1-Cyclopropanedi-	1	25	1.82
	carboxylic acid	2	25	7.43
$C_5H_6O_4$	*trans*-1-Propene-1,2-	1	25	3.09
	dicarboxylic acid	2	25	4.75
$C_5H_6O_4$	1-Propene-2,3-	1	25	3.85
	dicarboxylic acid	2	25	5.45
$C_5H_6O_5$	2-Oxoglutaric acid	1	25	2.47
		2	25	4.68
$C_5H_7NO_3$	5,5-Dimethyl-2,4-oxazolidinedione		37	6.13
$C_5H_7NO_3$	*L*-Pyroglutamic acid		25	3.32
$C_5H_7N_3$	2,5-Pyridinediamine		20	6.48
$C_5H_7N_3$	Methylaminopyrazine		25	3.39
$C_5H_7N_3O_4$	Azaserine			8.55
$C_5H_8N_2$	2,4-Dimethylimidazole		25	8.36
$C_5H_8N_4O_3S_2$	Methazolamide			7.30
$C_5H_8O_2$	*trans*-3-Pentenoic acid		25	4.51
$C_5H_8O_4$	Dimethylmalonic acid		25	3.15
$C_5H_8O_4$	Glutaric acid	1	18	4.32
		2	25	5.42
$C_5H_8O_4$	Methylsuccinic acid	1	25	4.13
		2	25	5.64
$C_5H_9NO_2$	*L*-Proline	1	25	1.95
		2	25	10.64
$C_5H_9NO_3$	5-Amino-4-oxopentanoic	1	25	4.05
	acid	2	25	8.90
$C_5H_9NO_3$	*trans*-4-Hydroxyproline	1	25	1.82

Mol. Form.	Name	Step	t/°C	pK_a
		2	25	9.66
$C_5H_9NO_4$	*L*-Glutamic acid	1	25	2.13
		2	25	4.31
		3		9.67
$C_5H_9N_3$	Histamine	1	25	6.04
		2	25	9.75
$C_5H_{10}N_2O_3$	Glycylalanine		25	3.15
$C_5H_{10}N_2O_3$	*L*-Glutamine	1	25	2.17
		2	25	9.13
$C_5H_{10}N_2O_4$	Glycylserine	1	25	2.98
		2	25	8.38
$C_5H_{10}O_2$	Pentanoic acid		20	4.83
$C_5H_{10}O_2$	2-Methylbutanoic acid		25	4.80
$C_5H_{10}O_2$	3-Methylbutanoic acid		25	4.77
$C_5H_{10}O_2$	2,2-Dimethylpropanoic acid		20	5.03
$C_5H_{10}O_4$	*D*-2-Deoxyribose		25	12.61
$C_5H_{10}O_5$	*L*-Ribose		25	12.22
$C_5H_{10}O_5$	*D*-Xylose		18	12.14
$C_5H_{11}N$	Piperidine		25	11.123
$C_5H_{11}N$	*N*-Methylpyrrolidine		25	10.46
$C_5H_{11}NO$	4-Methylmorpholine		25	7.38
$C_5H_{11}NO_2$	*L*-Valine	1	25	2.29
		2	25	9.74
$C_5H_{11}NO_2$	*DL*-Norvaline	1		2.36
		2		9.72
$C_5H_{11}NO_2$	*L*-Norvaline	1	25	2.32
		2	25	9.81
$C_5H_{11}NO_2$	*N*-Propylglycine	1	25	2.35
		2	25	10.19
$C_5H_{11}NO_2$	5-Aminopentanoic acid	1	25	4.27
		2	25	10.77
$C_5H_{11}NO_2$	Betaine		0	1.83
$C_5H_{11}NO_2S$	*L*-Methionine	1	25	2.13
		2	25	9.27
$C_5H_{12}N_2O$	Tetramethylurea			2
$C_5H_{12}N_2O_2$	*L*-Ornithine	1	25	1.71
		2	25	8.69
		3	25	10.76
$C_5H_{13}N$	Pentylamine		25	10.63
$C_5H_{13}N$	3-Pentanamine		17	10.59
$C_5H_{13}N$	3-Methyl-1-butanamine		25	10.60
$C_5H_{13}N$	2-Methyl-2-butanamine		19	10.85
$C_5H_{13}N$	2,2-Dimethylpropylamine		25	10.15
$C_5H_{13}N$	Diethylmethylamine		25	10.35
$C_5H_{14}NO$	Choline		25	13.9
$C_5H_{14}N_2$	1,5-Pentanediamine	1	25	10.05
		2	25	10.93
$C_6H_3Cl_3N_2O_2$	4-Amino-3,5,6-trichloro-2-pyridinecarboxlic acid			3.6
$C_6H_3N_3O_7$	2,4,6-Trinitrophenol		24	0.42
$C_6H_4Cl_2O$	2,3-Dichlorophenol		25	7.44
$C_6H_4N_2O_5$	2,4-Dinitrophenol		25	4.07
$C_6H_4N_2O_5$	2,5-Dinitrophenol		15	5.15
$C_6H_4N_4$	Pteridine		20	4.05
C_6H_5BrO	2-Bromophenol		25	8.45
C_6H_5BrO	3-Bromophenol		25	9.03
C_6H_5BrO	4-Bromophenol		25	9.37
$C_6H_5Br_2N$	3,5-Dibromoaniline		25	2.34
C_6H_5ClO	2-Chlorophenol		25	8.56
C_6H_5ClO	3-Chlorophenol		25	9.12
C_6H_5ClO	4-Chlorophenol		25	9.41
$C_6H_5Cl_2N$	2,4-Dichloroaniline		22	2.05
C_6H_5FO	2-Fluorophenol		25	8.73
C_6H_5FO	3-Fluorophenol		25	9.29
C_6H_5FO	4-Fluorophenol		25	9.89
C_6H_5IO	2-Iodophenol		25	8.51
C_6H_5IO	3-Iodophenol		25	9.03
C_6H_5IO	4-Iodophenol		25	9.33
C_6H_5NO	2-Pyridinecarboxaldehyde		25	12.68
C_6H_5NO	4-Pyridinecarboxaldehyde		30	12.05
$C_6H_5NO_2$	Nitrobenzene		0	3.98
$C_6H_5NO_2$	2-Pyridinecarboxylic acid	1	20	0.99
		2	20	5.39
$C_6H_5NO_2$	3-Pyridinecarboxylic acid	1	25	2.00
		2	25	4.82
$C_6H_5NO_2$	4-Pyridinecarboxylic acid	1	25	1.77
		2	25	4.84
$C_6H_5NO_3$	2-Nitrophenol		25	7.23
$C_6H_5NO_3$	3-Nitrophenol		25	8.36
$C_6H_5NO_3$	4-Nitrophenol		25	7.15
$C_6H_5N_3$	1*H*-Benzotriazole		20	1.6
$C_6H_5N_5O$	2-Amino-4-hydroxypteridine	1	20	2.27
		2	20	7.96
$C_6H_5N_5O_2$	Xanthopterin	2	20	6.59
		3	20	9.31
C_6H_6BrN	2-Bromoaniline		25	2.53
C_6H_6BrN	3-Bromoaniline		25	3.53
C_6H_6BrN	4-Bromoaniline		25	3.89
C_6H_6ClN	2-Chloroaniline		25	2.66
C_6H_6ClN	3-Chloroaniline		25	3.52
C_6H_6ClN	4-Chloroaniline		25	3.98
C_6H_6FN	2-Fluoroaniline		25	3.20
C_6H_6FN	3-Fluoroaniline		25	3.59
C_6H_6FN	4-Fluoroaniline		25	4.65
C_6H_6IN	2-Iodoaniline		25	2.54
C_6H_6IN	3-Iodoaniline		25	3.58
C_6H_6IN	4-Iodoaniline		25	3.81
$C_6H_6N_2O$	3-Pyridinecarboxamide		20	3.3
$C_6H_6N_2O$	2-Pyridinecarboxaldehyde oxime	1	20	3.59
		2	20	10.18
$C_6H_6N_2O_2$	2-Nitroaniline		25	-0.25
$C_6H_6N_2O_2$	3-Nitroaniline		25	2.46
$C_6H_6N_2O_2$	4-Nitroaniline		25	1.02
C_6H_6O	Phenol		25	9.99
$C_6H_6O_2$	*p*-Hydroquinone	1	25	9.85
		2	25	11.4
$C_6H_6O_2$	Pyrocatechol	1	25	9.34
		2	25	12.6
$C_6H_6O_2$	Resorcinol	1	25	9.32
		2	25	11.1
$C_6H_6O_2S$	Benzenesulfinic acid		20	1.3
$C_6H_6O_3S$	Benzenesulfonic acid		25	0.70
$C_6H_6O_4$	5-Hydroxy-2-(hydroxymethyl)-4H-pyran-4-one			7.9
$C_6H_6O_4S$	3-Hydroxybenzenesulfonic acid		25	9.07

Mol. Form.	Name	Step	t/°C	pK_a
$C_6H_6O_4S$	4-Hydroxybenzene-sulfonic acid		25	9.11
$C_6H_6O_6$	*cis*-1-Propene-1,2,3-tricarboxylic acid		25	1.95
$C_6H_6O_6$	*trans*-1-Propene-1,2,3-tricarboxylic acid	1	25	2.80
		2	25	4.46
C_6H_6S	Benzenethiol		25	6.62
$C_6H_7BO_2$	Benzeneboronic acid			8.83
C_6H_7N	Aniline		25	4.87
C_6H_7N	2-Methylpyridine		25	6.00
C_6H_7N	3-Methylpyridine		25	5.70
C_6H_7N	4-Methylpyridine		25	5.99
C_6H_7NO	2-Aminophenol	1	20	4.78
		2	20	9.97
C_6H_7NO	3-Aminophenol	1	20	4.37
		2	20	9.82
C_6H_7NO	4-Aminophenol	1	25	5.48
		2	25	10.30
C_6H_7NO	2-Methoxypyridine		20	3.28
C_6H_7NO	3-Methoxypyridine		25	4.78
C_6H_7NO	4-Methoxypyridine		25	6.58
$C_6H_7NO_3S$	2-Aminobenzenesulfonic acid		25	2.46
$C_6H_7NO_3S$	3-Aminobenzenesulfonic acid		25	3.74
$C_6H_7NO_3S$	4-Aminobenzenesulfonic acid		25	3.23
$C_6H_8N_2$	*N*-Methylpyridinamine		20	9.65
$C_6H_8N_2$	*o*-Phenylenediamine	1	20	4.57
		2	20	0.80
$C_6H_8N_2$	*m*-Phenylenediamine	1	20	5.11
		2	20	2.50
$C_6H_8N_2$	*p*-Phenylenediamine	1	20	6.31
		2	20	2.97
$C_6H_8N_2$	Phenylhydrazine		15	8.79
$C_6H_8O_2$	2,4-Hexadienoic acid		25	4.76
$C_6H_8O_2$	1,3-Cyclohexanedione		25	5.26
$C_6H_8O_4$	2,2-Dimethyl-1,3-dioxane-4,6-dione			5.1
$C_6H_8O_6$	*L*-Ascorbic acid	1	25	4.04
		2	16	11.7
$C_6H_8O_7$	Citric acid	1	25	3.13
		2	25	4.76
		3	25	6.40
$C_6H_8O_7$	Isocitric acid	1	25	3.29
		2	25	4.71
		3	25	6.40
$C_6H_9NO_6$	Nitrilotriacetic acid	1	20	3.03
		2	20	3.07
		3	20	10.70
$C_6H_9NO_6$	*L*-γ-Carboxyglutamic acid	1	25	1.7
		2	25	3.2
		3	25	4.75
		4	25	9.9
$C_6H_9N_3$	4,6-Dimethylpyrimidinamine		20	4.82
$C_6H_9N_3O_2$	*L*-Histidine	1	25	1.80
		2	25	6.04
		3	25	9.33
$C_6H_{10}O_2$	Cyclopentanecarboxylic acid		25	4.99
$C_6H_{10}O_3$	Ethyl acetoacetate		25	10.68
$C_6H_{10}O_4$	3-Methylglutaric acid		25	4.24
$C_6H_{10}O_4$	Adipic acid	1	18	4.41
		2	18	5.41
$C_6H_{11}NO_2$	2-Piperidinecarboxylic acid	1	25	2.28
		2	25	10.72
$C_6H_{11}NO_3$	Adipamic acid		25	4.63
$C_6H_{11}NO_4$	2-Aminoadipic acid	1	25	2.14
		2	25	4.21
		3	25	9.77
$C_6H_{11}N_3O_4$	*N*-(*N*-Glycylglycyl)glycine	1	25	3.225
		2	25	8.09
$C_6H_{11}N_3O_4$	Glycylasparagine	1	25	2.942
		2	18	8.44
$C_6H_{12}N_2$	Triethylenediamine	1		3.0
		2		8.7
$C_6H_{12}N_2O_4S_2$	*L*-Cystine	1		1
		2		2.1
		3		8.02
		4		8.71
$C_6H_{12}O_2$	Hexanoic acid		25	4.85
$C_6H_{12}O_2$	4-Methylpentanoic acid		18	4.84
$C_6H_{12}O_6$	β-*D*-Fructose		25	12.27
$C_6H_{12}O_6$	α-*D*-Glucose		25	12.46
$C_6H_{12}O_6$	*D*-Mannose		25	12.08
$C_6H_{13}N$	Cyclohexylamine		25	10.64
$C_6H_{13}N$	1-Methylpiperidine		25	10.38
$C_6H_{13}N$	1,2-Dimethylpyrrolidine		26	10.20
$C_6H_{13}NO$	*N*-Ethylmorpholine		25	7.67
$C_6H_{13}NO_2$	*L*-Leucine	1	25	2.33
		2	25	9.74
$C_6H_{13}NO_2$	*L*-Isoleucine	1	25	2.32
		2	25	9.76
$C_6H_{13}NO_2$	*L*-Norleucine	1	25	2.34
		2	25	9.83
$C_6H_{13}NO_2$	6-Aminohexanoic acid	1	25	4.37
		2	25	10.80
$C_6H_{13}NO_4$	*N,N*-Bis(2-hydroxyethyl)glycine	2	20	8.35
$C_6H_{13}N_3O_3$	Citrulline	1	25	2.43
		2	25	9.69
$C_6H_{14}N_2$	*cis*-1,2-Cyclohexanediamine	1	20	9.93
		2	20	6.13
$C_6H_{14}N_2$	*trans*-1,2-Cyclohexanediamine	1	20	9.94
		2	20	6.47
$C_6H_{14}N_2$	*cis*-2,5-Dimethylpiperazine	1	25	9.66
		2	25	5.20
$C_6H_{14}N_2O_2$	*L*-Lysine	1	25	2.16
		2	25	9.06
		3	25	10.54
$C_6H_{14}N_4O_2$	*L*-Arginine	1	25	1.82
		2	25	8.99
		3	25	12.5
$C_6H_{14}O_6$	*D*-Mannitol		18	13.5
$C_6H_{15}N$	Hexylamine		25	10.56
$C_6H_{15}N$	Diisopropylamine		25	11.05
$C_6H_{15}N$	Triethylamine		25	10.75

Mol. Form.	Name	Step	t/°C	pK_a
$C_6H_{15}NO_3$	Triethanolamine		25	7.76
$C_6H_{16}N_2$	1,6-Hexanediamine	1	0	11.86
		2	0	10.76
$C_6H_{16}N_2$	*N,N,N',N'*-Tetramethyl-1,2-ethanediamine	1	25	10.40
		2	25	8.26
$C_6H_{19}NSi_2$	Hexamethyldisilazane			7.55
$C_7HF_5O_2$	Pentafluorobenzoic acid		25	1.75
$C_7H_3Br_2NO$	3,5-Dibromo-4-hydroxybenzonitrile			4.06
$C_7H_3N_3O_8$	2,4,6-Trinitrobenzoic acid		25	0.65
$C_7H_4Cl_3NO_3$	Triclopyr			2.68
$C_7H_4N_2O_6$	2,4-Dinitrobenzoic acid		25	1.43
$C_7H_5BrO_2$	2-Bromobenzoic acid		25	2.85
$C_7H_5BrO_2$	3-Bromobenzoic acid		25	3.81
$C_7H_5BrO_2$	4-Bromobenzoic acid		25	3.96
$C_7H_5ClO_2$	2-Chlorobenzoic acid		25	2.90
$C_7H_5ClO_2$	3-Chlorobenzoic acid		25	3.84
$C_7H_5ClO_2$	4-Chlorobenzoic acid		25	4.00
$C_7H_5FO_2$	2-Fluorobenzoic acid		25	3.27
$C_7H_5FO_2$	3-Fluorobenzoic acid		25	3.86
$C_7H_5FO_2$	4-Fluorobenzoic acid		25	4.15
$C_7H_5F_3O$	2-(Trifluoromethyl)phenol		25	8.95
$C_7H_5F_3O$	3-(Trifluoromethyl)phenol		25	8.68
$C_7H_5IO_2$	2-Iodobenzoic acid		25	2.86
$C_7H_5IO_2$	3-Iodobenzoic acid		25	3.87
$C_7H_5IO_2$	4-Iodobenzoic acid		25	4.00
C_7H_5NO	2-Hydroxybenzonitrile		25	6.86
C_7H_5NO	3-Hydroxybenzonitrile		25	8.61
C_7H_5NO	4-Hydroxybenzonitrile		25	7.97
$C_7H_5NO_3S$	Saccharin		18	11.68
$C_7H_5NO_4$	2-Nitrobenzoic acid		25	2.17
$C_7H_5NO_4$	3-Nitrobenzoic acid		25	3.46
$C_7H_5NO_4$	4-Nitrobenzoic acid		25	3.43
$C_7H_5NO_4$	2,3-Pyridinedicarboxylic acid	1	25	2.43
		2	25	4.78
$C_7H_5NO_4$	2,4-Pyridinedicarboxylic acid	1	25	2.15
$C_7H_5NO_4$	2,6-Pyridinedicarboxylic acid	1	25	2.16
		2	25	4.76
$C_7H_5NO_4$	3,5-Pyridinedicarboxylic acid	1	25	2.80
$C_7H_6ClN_3O_4S_2$	Chlorothiazide	1		6.85
		2		9.45
$C_7H_6F_3N$	3-(Trifluoromethyl)aniline		25	3.49
$C_7H_6F_3N$	4-(Trifluoromethyl)aniline		25	2.45
$C_7H_6N_2$	1*H*-Benzimidazole		25	5.53
$C_7H_6N_2$	2-Aminobenzonitrile		25	0.77
$C_7H_6N_2$	3-Aminobenzonitrile		25	2.75
$C_7H_6N_2$	4-Aminobenzonitrile		25	1.74
C_7H_6O	Benzaldehyde		25	14.90
$C_7H_6O_2$	Benzoic acid		25	4.204
$C_7H_6O_2$	Salicylaldehyde		25	8.37
$C_7H_6O_2$	3-Hydroxybenzaldehyde		25	8.98
$C_7H_6O_2$	4-Hydroxybenzaldehyde		25	7.61
$C_7H_6O_3$	2-Hydroxybenzoic acid	1	20	2.98
		2	20	13.6
$C_7H_6O_3$	3-Hydroxybenzoic acid	1	25	4.08
		2	19	9.92
$C_7H_6O_3$	4-Hydroxybenzoic acid	1	25	4.57

Mol. Form.	Name	Step	t/°C	pK_a
		2	25	9.46
$C_7H_6O_4$	2,4-Dihydroxybenzoic acid	1	25	3.11
		2	25	8.55
		3	25	14.0
$C_7H_6O_4$	2,5-Dihydroxybenzoic acid	1	25	2.97
$C_7H_6O_4$	3,4-Dihydroxybenzoic acid	1	25	4.48
		2	25	8.83
		3	25	12.6
$C_7H_6O_4$	3,5-Dihydroxybenzoic acid	1	25	4.04
$C_7H_6O_5$	2,4,6-Trihydroxybenzoic acid		25	1.68
$C_7H_6O_5$	3,4,5-Trihydroxybenzoic acid		25	4.41
C_7H_7NO	Benzamide		25	˜13
$C_7H_7NO_2$	Aniline-2-carboxylic acid	1	25	2.17
		2	25	4.85
$C_7H_7NO_2$	Aniline-3-carboxylic acid	1	25	3.07
		2	25	4.79
$C_7H_7NO_2$	Aniline-4-carboxylic acid	1	25	2.50
		2	25	4.87
$C_7H_7NO_3$	4-Amino-2-hydroxybenzoic acid			3.25
$C_7H_8ClN_3O_4S_2$	Hydrochlorothiazide	1		7.9
		2		9.2
$C_7H_8N_4O_2$	Theobromine		18	7.89
$C_7H_8N_4O_2$	Theophylline	1	25	8.77
C_7H_8O	*o*-Cresol		25	10.29
C_7H_8O	*m*-Cresol		25	10.09
C_7H_8O	*p*-Cresol		25	10.26
C_7H_8OS	4-(Methylthio)phenol		25	9.53
$C_7H_8O_2$	2-Methoxyphenol		25	9.98
$C_7H_8O_2$	3-Methoxyphenol		25	9.65
$C_7H_8O_2$	4-Methoxyphenol		25	10.21
C_7H_8S	Benzenemethanethiol		25	9.43
C_7H_9N	Benzylamine		25	9.34
C_7H_9N	2-Methylaniline		25	4.45
C_7H_9N	3-Methylaniline		25	4.71
C_7H_9N	4-Methylaniline		25	5.08
C_7H_9N	*N*-Methylaniline		25	4.85
C_7H_9N	2-Ethylpyridine		25	5.89
C_7H_9N	2,3-Dimethylpyridine		25	6.57
C_7H_9N	2,4-Dimethylpyridine		25	6.99
C_7H_9N	2,5-Dimethylpyridine		25	6.40
C_7H_9N	2,6-Dimethylpyridine		25	6.65
C_7H_9N	3,4-Dimethylpyridine		25	6.46
C_7H_9N	3,5-Dimethylpyridine		25	6.15
C_7H_9NO	2-Methoxyaniline		25	4.53
C_7H_9NO	3-Methoxyaniline		25	4.20
C_7H_9NO	4-Methoxyaniline		25	5.36
C_7H_9NS	2-(Methylthio)aniline		25	3.45
C_7H_9NS	4-(Methylthio)aniline		25	4.35
$C_7H_9N_5$	2-Dimethylaminopurine	1	20	4.00
		2	20	10.24
$C_7H_{11}N_3O_2$	*L*-1-Methylhistidine	1	25	1.69
		2	25	6.48
		3	25	8.85
$C_7H_{11}N_3O_2$	*L*-3-Methylhistidine	1	25	1.92
		2	25	6.56
		3	25	8.73

Mol. Form.	Name	Step	t/°C	pK_a
$C_7H_{12}O_2$	Cyclohexanecarboxylic acid		25	4.91
$C_7H_{12}O_4$	Heptanedioic acid	1	25	4.71
		2	25	5.58
$C_7H_{12}O_4$	Butylpropanedioic acid	1	5	2.96
$C_7H_{13}NO_4$	α-Ethylglutamic acid	1	25	3.846
		2	25	7.838
$C_7H_{14}O_2$	Heptanoic acid		25	4.89
$C_7H_{14}O_6$	α-Methylglucoside		25	13.71
$C_7H_{15}N$	1-Ethylpiperidine		23	10.45
$C_7H_{15}N$	1,2-Dimethylpiperidine,(±)		25	10.22
$C_7H_{15}NO_3$	Carnitine		25	3.80
$C_7H_{17}N$	Heptylamine		25	10.67
$C_7H_{17}N$	2-Heptanamine		19	10.7
$C_8H_5NO_2$	3-Cyanobenzoic acid		25	3.60
$C_8H_5NO_2$	4-Cyanobenzoic acid		25	3.55
$C_8H_6N_2$	Cinnoline		20	2.37
$C_8H_6N_2$	Quinazoline		29	3.43
$C_8H_6N_2$	Quinoxaline		20	0.56
$C_8H_6N_2$	Phthalazine		20	3.47
$C_8H_6N_4O_5$	Nitrofurantoin			7.2
$C_8H_6O_3$	3-Formylbenzoic acid		25	3.84
$C_8H_6O_3$	4-Formylbenzoic acid		25	3.77
$C_8H_6O_4$	Phthalic acid	1	25	2.943
		2	25	5.432
$C_8H_6O_4$	Isophthalic acid	1	25	3.70
		2	25	4.60
$C_8H_6O_4$	Terephthalic acid	1	25	3.54
		2	25	4.34
$C_8H_7ClO_2$	2-Chlorobenzeneacetic acid		25	4.07
$C_8H_7ClO_2$	3-Chlorobenzeneacetic acid		25	4.14
$C_8H_7ClO_2$	4-Chlorobenzeneacetic acid		25	4.19
$C_8H_7ClO_3$	2-Chlorophenoxyacetic acid		25	3.05
$C_8H_7ClO_3$	3-Chlorophenoxyacetic acid		25	3.10
$C_8H_7NO_4$	2-Nitrobenzeneacetic acid		25	4.00
$C_8H_7NO_4$	3-Nitrobenzeneacetic acid		25	3.97
$C_8H_7NO_4$	4-Nitrobenzeneacetic acid		25	3.85
$C_8H_8F_3N_3O_4S_2$	Hydroflumethiazide	1		8.9
		2		9.7
$C_8H_8N_2$	2-Methyl-1*H*-benzimidazole		25	6.19
$C_8H_8O_2$	*o*-Toluic acid		25	3.91
$C_8H_8O_2$	*m*-Toluic acid		25	4.25
$C_8H_8O_2$	*p*-Toluic acid		25	4.37
$C_8H_8O_2$	Benzeneacetic acid		25	4.31
$C_8H_8O_2$	1-(2-Hydroxyphenyl)ethanone		25	10.06
$C_8H_8O_2$	1-(3-Hydroxyphenyl)ethanone		25	9.19
$C_8H_8O_2$	1-(4-Hydroxyphenyl)ethanone		25	8.05
$C_8H_8O_3$	2-Methoxybenzoic acid		25	4.08
$C_8H_8O_3$	3-Methoxybenzoic acid		25	4.10
$C_8H_8O_3$	4-Methoxybenzoic acid		25	4.50
$C_8H_8O_3$	Phenoxyacetic acid		25	3.17
$C_8H_8O_3$	Mandelic acid		25	3.37
$C_8H_8O_4$	2,5-Hydroxybenzeneacetic acid		25	4.40
C_8H_9NO	Acetanilide		25	0.5
$C_8H_9NO_2$	2-(Methylamino)benzoic acid		25	5.34
$C_8H_9NO_2$	3-(Methylamino)benzoic acid		25	5.10
$C_8H_9NO_2$	4-(Methylamino)benzoic acid		25	5.04
$C_8H_9NO_2$	*N*-Phenylglycine	1	25	1.83
		2		4.39
$C_8H_{10}BrN$	4-Bromo-*N*,*N*-dimethylaniline		25	4.23
$C_8H_{10}ClN$	3-Chloro-*N*,*N*-dimethylaniline		20	3.83
$C_8H_{10}ClN$	4-Chloro-*N*,*N*-dimethylaniline		20	4.39
$C_8H_{10}N_2O_2$	*N*,*N*-Dimethyl-3-nitroaniline		25	2.62
$C_8H_{11}N$	*N*-Ethylaniline		25	5.12
$C_8H_{11}N$	*N*,*N*-Dimethylaniline		25	5.07
$C_8H_{11}N$	2,6-Dimethylaniline		25	3.89
$C_8H_{11}N$	Benzeneethanamine		25	9.83
$C_8H_{11}N$	2,4,6-Trimethylpyridine		25	7.43
$C_8H_{11}NO$	2-Ethoxyaniline		28	4.43
$C_8H_{11}NO$	3-Ethoxyaniline		25	4.18
$C_8H_{11}NO$	4-Ethoxyaniline		28	5.20
$C_8H_{11}NO$	4-(2-Aminoethyl)phenol	1	25	9.74
		2	25	10.52
$C_8H_{11}NO$	2-(2-Methoxyethyl)pyridine			5.5
$C_8H_{11}NO_2$	Dopamine	1	25	8.9
		2	25	10.6
$C_8H_{11}NO_3$	Norepinephrine	1	25	8.64
		2	25	9.70
$C_8H_{11}N_3O_6$	6-Azauridine			6.70
$C_8H_{11}N_5$	Phenylbiguanide	1		10.76
		2		2.13
$C_8H_{12}N_2O_3$	Barbital		25	7.43
$C_8H_{12}O_2$	5,5-Dimethyl-1,3-cyclohexanedione		25	5.15
$C_8H_{13}NO_2$	Arecoline			6.84
$C_8H_{14}O_2S_2$	Thioctic acid			5.4
$C_8H_{14}O_4$	Octanedioic acid	1	25	4.52
$C_8H_{15}NO$	Tropine		15	3.80
$C_8H_{15}NO$	Pseudotropine		15	3.80
$C_8H_{16}N_2O_3$	*N*-Glycylleucine		25	3.18
$C_8H_{16}N_2O_3$	*N*-Leucylglycine	1	25	3.25
		2	25	8.2
$C_8H_{16}N_2O_4S_2$	Homocystine	1	25	1.59
		2	25	2.54
		3	25	8.52
		4	25	9.44
$C_8H_{16}O_2$	Octanoic acid		25	4.89
$C_8H_{16}O_2$	2-Propylpentanoic acid			4.6
$C_8H_{17}N$	2-Propylpiperidine,(*S*)			10.9
$C_8H_{17}N$	2,2,4-Trimethylpiperidine		30	11.04
$C_8H_{17}NO$	*trans*-6-Propyl-3-piperidinol,(3*S*)			10.3
$C_8H_{19}N$	Octylamine		25	10.65
$C_8H_{19}N$	*N*-Methyl-2-heptanamine		17	10.99
$C_8H_{19}N$	Dibutylamine		21	11.25
$C_8H_{20}N_2$	1,8-Octanediamine	1	20	11.00
		2	20	10.1
C_9H_6BrN	3-Bromoquinoline		25	2.69
$C_9H_7ClO_2$	*trans*-*o*-Chlorocinnamic acid		25	4.23

Mol. Form.	Name	Step	t/°C	pK_a
$C_9H_7ClO_2$	*trans*-*m*-Chlorocinnamic acid		25	4.29
$C_9H_7ClO_2$	*trans*-*p*-Chlorocinnamic acid		25	4.41
C_9H_7N	Quinoline		20	4.90
C_9H_7N	Isoquinoline		20	5.40
C_9H_7NO	2-Quinolinol	1	20	-0.31
		2	20	11.76
C_9H_7NO	3-Quinolinol	1	20	4.28
		2	20	8.08
C_9H_7NO	4-Quinolinol	1	20	2.23
		2	20	11.28
C_9H_7NO	6-Quinolinol	1	20	5.15
		2	20	8.90
C_9H_7NO	8-Quinolinol	1	25	4.91
		2	25	9.81
C_9H_7NO	7-Isoquinolinol	1	20	5.68
		2	20	8.90
$C_9H_7NO_3$	2-Cyanophenoxyacetic acid		25	2.98
$C_9H_7NO_3$	3-Cyanophenoxyacetic acid		25	3.03
$C_9H_7NO_3$	4-Cyanophenoxyacetic acid		25	2.93
$C_9H_7N_7O_2S$	Azathioprine			8.2
$C_9H_8N_2$	2-Quinolinamine		20	7.34
$C_9H_8N_2$	3-Quinolinamine		20	4.91
$C_9H_8N_2$	4-Quinolinamine		20	9.17
$C_9H_8N_2$	1-Isoquinolinamine		20	7.62
$C_9H_8N_2$	3-Isoquinolinamine		20	5.05
$C_9H_8O_2$	*cis*-Cinnamic acid		25	3.88
$C_9H_8O_2$	*trans*-Cinnamic acid		25	4.44
$C_9H_8O_2$	α-Methylenebenezene-acetic acid			4.35
$C_9H_8O_4$	2-(Acetyloxy)benzoic acid		25	3.48
$C_9H_9Br_2NO_3$	3,5-Dibromo-*L*-tyrosine	1		2.17
		2		6.45
		3		7.60
$C_9H_9ClO_2$	3-(2-Chlorophenyl)-propanoic acid		25	4.58
$C_9H_9ClO_2$	3-(3-Chlorophenyl)-propanoic acid		25	4.59
$C_9H_9ClO_2$	3-(4-Chlorophenyl)-propanoic acid		25	4.61
$C_9H_9I_2NO_3$	*L*-3,5-Diiodotyrosine	1	25	2.12
		2	25	5.32
		3	25	9.48
$C_9H_9NO_3$	*N*-Benzoylglycine		25	3.62
$C_9H_9NO_4$	3-(2-Nitrophenyl)-propanoic acid		25	4.50
$C_9H_9NO_4$	3-(4-Nitrophenyl)-propanoic acid		25	4.47
$C_9H_9N_3O_2$	Carbendazim			4.48
$C_9H_9N_3O_2S_2$	Sulfathiazole			7.2
$C_9H_{10}INO_3$	*L*-3-Iodotyrosine	1	25	2.2
		2	25	8.7
		3	25	9.1
$C_9H_{10}N_2$	2-Ethylbenzimidazole		25	6.18
$C_9H_{10}O_2$	3,5-Dimethylbenzoic acid		25	4.32
$C_9H_{10}O_2$	Benzenepropanoic acid		25	4.66
$C_9H_{10}O_2$	α-Methylbenzeneacetic acid		25	4.64
$C_9H_{10}O_3$	α-Hydroxy-α-methyl-benezeneacetic acid		25	3.47
$C_9H_{11}Cl_2N_3O_4S_2$	Methylclothiazide			9.4
$C_9H_{11}N$	*N*-Allylaniline		25	4.17
$C_9H_{11}N$	1-Indanamine		22	9.21
$C_9H_{11}NO_2$	4-(Dimethylamino)-benzoic acid	1		6.03
		2		11.49
$C_9H_{11}NO_2$	Ethyl 4-aminobenzoate			2.5
$C_9H_{11}NO_2$	*L*-Phenylalanine	1	25	2.20
		2	25	9.31
$C_9H_{11}NO_3$	*L*-Tyrosine	1	25	2.20
		2	25	9.11
		3	25	10.1
$C_9H_{11}NO_4$	Levodopa	1	25	2.32
		2	25	8.72
		3	25	9.96
		4	25	11.79
$C_9H_{12}N_2O_2$	Tyrosineamide		25	7.33
$C_9H_{13}N$	*N*-Isopropylaniline		25	5.77
$C_9H_{13}NO_3$	Epinephrine	1	25	8.66
		2	25	9.95
$C_9H_{13}N_2O_9P$	5'-Uridylic acid	1		6.4
		2		9.5
$C_9H_{13}N_3O_5$	Cytidine	1		4.22
		2		12.5
$C_9H_{14}ClNO$	Phenylpropanolamine hydrochloride			9.44
$C_9H_{14}N_2O_3$	Metharbital			8.45
$C_9H_{14}N_3O_8P$	3'-Cytidylic acid	1		0.8
		2		4.28
		3		6.0
$C_9H_{14}N_4O_3$	Carnosine	1	20	2.73
		2	20	6.87
		3	20	9.73
$C_9H_{15}NO_3S$	Captopril	1		3.7
		2		9.8
$C_9H_{15}N_5O$	Minoxidil			4.61
$C_9H_{16}O_4$	Nonanedioic acid	1	25	4.53
		2	25	5.33
$C_9H_{18}O_2$	Nonanoic acid		25	4.96
$C_9H_{19}N$	*N*-Butylpiperidine		23	10.47
$C_9H_{19}N$	2,2,6,6-Tetramethyl-piperidine		25	11.07
$C_9H_{21}N$	Nonylamine		25	10.64
$C_{10}H_7NO_2$	8-Quinolinecarboxylic acid		25	1.82
$C_{10}H_8O$	1-Naphthol		25	9.39
$C_{10}H_8O$	2-Naphthol		25	9.63
$C_{10}H_9N$	1-Naphthylamine		25	3.92
$C_{10}H_9N$	2-Naphthylamine		25	4.16
$C_{10}H_9N$	2-Methylquinoline		20	5.83
$C_{10}H_9N$	4-Methylquinoline		20	5.67
$C_{10}H_9N$	5-Methylquinoline		20	5.20
$C_{10}H_9NO$	5-Amino-1-naphthol		25	3.97
$C_{10}H_9NO$	6-Methoxyquinoline		20	5.03
$C_{10}H_9NO_2$	1H-Indole-3-acetic acid			4.75
$C_{10}H_{10}O_2$	*o*-Methylcinnamic acid		25	4.50
$C_{10}H_{10}O_2$	*m*-Methylcinnamic acid		25	4.44
$C_{10}H_{10}O_2$	*p*-Methylcinnamic acid		25	4.56
$C_{10}H_{12}N_2$	Tryptamine		25	10.2
$C_{10}H_{12}N_2O$	5-Hydroxytryptamine	1	25	9.8
		2	25	11.1

Mol. Form.	Name	Step	t/°C	pK_a
$C_{10}H_{12}N_2O_5$	Dinoseb			4.62
$C_{10}H_{12}N_4O_3$	Dideoxyinosine			9.12
$C_{10}H_{12}O$	5,6,7,8-Tetrahydro-2-naphthalenol		25	10.48
$C_{10}H_{12}O_2$	Benzenebutanoic acid		25	4.76
$C_{10}H_{12}O_5$	Propyl 3,4,5-trihydroxybenzoate			8.11
$C_{10}H_{13}N_5O_4$	Adenosine	1	25	3.6
		2	25	12.4
$C_{10}H_{14}N_2$	*L*-Nicotine	1		8.02
		2		3.12
$C_{10}H_{14}N_5O_7P$	5'-Adenylic acid	1		3.8
		2		6.2
$C_{10}H_{14}O$	2-*tert*-Butylphenol		25	10.62
$C_{10}H_{14}O$	3-*tert*-Butylphenol		25	10.12
$C_{10}H_{14}O$	4-*tert*-Butylphenol		25	10.23
$C_{10}H_{15}N$	*N*-*tert*-Butylaniline		25	7.00
$C_{10}H_{15}N$	*N*,*N*-Diethylaniline		25	6.57
$C_{10}H_{15}NO$	*d*-Ephedrine		10	10.139
$C_{10}H_{15}NO$	*l*-Ephedrine		10	9.958
$C_{10}H_{17}N_3O_6S$	*l*-Glutathione	1	25	2.12
		2	25	3.59
		3	25	8.75
		4	25	9.65
$C_{10}H_{18}N_4O_5$	*L*-Argininosuccinic acid	1	25	1.62
		2	25	2.70
		3	25	4.26
		4	25	9.58
$C_{10}H_{18}O_4$	Sebacic acid	1		4.59
		2		5.59
$C_{10}H_{19}N$	Bornylamine		25	10.17
$C_{10}H_{19}N$	Neobornylamine		25	10.01
$C_{10}H_{21}N$	Butylcyclohexylamine		25	11.23
$C_{10}H_{21}N$	1,2,2,6,6-Pentamethylpiperidine		30	11.25
$C_{10}H_{23}N$	Decylamine		25	10.64
$C_{11}H_8N_2$	1*H*-Perimidine		20	6.35
$C_{11}H_8O_2$	1-Naphthalenecarboxylic acid		25	3.69
$C_{11}H_8O_2$	2-Naphthalenecarboxylic acid		25	4.16
$C_{11}H_{11}N$	Methyl-1-naphthylamine		27	3.67
$C_{11}H_{12}I_3NO_2$	Iopanoic acid			4.8
$C_{11}H_{12}N_2O_2$	*L*-Tryptophan	1	25	2.46
		2	25	9.41
$C_{11}H_{12}N_4O_3S$	Sulfamethoxypyridazine			6.7
$C_{11}H_{13}F_3N_2O_3S$	Mefluidide			4.6
$C_{11}H_{13}NO_3$	Hydrastinine			11.38
$C_{11}H_{13}N_3O_3S$	Sulfisoxazole			5
$C_{11}H_{14}N_2O$	Cytisine	1		6.11
		2		13.08
$C_{11}H_{14}O_2$	2-*tert*-Butylbenzoic acid		25	3.54
$C_{11}H_{14}O_2$	3-*tert*-Butylbenzoic acid		25	4.20
$C_{11}H_{14}O_2$	4-*tert*-Butylbenzoic acid		25	4.38
$C_{11}H_{16}N_2O_2$	Pilocarpine	1	25	1.6
		2	25	6.9
$C_{11}H_{16}N_4O_4$	Pentostatin			5.2
$C_{11}H_{17}N$	*N*,*N*-Diethyl-2-methylaniline		25	7.24
$C_{11}H_{17}NO_3$	Isoproterenol			8.64
$C_{11}H_{17}N_3O_8$	Tetrodotoxin			8.76
$C_{11}H_{18}ClNO_3$	Methoxamine hydrochloride		25	9.2
$C_{11}H_{18}N_2O_3$	Amobarbital		25	8.0
$C_{11}H_{25}N$	Undecylamine		25	10.63
$C_{11}H_{26}NO_2PS$	Methylphosphonothioic acid *S*[2-[bis(1-isopropyl)amino]-ethyl],*O*-ethylester			7.9
$C_{12}H_6Cl_4O_2S$	Bithionol	1		4.82
		2		10.50
$C_{12}H_8N_2$	1,10-Phenanthroline		25	4.84
$C_{12}H_8N_2$	Phenazine		20	1.20
$C_{12}H_{10}O$	2-Hydroxybiphenyl		25	10.01
$C_{12}H_{10}O$	3-Hydroxybiphenyl		25	9.64
$C_{12}H_{10}O$	4-Hydroxybiphenyl		25	9.55
$C_{12}H_{11}N$	Diphenylamine		25	0.79
$C_{12}H_{11}N$	2-Aminobiphenyl		25	3.83
$C_{12}H_{11}N$	3-Aminobiphenyl		18	4.25
$C_{12}H_{11}N$	4-Aminobiphenyl		18	4.35
$C_{12}H_{11}N$	2-Benzylpyridine		25	5.13
$C_{12}H_{11}N_3$	4-Aminoazobenzene		25	2.82
$C_{12}H_{12}N_2$	*p*-Benzidine	1	20	4.65
		2	20	3.43
$C_{12}H_{12}N_2O_3$	Phenobarbital	1		7.3
		2		11.8
$C_{12}H_{13}I_3N_2O_3$	Iocetamic acid			4
$C_{12}H_{13}N$	*N*,*N*-Dimethyl-1-naphthylamine		25	4.83
$C_{12}H_{13}N$	*N*,*N*-Dimethyl-2-naphthylamine		25	4.566
$C_{12}H_{14}N_4O_2S$	Sulfamethazine	1		7.4
		2		2.65
$C_{12}H_{14}N_4O_3S$	Sulfacytine			6.9
$C_{12}H_{17}N_3O_4$	Agaritine	1		3.4
		2		8.86
$C_{12}H_{20}N_2O_2$	Aspergillic acid			5.5
$C_{12}H_{21}N_5O_2S_2$	Nizatidine	1		2.1
		2		6.8
$C_{12}H_{22}O_{11}$	Sucrose		25	12.7
$C_{12}H_{22}O_{11}$	α-Maltose		21	12.05
$C_{12}H_{23}N$	Dicyclohexylamine			10.4
$C_{12}H_{27}N$	Dodecylamine		25	10.63
$C_{13}H_9N$	Acridine		20	5.58
$C_{13}H_9N$	Phenanthridine		20	5.58
$C_{13}H_{10}N_2$	9-Acridinamine		20	9.99
$C_{13}H_{10}N_2$	2-Phenylbenzimidazole	1	25	5.23
		2	25	11.91
$C_{13}H_{10}O_2$	2-Phenylbenzoic acid		25	3.46
$C_{13}H_{10}O_3$	2-Phenoxybenzoic acid		25	3.53
$C_{13}H_{10}O_3$	3-Phenoxybenzoic acid		25	3.95
$C_{13}H_{10}O_3$	4-Phenoxybenzoic acid		25	4.57
$C_{13}H_{11}N_3$	3,6-Acridinediamine		20	9.65
$C_{13}H_{12}Cl_2O_4$	Ethacrynic acid			3.50
$C_{13}H_{12}N_2O$	Harmine			7.70
$C_{13}H_{12}N_2O_3S$	Sulfabenzamide		25	4.57
$C_{13}H_{13}N$	4-Benzylaniline		25	2.17
$C_{13}H_{14}N_2O_{13}$	Harmaline			4.2
$C_{13}H_{15}N_3O_3$	Imazapyr	1		1.9
		2		3.6

Mol. Form.	Name	Step	t/°C	pK_a
$C_{13}H_{16}ClNO$	Ketamine			7.5
$C_{13}H_{19}NO_4S$	4-[(Dipropylamino)-sulfonyl]benzoic acid			5.8
$C_{13}H_{21}N$	2,6-Di-*tert*-butylpyridine			3.58
$C_{13}H_{29}N$	(Tridecyl)amine		25	10.63
$C_{14}H_{12}F_3NO_4S_2$	Perfluidone			2.5
$C_{14}H_{12}O_2$	α-Phenylbenzeneacetic acid		25	3.94
$C_{14}H_{12}O_3$	α-Hydroxy-α-phenyl-benzeneacetic acid		25	3.04
$C_{14}H_{18}N_4O_3$	Trimethoprim			6.6
$C_{14}H_{19}NO_2$	Methylphenidate			8.9
$C_{14}H_{21}N_3O_3S$	Tolazamide		25	3.6
$C_{14}H_{22}N_2O_3$	Atenolol			9.6
$C_{14}H_{31}N$	Tetradecylamine		25	10.62
$C_{15}H_{10}ClN_3O_3$	Clonazepam	1		1.5
		2		10.5
$C_{15}H_{11}I_4NO_4$	*L*-Thyroxine	1	25	2.2
		2	25	6.45
		3	25	10.1
$C_{15}H_{14}O_3$	Fenoprofen			7.3
$C_{15}H_{15}NO_2$	Mefenamic acid			4.2
$C_{15}H_{15}N_3O_2$	Methyl Red	1		2.5
		2		9.5
$C_{15}H_{17}ClN_4$	NeutralRed			6.7
$C_{15}H_{19}NO_2$	Tropacocaine		15	4.32
$C_{15}H_{19}N_3O_3$	Imazethapyr	1		2.1
		2		3.9
$C_{15}H_{21}N_3O_2$	Physostigmine	1		6.12
		2		12.24
$C_{15}H_{26}N_2$	Sparteine	1	20	2.24
		2	20	9.46
$C_{15}H_{33}N$	Pentadecylamine		25	10.61
$C_{16}H_{13}ClN_2O$	Valium			3.4
$C_{16}H_{14}ClN_3O$	Chlorodiazepoxide			4.8
$C_{16}H_{16}N_2O_2$	Lysergic acid	1		3.44
		2		7.68
$C_{16}H_{17}N_3O_4S$	Cephalexin	1		5.2
		2		7.3
$C_{16}H_{19}N_3O_4S$	Cephradine	1		2.63
		2		7.27
$C_{16}H_{22}N_2$	Lycodine	1		3.97
		2		8.08
$C_{16}H_{35}N$	Hexadecylamine		25	10.61
$C_{17}H_{17}NO_2$	Apomorphine	1		7.0
		2		8.92
$C_{17}H_{19}NO_3$	Piperine		18	12.22
$C_{17}H_{19}NO_3$	Morphine	1	25	8.21
		2	20	9.85
$C_{17}H_{20}N_4O_6$	Riboflavin	1		1.7
		2	25	9.69
$C_{17}H_{20}O_6$	Mycophenolic acid			4.5
$C_{17}H_{23}NO_3$	Hyoscyamine		21	9.7
$C_{17}H_{27}NO_4$	Nadolol			9.67
$C_{18}H_{19}ClN_4$	Clozapine	1		3.70
		2		7.60
$C_{18}H_{21}NO_3$	Codeine			8.21
$C_{18}H_{21}N_3O$	Dibenzepin			8.25
$C_{18}H_{32}O_2$	Linoleic acid			7.6
$C_{18}H_{33}ClN_2O_5S$	Clindamycin			7.6
$C_{18}H_{39}N$	Octadecylamine		25	10.60
$C_{19}H_{10}Br_4O_5S$	Bromophenol Blue			4.0
$C_{19}H_{14}O_5S$	Phenol Red			7.9
$C_{19}H_{16}ClNO_4$	Indomethacin			4.5
$C_{19}H_{17}N_3O_4S_2$	Cephaloridine			3.2
$C_{19}H_{20}N_2O_2$	Phenylbutazone			4.5
$C_{19}H_{21}N$	Protriptyline			8.2
$C_{19}H_{21}NO_3$	Thebaine		15	6.05
$C_{19}H_{22}N_2O$	Cinchonine	1		5.85
		2		9.92
$C_{19}H_{22}N_2O$	Cinchonidine	1		5.80
		2		10.03
$C_{19}H_{22}N_2O_2$	Cupreine			6.57
$C_{19}H_{22}O_6$	Gibberellic acid			4.0
$C_{19}H_{23}N_3O_2$	Ergometrinine			7.3
$C_{19}H_{23}N_3O_2$	Ergonovine			6.8
$C_{20}H_{14}O_4$	Phenolphthalein		25	9.7
$C_{20}H_{21}NO_4$	Papaverine			6.4
$C_{20}H_{23}N$	Amitriptyline			9.4
$C_{20}H_{23}N_7O_7$	Folinic acid	1		3.1
		2		4.8
		3		10.4
$C_{20}H_{24}N_2O_2$	Quinine	1	25	8.52
		2	25	4.13
$C_{20}H_{24}N_2O_2$	Quinidine	1	20	5.4
		2	20	10.0
$C_{20}H_{26}N_2O_2$	Hydroquinine			5.33
$C_{21}H_{14}Br_4O_5S$	Bromocresol Green			4.7
$C_{21}H_{16}Br_2O_5S$	Bromocresol Purple			6.3
$C_{21}H_{18}O_5S$	CresolRed			8.3
$C_{21}H_{21}NO_6$	Hydrastine			7.8
$C_{21}H_{22}N_2O_2$	Strychnine		25	8.26
$C_{21}H_{23}ClFNO_2$	Haloperidol			8.3
$C_{21}H_{31}NO_4$	Furethidine			7.48
$C_{21}H_{35}N_3O_7$	Lisinopril	1		2.5
		2		4.0
		3		6.7
		4		10.1
$C_{22}H_{18}O_4$	*o*-Cresolphthalein			9.4
$C_{22}H_{22}FN_3O_2$	Droperidol			7.64
$C_{22}H_{23}NO_7$	Noscapine			7.8
$C_{22}H_{25}NO_6$	Colchicine		20	12.36
$C_{22}H_{25}N_3O$	Benzpiperylon	1		6.73
		2		9.13
$C_{22}H_{33}NO_2$	Atisine			12.2
$C_{23}H_{26}N_2O_4$	Brucine	1		6.04
		2		11.07
$C_{24}H_{40}O_4$	Deoxycholic acid			6.58
$C_{24}H_{40}O_5$	Cholic acid			6.4
$C_{25}H_{29}I_2NO_3$	Amiodarone		25	6.56
$C_{25}H_{41}NO_9$	Aconine			9.52
$C_{26}H_{43}NO_6$	Glycocholic acid			4.4
$C_{26}H_{45}NO_7S$	Taurocholic acid			1.4
$C_{27}H_{28}Br_2O_5S$	Bromothymol Blue			7.0
$C_{27}H_{38}N_2O_4$	Verapamil			8.6
$C_{29}H_{32}O_{13}$	Etoposide			9.8
$C_{29}H_{40}N_2O_4$	Emetine	1		5.77
		2		6.64

Mol. Form.	Name	Step	t/°C	pK_a
$C_{30}H_{23}BrO_4$	Bromadiolone		21	4.04
$C_{30}H_{48}O_3$	Oleanolic acid			2.52
$C_{31}H_{36}N_2O_{11}$	Novobiocin	1		4.3
		2		9.1
$C_{32}H_{32}O_{13}S$	Teniposide			10.13
$C_{33}H_{40}N_2O_9$	Reserpine			6.6
$C_{34}H_{47}NO_{11}$	Aconitine			5.88
$C_{36}H_{51}NO_{11}$	Veratridine			9.54
$C_{37}H_{67}NO_{13}$	Erythromycin			8.8
$C_{43}H_{58}N_4O_{12}$	Rifampin	1		1.7
		2		7.9
$C_{45}H_{73}NO_{15}$	Solanine		15	6.66
$C_{46}H_{56}N_4O_{10}$	Vincristine			5.4
$C_{46}H_{58}N_4O_9$	Vinblastine	1		5.4
		2		7.4

CONCENTRATIVE PROPERTIES OF AQUEOUS SOLUTIONS: DENSITY, REFRACTIVE INDEX, FREEZING POINT DEPRESSION, AND VISCOSITY

This table gives properties of aqueous solutions of 66 substances as a function of concentration. All data refer to a temperature of 20°C. The properties are:

Mass %: Mass of solute divided by total mass of solution, expressed as percent.
m Molality (moles of solute per kg of water).
c Molarity (moles of solute per liter of solution).
ρ Density of solution in g/cm^3.
n Index of refraction, relative to air, at a wavelength of 589 nm (sodium D line); the index of pure water at 20°C is 1.3330.
Δ Freezing point depression in °C relative to pure water.
η Absolute (dynamic) viscosity in mPa s (equal to centipoise, cP); the viscosity of pure water at 20°C is 1.002 mPa s.

Density data for aqueous solutions over a wider range of temperatures and pressures (and for other compounds) may be found in Reference 2. Solutes are listed in the following order:

Acetic acid	Lithium chloride	2-Propanol
Acetone	Magnesium chloride	Silver nitrate
Ammonia	Magnesium sulfate	Sodium acetate
Ammonium chloride	Maltose	Sodium bicarbonate
Ammonium sulfate	Manganese(II) sulfate	Sodium bromide
Barium chloride	D-Mannitol	Sodium carbonate
Calcium chloride	Methanol	Sodium chloride
Cesium chloride	Nitric acid	Sodium citrate
Citric acid	Oxalic acid	Sodium hydroxide
Copper sulfate	Phosphoric acid	Sodium nitrate
Disodium ethylenediamine tetraacetate (EDTA sodium)	Potassium bicarbonate	Sodium phosphate
	Potassium bromide	Sodium hydrogen phosphate
Ethanol	Potassium carbonate	Sodium dihydrogen phosphate
Ethylene glycol	Potassium chloride	Sodium sulfate
Ferric chloride	Potassium hydroxide	Sodium thiosulfate
Formic acid	Potassium iodide	Strontium chloride
D-Fructose	Potassium nitrate	Sucrose
D-Glucose	Potassium permanganate	Sulfuric acid
Glycerol	Potassium hydrogen phosphate	Trichloroacetic acid
Hydrochloric acid	Potassium dihydrogen phosphate	Tris(hydroxymethyl)methylamine
Lactic acid	Potassium sulfate	Urea
Lactose	1-Propanol	Zinc sulfate

REFERENCES

1. Wolf, A. V., Aqueous Solutions and Body Fluids, Hoeber, 1966.
2. Söhnel, O., and Novotny, P., *Densities of Aqueous Solutions of Inorganic Substances*, Elsevier, Amsterdam, 1985.

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
Acetic acid	0.5	0.084	0.083	0.9989	1.3334	0.16	1.012
CH_3COOH	1.0	0.168	0.166	0.9996	1.3337	0.32	1.022
	2.0	0.340	0.333	1.0011	1.3345	0.63	1.042
	3.0	0.515	0.501	1.0025	1.3352	0.94	1.063
	4.0	0.694	0.669	1.0038	1.3359	1.26	1.084
	5.0	0.876	0.837	1.0052	1.3366	1.58	1.105
	6.0	1.063	1.006	1.0066	1.3373	1.90	1.125
	7.0	1.253	1.175	1.0080	1.3381	2.23	1.143
	8.0	1.448	1.345	1.0093	1.3388	2.56	1.162
	9.0	1.647	1.515	1.0107	1.3395	2.89	1.186
	10.0	1.850	1.685	1.0121	1.3402	3.23	1.210
	12.0	2.271	2.028	1.0147	1.3416	3.91	1.253
	14.0	2.711	2.372	1.0174	1.3430	4.61	1.298
	16.0	3.172	2.718	1.0200	1.3444	5.33	1.341
	18.0	3.655	3.065	1.0225	1.3458	6.06	1.380
	20.0	4.163	3.414	1.0250	1.3472	6.81	1.431

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	22.0	4.697	3.764	1.0275	1.3485	7.57	1.478
	24.0	5.259	4.116	1.0299	1.3498	8.36	1.525
	26.0	5.851	4.470	1.0323	1.3512	9.17	1.572
	28.0	6.476	4.824	1.0346	1.3525	10.00	1.613
	30.0	7.137	5.180	1.0369	1.3537	10.84	1.669
	32.0	7.837	5.537	1.0391	1.3550	11.70	1.715
	34.0	8.579	5.896	1.0413	1.3562	12.55	1.762
	36.0	9.367	6.255	1.0434	1.3574	13.38	1.812
	38.0	10.207	6.615	1.0454	1.3586		1.852
	40.0	11.102	6.977	1.0474	1.3598		1.912
	50.0	16.653	8.794	1.0562	1.3653		2.158
	60.0	24.979	10.620	1.0629	1.3700		2.409
	70.0	38.857	12.441	1.0673	1.3738		2.629
	80.0	66.611	14.228	1.0680	1.3767		2.720
	90.0	149.875	15.953	1.0644	1.3771		2.386
	92.0	191.507	16.284	1.0629	1.3766		2.240
	94.0	260.894	16.602	1.0606	1.3759		2.036
	96.0	399.667	16.911	1.0578	1.3748		1.813
	98.0	815.987	17.198	1.0538	1.3734		1.535
	100.0		17.447	1.0477	1.3716		1.223
Acetone	0.5	0.087	0.086	0.9975	1.3334	0.16	1.013
$(CH_3)_2CO$	1.0	0.174	0.172	0.9968	1.3337	0.32	1.024
	2.0	0.351	0.343	0.9954	1.3344	0.65	1.047
	3.0	0.533	0.513	0.9940	1.3352	0.97	1.072
	4.0	0.717	0.684	0.9926	1.3359	1.30	1.099
	5.0	0.906	0.853	0.9912	1.3366	1.63	1.125
	6.0	1.099	1.023	0.9899	1.3373	1.96	1.150
	7.0	1.296	1.191	0.9886	1.3381	2.29	1.174
	8.0	1.497	1.360	0.9874	1.3388	2.62	1.198
	9.0	1.703	1.528	0.9861	1.3395	2.95	1.221
	10.0	1.913	1.696	0.9849	1.3402	3.29	1.244
Ammonia	0.5	0.295	0.292	0.9960	1.3332	0.55	1.009
NH_3	1.0	0.593	0.584	0.9938	1.3335	1.14	1.015
	2.0	1.198	1.162	0.9895	1.3339	2.32	1.029
	3.0	1.816	1.736	0.9853	1.3344	3.53	1.043
	4.0	2.447	2.304	0.9811	1.3349	4.78	1.057
	5.0	3.090	2.868	0.9770	1.3354	6.08	1.071
	6.0	3.748	3.428	0.9730	1.3359	7.43	1.085
	7.0	4.420	3.983	0.9690	1.3365	8.95	1.099
	8.0	5.106	4.533	0.9651	1.3370	10.34	1.113
	9.0	5.807	5.080	0.9613	1.3376	11.90	1.127
	10.0	6.524	5.622	0.9575	1.3381	13.55	1.141
	12.0	8.007	6.695	0.9502	1.3393	17.13	1.169
	14.0	9.558	7.753	0.9431	1.3404	21.13	1.195
	16.0	11.184	8.794	0.9361	1.3416	25.63	1.218
	18.0	12.889	9.823	0.9294	1.3428	30.70	1.237
	20.0	14.679	10.837	0.9228	1.3440	36.42	1.254
	22.0	16.561	11.838	0.9164	1.3453	43.36	1.268
	24.0	18.542	12.826	0.9102	1.3465	51.38	1.280
	26.0	20.630	13.801	0.9040	1.3477	60.77	1.288
	28.0	22.834	14.764	0.8980	1.3490	71.66	
	30.0	25.164	15.713	0.8920	1.3502	84.06	
Ammonium	0.5	0.094	0.093	0.9998	1.3340	0.32	0.999
chloride	1.0	0.189	0.187	1.0014	1.3349	0.64	0.996
NH_4Cl	2.0	0.382	0.376	1.0045	1.3369	1.27	0.992

Solute	Mass %	m/mol kg^{-1}	c/mol L^{-1}	ρ/g cm^{-3}	n	Δ/°C	η/mPa s
	3.0	0.578	0.565	1.0076	1.3388	1.91	0.988
	4.0	0.779	0.756	1.0107	1.3407	2.57	0.985
	5.0	0.984	0.948	1.0138	1.3426	3.25	0.982
	6.0	1.193	1.141	1.0168	1.3445	3.94	0.979
	7.0	1.407	1.335	1.0198	1.3464	4.66	0.976
	8.0	1.626	1.529	1.0227	1.3483	5.40	0.974
	9.0	1.849	1.726	1.0257	1.3502	6.16	0.972
	10.0	2.077	1.923	1.0286	1.3521	6.95	0.970
	12.0	2.549	2.320	1.0344	1.3559	8.60	0.969
	14.0	3.043	2.722	1.0401	1.3596		0.969
	16.0	3.561	3.128	1.0457	1.3634		0.971
	18.0	4.104	3.537	1.0512	1.3671		0.973
	20.0	4.674	3.951	1.0567	1.3708		0.978
	22.0	5.273	4.368	1.0621	1.3745		0.986
	24.0	5.903	4.789	1.0674	1.3782		0.996
Ammonium	0.5	0.038	0.038	1.0012	1.3338	0.17	1.008
sulfate	1.0	0.076	0.076	1.0042	1.3346	0.33	1.014
$(NH_4)_2SO_4$	2.0	0.154	0.153	1.0101	1.3363	0.63	1.027
	3.0	0.234	0.231	1.0160	1.3379	0.92	1.041
	4.0	0.315	0.309	1.0220	1.3395	1.21	1.057
	5.0	0.398	0.389	1.0279	1.3411	1.49	1.073
	6.0	0.483	0.469	1.0338	1.3428	1.77	1.090
	7.0	0.570	0.551	1.0397	1.3444	2.05	1.108
	8.0	0.658	0.633	1.0456	1.3460	2.33	1.127
	9.0	0.748	0.716	1.0515	1.3476	2.61	1.147
	10.0	0.841	0.800	1.0574	1.3492	2.89	1.168
	12.0	1.032	0.971	1.0691	1.3523	3.47	1.210
	14.0	1.232	1.145	1.0808	1.3555	4.07	1.256
	16.0	1.441	1.323	1.0924	1.3586	4.69	1.305
	18.0	1.661	1.504	1.1039	1.3616		1.359
	20.0	1.892	1.688	1.1154	1.3647		1.421
	22.0	2.134	1.876	1.1269	1.3677		1.490
	24.0	2.390	2.067	1.1383	1.3707		1.566
	26.0	2.659	2.262	1.1496	1.3737		1.650
	28.0	2.943	2.460	1.1609	1.3766		1.743
	30.0	3.243	2.661	1.1721	1.3795		1.847
	32.0	3.561	2.866	1.1833	1.3824		1.961
	34.0	3.898	3.073	1.1945	1.3853		2.086
	36.0	4.257	3.284	1.2056	1.3881		2.222
	38.0	4.638	3.499	1.2166	1.3909		2.371
	40.0	5.045	3.716	1.2277	1.3938		2.530
Barium	0.5	0.024	0.024	1.0026	1.3337	0.12	1.009
chloride	1.0	0.049	0.048	1.0070	1.3345	0.23	1.016
$BaCl_2$	2.0	0.098	0.098	1.0159	1.3360	0.46	1.026
	3.0	0.149	0.148	1.0249	1.3375	0.69	1.037
	4.0	0.200	0.199	1.0341	1.3391	0.93	1.049
	5.0	0.253	0.251	1.0434	1.3406	1.18	1.062
	6.0	0.307	0.303	1.0528	1.3422	1.44	1.075
	7.0	0.361	0.357	1.0624	1.3438	1.70	1.087
	8.0	0.418	0.412	1.0721	1.3454	1.98	1.101
	9.0	0.475	0.468	1.0820	1.3470	2.27	1.114
	10.0	0.534	0.524	1.0921	1.3487	2.58	1.129
	12.0	0.655	0.641	1.1128	1.3520	3.22	1.161
	14.0	0.782	0.763	1.1342	1.3555	3.92	1.195
	16.0	0.915	0.889	1.1564	1.3591	4.69	1.234

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	18.0	1.054	1.019	1.1793	1.3627		1.277
	20.0	1.201	1.156	1.2031	1.3664		1.325
	22.0	1.355	1.297	1.2277	1.3703		1.378
	24.0	1.517	1.444	1.2531	1.3741		1.437
	26.0	1.687	1.597	1.2793	1.3781		1.503
Calcium	0.5	0.045	0.045	1.0024	1.3342	0.22	1.015
chloride	1.0	0.091	0.091	1.0065	1.3354	0.44	1.028
$CaCl_2$	2.0	0.184	0.183	1.0148	1.3378	0.88	1.050
	3.0	0.279	0.277	1.0232	1.3402	1.33	1.078
	4.0	0.375	0.372	1.0316	1.3426	1.82	1.110
	5.0	0.474	0.469	1.0401	1.3451	2.35	1.143
	6.0	0.575	0.567	1.0486	1.3475	2.93	1.175
	7.0	0.678	0.667	1.0572	1.3500	3.57	1.208
	8.0	0.784	0.768	1.0659	1.3525	4.28	1.242
	9.0	0.891	0.872	1.0747	1.3549	5.04	1.279
	10.0	1.001	0.976	1.0835	1.3575	5.86	1.319
	12.0	1.229	1.191	1.1014	1.3625	7.70	1.408
	14.0	1.467	1.413	1.1198	1.3677	9.83	1.508
	16.0	1.716	1.641	1.1386	1.3730	12.28	1.625
	18.0	1.978	1.878	1.1579	1.3784	15.11	1.764
	20.0	2.253	2.122	1.1775	1.3839	18.30	1.930
	22.0	2.541	2.374	1.1976	1.3895	21.70	2.127
	24.0	2.845	2.634	1.2180	1.3951	25.30	2.356
	26.0	3.166	2.902	1.2388	1.4008	29.70	2.645
	28.0	3.504	3.179	1.2600	1.4066	34.70	3.000
	30.0	3.862	3.464	1.2816	1.4124	41.00	3.467
	32.0	4.240	3.759	1.3036	1.4183	49.70	4.035
	34.0	4.642	4.062	1.3260	1.4242		4.820
	36.0	5.068	4.375	1.3488	1.4301		5.807
	38.0	5.522	4.698	1.3720	1.4361		7.321
	40.0	6.007	5.030	1.3957	1.4420		8.997
Cesium	0.5	0.030	0.030	1.0020	1.3334	0.10	1.000
chloride	1.0	0.060	0.060	1.0058	1.3337	0.20	0.997
CsCl	2.0	0.121	0.120	1.0135	1.3345	0.40	0.992
	3.0	0.184	0.182	1.0214	1.3353	0.61	0.988
	4.0	0.247	0.245	1.0293	1.3361	0.81	0.984
	5.0	0.313	0.308	1.0374	1.3369	1.02	0.980
	6.0	0.379	0.373	1.0456	1.3377	1.22	0.977
	7.0	0.447	0.438	1.0540	1.3386	1.43	0.974
	8.0	0.516	0.505	1.0625	1.3394	1.64	0.971
	9.0	0.587	0.573	1.0711	1.3403	1.85	0.969
	10.0	0.660	0.641	1.0798	1.3412	2.06	0.966
	12.0	0.810	0.782	1.0978	1.3430	2.51	0.961
	14.0	0.967	0.928	1.1163	1.3448	2.97	0.955
	16.0	1.131	1.079	1.1355	1.3468	3.46	0.950
	18.0	1.304	1.235	1.1552	1.3487	3.96	0.945
	20.0	1.485	1.397	1.1756	1.3507	4.49	0.939
	22.0	1.675	1.564	1.1967	1.3528		0.934
	24.0	1.876	1.737	1.2185	1.3550		0.930
	26.0	2.087	1.917	1.2411	1.3572		0.926
	28.0	2.310	2.103	1.2644	1.3594		0.924
	30.0	2.546	2.296	1.2885	1.3617		0.922
	32.0	2.795	2.497	1.3135	1.3641		0.922
	34.0	3.060	2.705	1.3393	1.3666		0.924
	36.0	3.341	2.921	1.3661	1.3691		0.926

Solute	Mass %	*m*/mol kg⁻¹	*c*/mol L⁻¹	ρ/g cm⁻³	*n*	Δ/°C	η/mPa s
	38.0	3.640	3.146	1.3938	1.3717		0.930
	40.0	3.960	3.380	1.4226	1.3744		0.934
	42.0	4.301	3.624	1.4525	1.3771		0.940
	44.0	4.667	3.877	1.4835	1.3800		0.947
	46.0	5.060	4.142	1.5158	1.3829		0.956
	48.0	5.483	4.418	1.5495	1.3860		0.967
	50.0	5.940	4.706	1.5846	1.3892		0.981
	60.0	8.910	6.368	1.7868	1.4076		1.120
	64.0	10.560	7.163	1.8842	1.4167		1.238
Citric acid	0.5	0.026	0.026	1.0002	1.3336	0.05	1.013
$(HO)C(COOH)_3$	1.0	0.053	0.052	1.0022	1.3343	0.11	1.024
	2.0	0.106	0.105	1.0063	1.3356	0.21	1.048
	3.0	0.161	0.158	1.0105	1.3368	0.32	1.073
	4.0	0.217	0.211	1.0147	1.3381	0.43	1.098
	5.0	0.274	0.265	1.0189	1.3394	0.54	1.125
	6.0	0.332	0.320	1.0232	1.3407	0.65	1.153
	7.0	0.392	0.374	1.0274	1.3420	0.76	1.183
	8.0	0.453	0.430	1.0316	1.3433	0.88	1.214
	9.0	0.515	0.485	1.0359	1.3446	1.00	1.247
	10.0	0.578	0.541	1.0402	1.3459	1.12	1.283
	12.0	0.710	0.655	1.0490	1.3486	1.38	1.357
	14.0	0.847	0.771	1.0580	1.3514	1.66	1.436
	16.0	0.991	0.889	1.0672	1.3541	1.95	1.525
	18.0	1.143	1.008	1.0764	1.3569	2.26	1.625
	20.0	1.301	1.130	1.0858	1.3598	2.57	1.740
	22.0	1.468	1.254	1.0953	1.3626	2.88	1.872
	24.0	1.644	1.380	1.1049	1.3655	3.21	2.017
	26.0	1.829	1.508	1.1147	1.3684	3.55	2.178
	28.0	2.024	1.639	1.1246	1.3714	3.89	2.356
	30.0	2.231	1.772	1.1346	1.3744	4.25	2.549
Copper	0.5	0.031	0.031	1.0033	1.3339	0.08	1.017
sulfate	1.0	0.063	0.063	1.0085	1.3348	0.14	1.036
$CuSO_4$	2.0	0.128	0.128	1.0190	1.3367	0.26	1.084
	3.0	0.194	0.194	1.0296	1.3386	0.37	1.129
	4.0	0.261	0.261	1.0403	1.3405	0.48	1.173
	5.0	0.330	0.329	1.0511	1.3424	0.59	1.221
	6.0	0.400	0.399	1.0620	1.3443	0.70	1.276
	7.0	0.472	0.471	1.0730	1.3462	0.82	1.336
	8.0	0.545	0.543	1.0842	1.3481	0.93	1.400
	9.0	0.620	0.618	1.0955	1.3501	1.05	1.469
	10.0	0.696	0.694	1.1070	1.3520	1.18	1.543
	12.0	0.854	0.850	1.1304	1.3560	1.45	1.701
	14.0	1.020	1.013	1.1545	1.3601	1.75	1.889
	16.0	1.193	1.182	1.1796	1.3644		2.136
	18.0	1.375	1.360	1.2059	1.3689		2.449
Disodium	0.5	0.015	0.015	1.0009	1.3339	0.07	1.017
ethylenediamine	1.0	0.030	0.030	1.0036	1.3348	0.14	1.032
tetraacetate	1.5	0.045	0.045	1.0062	1.3356	0.21	1.046
(EDTA sodium)	2.0	0.061	0.060	1.0089	1.3365	0.27	1.062
$Na_2C_{10}H_{14}N_2O_8$	2.5	0.076	0.075	1.0115	1.3374	0.33	1.077
	3.0	0.092	0.090	1.0142	1.3383	0.40	1.093
	3.5	0.108	0.106	1.0169	1.3392	0.46	1.109
	4.0	0.124	0.121	1.0196	1.3400	0.52	1.125
	4.5	0.140	0.137	1.0223	1.3409	0.58	1.142

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	5.0	0.157	0.152	1.0250	1.3418	0.65	1.160
	5.5	0.173	0.168	1.0277	1.3427	0.71	1.178
	6.0	0.190	0.184	1.0305	1.3436	0.77	1.197
Ethanol	0.5	0.109	0.108	0.9973	1.3333	0.20	1.023
CH_3CH_2OH	1.0	0.219	0.216	0.9963	1.3336	0.40	1.046
	2.0	0.443	0.432	0.9945	1.3342	0.81	1.095
	3.0	0.671	0.646	0.9927	1.3348	1.23	1.140
	4.0	0.904	0.860	0.9910	1.3354	1.65	1.183
	5.0	1.142	1.074	0.9893	1.3360	2.09	1.228
	6.0	1.385	1.286	0.9878	1.3367	2.54	1.279
	7.0	1.634	1.498	0.9862	1.3374	2.99	1.331
	8.0	1.887	1.710	0.9847	1.3381	3.47	1.385
	9.0	2.147	1.921	0.9833	1.3388	3.96	1.442
	10.0	2.412	2.131	0.9819	1.3395	4.47	1.501
	12.0	2.960	2.551	0.9792	1.3410	5.56	1.627
	14.0	3.534	2.967	0.9765	1.3425	6.73	1.761
	16.0	4.134	3.382	0.9739	1.3440	8.01	1.890
	18.0	4.765	3.795	0.9713	1.3455	9.40	2.019
	20.0	5.427	4.205	0.9687	1.3469	10.92	2.142
	22.0	6.122	4.613	0.9660	1.3484	12.60	2.259
	24.0	6.855	5.018	0.9632	1.3498	14.47	2.370
	26.0	7.626	5.419	0.9602	1.3511	16.41	2.476
	28.0	8.441	5.817	0.9571	1.3524	18.43	2.581
	30.0	9.303	6.212	0.9539	1.3535	20.47	2.667
	32.0	10.215	6.601	0.9504	1.3546	22.44	2.726
	34.0	11.182	6.987	0.9468	1.3557	24.27	2.768
	36.0	12.210	7.370	0.9431	1.3566	25.98	2.803
	38.0	13.304	7.747	0.9392	1.3575	27.62	2.829
	40.0	14.471	8.120	0.9352	1.3583	29.26	2.846
	42.0	15.718	8.488	0.9311	1.3590	30.98	2.852
	44.0	17.055	8.853	0.9269	1.3598	32.68	2.850
	46.0	18.490	9.213	0.9227	1.3604	34.36	2.843
	48.0	20.036	9.568	0.9183	1.3610	36.04	2.832
	50.0	21.706	9.919	0.9139	1.3616	37.67	2.813
	60.0	32.559	11.605	0.8911	1.3638	44.93	2.547
	70.0	50.648	13.183	0.8676	1.3652		2.214
	80.0	86.824	14.649	0.8436	1.3658		1.881
	90.0	195.355	15.980	0.8180	1.3650		1.542
	92.0	249.620	16.225	0.8125	1.3646		1.475
	94.0	340.062	16.466	0.8070	1.3642		1.407
	96.0	520.946	16.697	0.8013	1.3636		1.342
	98.0		16.920	0.7954	1.3630		1.273
	100.0		17.133	0.7893	1.3614		1.203
Ethylene	0.5	0.081	0.080	0.9988	1.3335	0.15	1.010
glycol	1.0	0.163	0.161	0.9995	1.3339	0.30	1.020
$(CH_2OH)_2$	2.0	0.329	0.322	1.0007	1.3348	0.61	1.048
	3.0	0.498	0.484	1.0019	1.3358	0.92	1.074
	4.0	0.671	0.646	1.0032	1.3367	1.24	1.099
	5.0	0.848	0.809	1.0044	1.3377	1.58	1.125
	6.0	1.028	0.972	1.0057	1.3386	1.91	1.153
	7.0	1.213	1.136	1.0070	1.3396	2.26	1.182
	8.0	1.401	1.299	1.0082	1.3405	2.62	1.212
	9.0	1.593	1.464	1.0095	1.3415	2.99	1.243
	10.0	1.790	1.628	1.0108	1.3425	3.37	1.277
	12.0	2.197	1.959	1.0134	1.3444	4.16	1.348

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	14.0	2.623	2.292	1.0161	1.3464	5.01	1.424
	16.0	3.069	2.626	1.0188	1.3484	5.91	1.500
	18.0	3.537	2.962	1.0214	1.3503	6.89	1.578
	20.0	4.028	3.300	1.0241	1.3523	7.93	1.661
	24.0	5.088	3.981	1.0296	1.3564	10.28	1.843
	28.0	6.265	4.669	1.0350	1.3605	13.03	2.047
	32.0	7.582	5.364	1.0405	1.3646	16.23	2.280
	36.0	9.062	6.067	1.0460	1.3687	19.82	2.537
	40.0	10.741	6.776	1.0514	1.3728	23.84	2.832
	44.0	12.659	7.491	1.0567	1.3769	28.32	3.166
	48.0	14.872	8.212	1.0619	1.3811	33.30	3.544
	52.0	17.453	8.939	1.0670	1.3851	38.81	3.981
	56.0	20.505	9.671	1.0719	1.3892	44.83	4.475
	60.0	24.166	10.406	1.0765	1.3931	51.23	5.026
Ferric	0.5	0.031	0.031	1.0025	1.3344	0.21	1.024
chloride	1.0	0.062	0.062	1.0068	1.3358	0.39	1.047
$FeCl_3$	2.0	0.126	0.125	1.0153	1.3386	0.75	1.093
	3.0	0.191	0.189	1.0238	1.3413	1.15	1.139
	4.0	0.257	0.255	1.0323	1.3441	1.56	1.187
	5.0	0.324	0.321	1.0408	1.3468	2.00	1.238
	6.0	0.394	0.388	1.0493	1.3496	2.48	1.292
	7.0	0.464	0.457	1.0580	1.3524	2.99	1.350
	8.0	0.536	0.526	1.0668	1.3552	3.57	1.412
	9.0	0.610	0.597	1.0760	1.3581	4.19	1.480
	10.0	0.685	0.669	1.0853	1.3611	4.85	1.553
	12.0	0.841	0.817	1.1040	1.3670	6.38	1.707
	14.0	1.004	0.969	1.1228	1.3730	8.22	1.879
	16.0	1.174	1.126	1.1420		10.45	2.080
	18.0	1.353	1.289	1.1615		13.08	2.311
	20.0	1.541	1.457	1.1816		16.14	2.570
	24.0	1.947	1.810	1.2234		23.79	3.178
	28.0	2.398	2.189	1.2679		33.61	4.038
	32.0	2.901	2.595	1.3153		49.16	5.274
	36.0	3.468	3.030	1.3654			7.130
	40.0	4.110	3.496	1.4176			9.674
Formic acid	0.5	0.109	0.109	0.9994	1.3333	0.21	1.006
HCOOH	1.0	0.219	0.217	1.0006	1.3336	0.42	1.011
	2.0	0.443	0.436	1.0029	1.3342	0.82	1.017
	3.0	0.672	0.655	1.0053	1.3348	1.24	1.195
	4.0	0.905	0.876	1.0077	1.3354	1.67	1.032
	5.0	1.143	1.097	1.0102	1.3359	2.10	1.039
	6.0	1.387	1.320	1.0126	1.3365	2.53	1.046
	7.0	1.635	1.544	1.0150	1.3371	2.97	1.052
	8.0	1.889	1.768	1.0175	1.3376	3.40	1.058
	9.0	2.149	1.994	1.0199	1.3382	3.84	1.064
	10.0	2.414	2.221	1.0224	1.3387	4.27	1.070
	12.0	2.962	2.678	1.0273	1.3397	5.19	1.082
	14.0	3.537	3.139	1.0322	1.3408	6.11	1.094
	16.0	4.138	3.605	1.0371	1.3418	7.06	1.106
	18.0	4.769	4.074	1.0419	1.3428	8.08	1.119
	20.0	5.431	4.548	1.0467	1.3437	9.11	1.132
	28.0	8.449	6.481	1.0654	1.3475	13.10	1.179
	36.0	12.220	8.477	1.0839	1.3511	17.65	1.227
	44.0	17.070	10.529	1.1015	1.3547	22.93	1.281
	52.0	23.535	12.633	1.1183	1.3581	29.69	1.340

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	60.0	32.587	14.813	1.1364	1.3612	38.26	1.410
	68.0	46.166	17.054	1.1544	1.3641		1.490
D-Fructose	0.5	0.028	0.028	1.0002	1.3337	0.05	1.015
$C_6H_{12}O_6$	1.0	0.056	0.056	1.0021	1.3344	0.10	1.028
	2.0	0.113	0.112	1.0061	1.3358	0.21	1.054
	3.0	0.172	0.168	1.0101	1.3373	0.32	1.080
	4.0	0.231	0.225	1.0140	1.3387	0.43	1.106
	5.0	0.292	0.283	1.0181	1.3402	0.54	1.134
	6.0	0.354	0.340	1.0221	1.3417	0.66	1.165
	7.0	0.418	0.399	1.0262	1.3431	0.78	1.198
	8.0	0.483	0.458	1.0303	1.3446	0.90	1.232
	9.0	0.549	0.517	1.0344	1.3461	1.03	1.270
	10.0	0.617	0.576	1.0385	1.3476	1.16	1.309
	12.0	0.757	0.697	1.0469	1.3507	1.43	1.391
	14.0	0.904	0.820	1.0554	1.3538	1.71	1.483
	16.0	1.057	0.945	1.0640	1.3569	2.01	1.587
	18.0	1.218	1.072	1.0728	1.3601	2.32	1.703
	20.0	1.388	1.201	1.0816	1.3634	2.64	1.837
	22.0	1.566	1.332	1.0906	1.3667	3.05	1.986
	24.0	1.753	1.465	1.0996	1.3700	3.43	2.154
	26.0	1.950	1.600	1.1089	1.3734	3.82	2.348
	28.0	2.159	1.738	1.1182	1.3768	4.20	2.562
	30.0	2.379	1.878	1.1276	1.3803		2.817
	32.0	2.612	2.020	1.1372	1.3839		3.112
	34.0	2.859	2.164	1.1469	1.3874		3.462
	36.0	3.122	2.312	1.1568	1.3911		3.899
	38.0	3.402	2.461	1.1668	1.3948		4.418
	40.0	3.700	2.613	1.1769	1.3985		5.046
	42.0	4.019	2.767	1.1871	1.4023		5.773
	44.0	4.361	2.925	1.1975	1.4062		6.644
	46.0	4.728	3.084	1.2080	1.4101		7.753
	48.0	5.124	3.247	1.2187	1.4141		9.060
D-Glucose	0.5	0.028	0.028	1.0001	1.3337	0.05	1.010
$C_6H_{12}O_6$	1.0	0.056	0.056	1.0020	1.3344	0.11	1.021
	2.0	0.113	0.112	1.0058	1.3358	0.21	1.052
	3.0	0.172	0.168	1.0097	1.3373	0.32	1.083
	4.0	0.231	0.225	1.0136	1.3387	0.43	1.113
	5.0	0.292	0.282	1.0175	1.3402	0.55	1.145
	6.0	0.354	0.340	1.0214	1.3417	0.67	1.179
	7.0	0.418	0.398	1.0254	1.3432	0.79	1.214
	8.0	0.483	0.457	1.0294	1.3447	0.91	1.250
	9.0	0.549	0.516	1.0334	1.3462	1.04	1.289
	10.0	0.617	0.576	1.0375	1.3477	1.17	1.330
	12.0	0.757	0.697	1.0457	1.3508	1.44	1.416
	14.0	0.904	0.819	1.0540	1.3539	1.73	1.512
	16.0	1.057	0.944	1.0624	1.3571	2.03	1.625
	18.0	1.218	1.070	1.0710	1.3603	2.35	1.757
	20.0	1.388	1.199	1.0797	1.3635	2.70	1.904
	22.0	1.566	1.329	1.0884	1.3668	3.07	2.063
	24.0	1.753	1.462	1.0973	1.3702	3.48	2.242
	26.0	1.950	1.597	1.1063	1.3736	3.90	2.458
	28.0	2.159	1.734	1.1154	1.3770	4.34	2.707
	30.0	2.379	1.873	1.1246	1.3805	4.79	2.998
	32.0	2.612	2.014	1.1340	1.3840		3.324
	34.0	2.859	2.158	1.1434	1.3876		3.704

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	36.0	3.122	2.304	1.1529	1.3912		4.193
	38.0	3.402	2.452	1.1626	1.3949		4.786
	40.0	3.700	2.603	1.1724	1.3986		5.493
	42.0	4.019	2.756	1.1823	1.4024		6.288
	44.0	4.361	2.912	1.1924	1.4062		7.235
	46.0	4.728	3.071	1.2026	1.4101		8.454
	48.0	5.124	3.232	1.2130	1.4141		9.883
	50.0	5.551	3.396	1.2235	1.4181		11.884
	52.0	6.013	3.562	1.2342	1.4222		14.489
	54.0	6.516	3.732	1.2451	1.4263		17.916
	56.0	7.064	3.905	1.2562	1.4306		22.886
	58.0	7.665	4.081	1.2676	1.4349		29.389
	60.0	8.326	4.261	1.2793	1.4394		37.445
Glycerol	0.5	0.055	0.054	0.9994	1.3336	0.07	1.011
$CH_2OHCHOHCH_2OH$	1.0	0.110	0.109	1.0005	1.3342	0.18	1.022
	2.0	0.222	0.218	1.0028	1.3353	0.41	1.048
	3.0	0.336	0.327	1.0051	1.3365	0.63	1.074
	4.0	0.452	0.438	1.0074	1.3376	0.85	1.100
	5.0	0.572	0.548	1.0097	1.3388	1.08	1.127
	6.0	0.693	0.659	1.0120	1.3400	1.32	1.157
	7.0	0.817	0.771	1.0144	1.3412	1.56	1.188
	8.0	0.944	0.883	1.0167	1.3424	1.81	1.220
	9.0	1.074	0.996	1.0191	1.3436	2.06	1.256
	10.0	1.207	1.109	1.0215	1.3448	2.32	1.291
	12.0	1.481	1.337	1.0262	1.3472	2.88	1.365
	14.0	1.768	1.568	1.0311	1.3496	3.47	1.445
	16.0	2.068	1.800	1.0360	1.3521	4.09	1.533
	18.0	2.384	2.035	1.0409	1.3547	4.76	1.630
	20.0	2.715	2.271	1.0459	1.3572	5.46	1.737
	24.0	3.429	2.752	1.0561	1.3624	7.01	1.988
	28.0	4.223	3.242	1.0664	1.3676	8.77	2.279
	32.0	5.110	3.742	1.0770	1.3730	10.74	2.637
	36.0	6.108	4.252	1.0876	1.3785	12.96	3.088
	40.0	7.239	4.771	1.0984	1.3841	15.50	3.653
	44.0	8.532	5.300	1.1092	1.3897		4.443
	48.0	10.024	5.838	1.1200	1.3954		5.413
	52.0	11.764	6.385	1.1308	1.4011		6.666
	56.0	13.820	6.944	1.1419	1.4069		8.349
	60.0	16.288	7.512	1.1530	1.4129		10.681
	64.0	19.305	8.092	1.1643	1.4189		13.657
	68.0	23.075	8.680	1.1755	1.4249		18.457
	72.0	27.923	9.277	1.1866	1.4310		27.625
	76.0	34.387	9.884	1.1976	1.4370		40.571
	80.0	43.436	10.498	1.2085	1.4431		59.900
	84.0	57.009	11.121	1.2192	1.4492		84.338
	88.0	79.632	11.753	1.2299	1.4553		147.494
	92.0	124.878	12.392	1.2404	1.4613		384.467
	96.0	260.615	13.039	1.2508	1.4674		780.458
	100.0		13.694	1.2611	1.4735		
Hydrochloric	0.5	0.138	0.137	1.0007	1.3341	0.49	1.008
acid	1.0	0.277	0.275	1.0031	1.3353	0.99	1.015
HCl	2.0	0.560	0.553	1.0081	1.3376	2.08	1.029
	3.0	0.848	0.833	1.0130	1.3399	3.28	1.044
	4.0	1.143	1.117	1.0179	1.3422	4.58	1.059
	5.0	1.444	1.403	1.0228	1.3445	5.98	1.075

CONCENTRATIVE PROPERTIES OF AQUEOUS SOLUTIONS: DENSITY, REFRACTIVE INDEX, FREEZING POINT DEPRESSION, AND VISCOSITY (continued)

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	6.0	1.751	1.691	1.0278	1.3468	7.52	1.091
	7.0	2.064	1.983	1.0327	1.3491	9.22	1.108
	8.0	2.385	2.277	1.0377	1.3515	11.10	1.125
	9.0	2.713	2.574	1.0426	1.3538	13.15	1.143
	10.0	3.047	2.873	1.0476	1.3561	15.40	1.161
	12.0	3.740	3.481	1.0576	1.3607	20.51	1.199
	14.0	4.465	4.099	1.0676	1.3653		1.239
	16.0	5.224	4.729	1.0777	1.3700		1.282
	18.0	6.020	5.370	1.0878	1.3746		1.326
	20.0	6.857	6.023	1.0980	1.3792		1.374
	22.0	7.736	6.687	1.1083	1.3838		1.426
	24.0	8.661	7.362	1.1185	1.3884		1.483
	26.0	9.636	8.049	1.1288	1.3930		1.547
	28.0	10.666	8.748	1.1391	1.3976		1.620
	30.0	11.754	9.456	1.1492	1.4020		1.705
	32.0	12.907	10.175	1.1594	1.4066		1.799
	34.0	14.129	10.904	1.1693	1.4112		1.900
	36.0	15.427	11.642	1.1791	1.4158		2.002
	38.0	16.810	12.388	1.1886	1.4204		2.105
	40.0	18.284	13.140	1.1977	1.4250		
Lactic acid	0.5	0.056	0.055	0.9992	1.3335	0.10	1.014
$CH_3CHOHCOOH$	1.0	0.112	0.111	1.0002	1.3340	0.19	1.027
	2.0	0.227	0.223	1.0023	1.3350	0.38	1.056
	3.0	0.343	0.334	1.0043	1.3360	0.57	1.084
	4.0	0.463	0.447	1.0065	1.3370	0.76	1.110
	5.0	0.584	0.560	1.0086	1.3380	0.95	1.138
	6.0	0.709	0.673	1.0108	1.3390	1.16	1.167
	7.0	0.836	0.787	1.0131	1.3400	1.36	1.198
	8.0	0.965	0.902	1.0153	1.3410	1.57	1.229
	9.0	1.098	1.017	1.0176	1.3420	1.79	1.262
	10.0	1.233	1.132	1.0199	1.3430	2.02	1.296
	12.0	1.514	1.365	1.0246	1.3450	2.49	1.366
	14.0	1.807	1.600	1.0294	1.3470	2.99	1.441
	16.0	2.115	1.837	1.0342	1.3491	3.48	1.522
	18.0	2.437	2.076	1.0390	1.3511	3.96	1.607
	20.0	2.775	2.318	1.0439	1.3532	4.44	1.699
	24.0	3.506	2.807	1.0536	1.3573		1.902
	28.0	4.317	3.305	1.0632	1.3615		2.136
	32.0	5.224	3.811	1.0728	1.3657		2.414
	36.0	6.244	4.325	1.0822	1.3700		2.730
	40.0	7.401	4.847	1.0915	1.3743		3.114
	44.0	8.722	5.377	1.1008	1.3786		3.566
	48.0	10.247	5.917	1.1105	1.3828		4.106
	52.0	12.026	6.466	1.1201	1.3871		4.789
	56.0	14.129	7.023	1.1297	1.3914		5.579
	60.0	16.652	7.588	1.1392	1.3958		6.679
	64.0	19.736	8.161	1.1486	1.4001		8.024
	68.0	23.590	8.741	1.1579	1.4045		9.863
	72.0	28.546	9.328	1.1670	1.4088		12.866
	76.0	35.154	9.922	1.1760	1.4131		16.974
	80.0	44.405	10.522	1.1848	1.4173		22.164
Lactose	0.5	0.015	0.015	1.0002	1.3337	0.03	1.013
$C_{12}H_{22}O_{11}$	1.0	0.030	0.029	1.0021	1.3345	0.06	1.026
	2.0	0.060	0.059	1.0061	1.3359	0.11	1.058
	3.0	0.090	0.089	1.0102	1.3375	0.17	1.089
	4.0	0.122	0.119	1.0143	1.3390	0.23	1.120

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	5.0	0.154	0.149	1.0184	1.3406	0.29	1.154
	6.0	0.186	0.179	1.0225	1.3421	0.35	1.191
	7.0	0.220	0.210	1.0267	1.3437	0.42	1.232
	8.0	0.254	0.241	1.0308	1.3453	0.50	1.276
	9.0	0.289	0.272	1.0349	1.3468		1.321
	10.0	0.325	0.304	1.0390	1.3484		1.370
	12.0	0.398	0.367	1.0473	1.3515		1.476
	14.0	0.476	0.432	1.0558	1.3548		1.593
	16.0	0.556	0.498	1.0648	1.3582		1.724
	18.0	0.641	0.565	1.0746	1.3619		1.869
Lithium	0.5	0.119	0.118	1.0012	1.3341	0.42	1.019
chloride	1.0	0.238	0.237	1.0041	1.3351	0.84	1.037
LiCl	2.0	0.481	0.476	1.0099	1.3373	1.72	1.072
	3.0	0.730	0.719	1.0157	1.3394	2.68	1.108
	4.0	0.983	0.964	1.0215	1.3415	3.73	1.146
	5.0	1.241	1.211	1.0272	1.3436	4.86	1.185
	6.0	1.506	1.462	1.0330	1.3457	6.14	1.226
	7.0	1.775	1.715	1.0387	1.3478	7.56	1.269
	8.0	2.051	1.971	1.0444	1.3499	9.11	1.313
	9.0	2.333	2.230	1.0502	1.3520	10.79	1.360
	10.0	2.621	2.491	1.0560	1.3541	12.61	1.411
	12.0	3.217	3.022	1.0675	1.3583	16.59	1.522
	14.0	3.840	3.564	1.0792	1.3625	21.04	1.647
	16.0	4.493	4.118	1.0910	1.3668		1.787
	18.0	5.178	4.683	1.1029	1.3711		1.942
	20.0	5.897	5.260	1.1150	1.3755		2.128
	22.0	6.653	5.851	1.1274	1.3799		2.341
	24.0	7.449	6.453	1.1399	1.3844		2.600
	26.0	8.288	7.069	1.1527	1.3890		2.925
	28.0	9.173	7.700	1.1658	1.3936		3.318
	30.0	10.109	8.344	1.1791	1.3983		3.785
Magnesium	0.5	0.053	0.053	1.0022	1.3343	0.26	1.024
chloride	1.0	0.106	0.106	1.0062	1.3356	0.52	1.046
$MgCl_2$	2.0	0.214	0.213	1.0144	1.3381	1.06	1.091
	3.0	0.325	0.322	1.0226	1.3406	1.65	1.139
	4.0	0.438	0.433	1.0309	1.3432	2.30	1.188
	5.0	0.553	0.546	1.0394	1.3457	3.01	1.241
	6.0	0.670	0.660	1.0479	1.3483		1.298
	7.0	0.791	0.777	1.0564	1.3508		1.358
	8.0	0.913	0.895	1.0651	1.3534		1.423
	9.0	1.039	1.015	1.0738	1.3560		1.493
	10.0	1.167	1.137	1.0826	1.3587		1.570
	12.0	1.432	1.387	1.1005	1.3641		1.745
	14.0	1.710	1.645	1.1189	1.3695		1.956
	16.0	2.001	1.911	1.1372	1.3749		2.207
	18.0	2.306	2.184	1.1553	1.3804		2.507
	20.0	2.626	2.467	1.1742	1.3859		2.867
	22.0	2.962	2.758	1.1938	1.3915		3.323
	24.0	3.317	3.060	1.2140	1.3972		3.917
	26.0	3.690	3.371	1.2346	1.4030		4.694
	28.0	4.085	3.692	1.2555	1.4089		5.709
	30.0	4.501	4.022	1.2763	1.4148		7.017
Magnesium	0.5	0.042	0.042	1.0033	1.3340	0.10	1.027
sulfate	1.0	0.084	0.084	1.0084	1.3350	0.19	1.054
$MgSO_4$	2.0	0.170	0.169	1.0186	1.3371	0.36	1.112

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	3.0	0.257	0.256	1.0289	1.3391	0.52	1.177
	4.0	0.346	0.345	1.0392	1.3411	0.69	1.249
	5.0	0.437	0.436	1.0497	1.3431	0.87	1.328
	6.0	0.530	0.528	1.0602	1.3451	1.05	1.411
	7.0	0.625	0.623	1.0708	1.3471	1.24	1.498
	8.0	0.722	0.719	1.0816	1.3492	1.43	1.593
	9.0	0.822	0.817	1.0924	1.3512	1.64	1.702
	10.0	0.923	0.917	1.1034	1.3532	1.85	1.829
	12.0	1.133	1.122	1.1257	1.3572	2.31	2.104
	14.0	1.352	1.336	1.1484	1.3613	2.86	2.412
	16.0	1.582	1.557	1.1717	1.3654	3.67	2.809
	18.0	1.824	1.788	1.1955	1.3694		3.360
	20.0	2.077	2.027	1.2198	1.3735		4.147
	22.0	2.343	2.275	1.2447	1.3776		5.199
	24.0	2.624	2.532	1.2701	1.3817		6.498
	26.0	2.919	2.800	1.2961	1.3858		8.066
Maltose	0.5	0.015	0.015	1.0003	1.3337	0.03	1.016
$C_{12}H_{22}O_{11}$	1.0	0.030	0.029	1.0023	1.3345	0.06	1.030
	2.0	0.060	0.059	1.0063	1.3359	0.11	1.060
	3.0	0.090	0.089	1.0104	1.3374	0.17	1.092
	4.0	0.122	0.119	1.0144	1.3389	0.23	1.126
	5.0	0.154	0.149	1.0184	1.3404	0.29	1.162
	6.0	0.186	0.179	1.0224	1.3420	0.35	1.200
	7.0	0.220	0.210	1.0265	1.3435	0.42	1.239
	8.0	0.254	0.241	1.0305	1.3450	0.48	1.281
	9.0	0.289	0.272	1.0345	1.3466	0.55	1.325
	10.0	0.325	0.303	1.0385	1.3482	0.62	1.372
	12.0	0.398	0.367	1.0465	1.3513	0.77	1.474
	14.0	0.476	0.431	1.0545	1.3546	0.92	1.588
	16.0	0.556	0.497	1.0629	1.3578	1.08	1.715
	18.0	0.641	0.564	1.0716	1.3612	1.25	1.859
	20.0	0.730	0.631	1.0801	1.3644	1.43	2.021
	22.0	0.824	0.700	1.0894	1.3678	1.64	2.216
	24.0	0.923	0.770	1.0984	1.3714	1.85	2.463
	26.0	1.026	0.842	1.1080	1.3749	2.08	2.753
	28.0	1.136	0.914	1.1171	1.3785	2.34	3.066
	30.0	1.252	0.988	1.1269	1.3821	2.62	3.427
	40.0	1.948	1.375	1.1769	1.4013	4.41	6.926
	50.0	2.921	1.797	1.2304	1.4217		17.786
	52.0	3.165	1.886	1.2416	1.4260		22.034
	54.0	3.429	1.976	1.2528	1.4308		28.757
	56.0	3.718	2.068	1.2638	1.4350		38.226
	58.0	4.034	2.159	1.2740	1.4394		49.298
	60.0	4.382	2.253	1.2855	1.4440		
Manganese(II)	1.0	0.067	0.067	1.0080	1.3348	0.16	1.046
sulfate	2.0	0.135	0.135	1.0178	1.3366	0.31	1.090
$MnSO_4$	3.0	0.205	0.204	1.0277	1.3384	0.44	1.137
	4.0	0.276	0.275	1.0378	1.3402	0.57	1.187
	5.0	0.349	0.347	1.0480	1.3420	0.70	1.242
	6.0	0.423	0.421	1.0583	1.3438	0.84	1.301
	7.0	0.498	0.495	1.0688	1.3457	0.98	1.363
	8.0	0.576	0.572	1.0794	1.3475	1.12	1.431
	9.0	0.655	0.650	1.0902	1.3494	1.28	1.505
	10.0	0.736	0.729	1.1012	1.3513	1.44	1.587
	12.0	0.903	0.893	1.1236	1.3551	1.80	1.779

Solute	Mass %	m/mol kg^{-1}	c/mol L^{-1}	ρ/g cm^{-3}	n	Δ/°C	η/mPa s
	14.0	1.078	1.063	1.1467	1.3589	2.21	2.005
	16.0	1.261	1.240	1.1705	1.3629	2.67	2.272
	18.0	1.454	1.424	1.1950	1.3668	3.19	2.580
	20.0	1.656	1.616	1.2203	1.3708	3.80	2.938
D-Mannitol	0.5	0.028	0.027	1.0000	1.3337	0.05	1.019
$CH_2(CHOH)_4CH_2OH$	1.0	0.055	0.055	1.0017	1.3345	0.10	1.032
	2.0	0.112	0.110	1.0053	1.3359	0.21	1.057
	3.0	0.170	0.166	1.0088	1.3374	0.32	1.081
	4.0	0.229	0.222	1.0124	1.3389	0.43	1.107
	5.0	0.289	0.279	1.0159	1.3403	0.54	1.135
	6.0	0.350	0.336	1.0195	1.3418	0.66	1.166
	7.0	0.413	0.393	1.0230	1.3433	0.77	1.200
	8.0	0.477	0.451	1.0266	1.3447	0.90	1.236
	9.0	0.543	0.509	1.0302	1.3462	1.02	1.275
	10.0	0.610	0.567	1.0338	1.3477	1.15	1.314
	11.0	0.678	0.626	1.0375	1.3491	1.28	1.355
	12.0	0.749	0.686	1.0412	1.3506	1.41	1.398
	13.0	0.820	0.746	1.0450	1.3521	1.55	1.443
	14.0	0.894	0.806	1.0489	1.3536	1.69	1.489
	15.0	0.969	0.867	1.0529	1.3552	1.84	1.537
Methanol	0.5	0.157	0.156	0.9973	1.3331	0.28	1.022
CH_3OH	1.0	0.315	0.311	0.9964	1.3332	0.56	1.040
	2.0	0.637	0.621	0.9947	1.3334	1.14	1.070
	3.0	0.965	0.930	0.9930	1.3336	1.75	1.100
	4.0	1.300	1.238	0.9913	1.3339	2.37	1.131
	5.0	1.643	1.544	0.9896	1.3341	3.02	1.163
	6.0	1.992	1.850	0.9880	1.3343	3.71	1.196
	7.0	2.349	2.155	0.9864	1.3346	4.41	1.229
	8.0	2.714	2.459	0.9848	1.3348	5.13	1.264
	9.0	3.087	2.762	0.9832	1.3351	5.85	1.297
	10.0	3.468	3.064	0.9816	1.3354	6.60	1.329
	12.0	4.256	3.665	0.9785	1.3359	8.14	1.389
	14.0	5.081	4.262	0.9755	1.3365	9.72	1.446
	16.0	5.945	4.856	0.9725	1.3370	11.36	1.501
	18.0	6.851	5.447	0.9695	1.3376	13.13	1.554
	20.0	7.803	6.034	0.9666	1.3381	15.02	1.604
	22.0	8.803	6.616	0.9636	1.3387	16.98	1.652
	24.0	9.856	7.196	0.9606	1.3392	19.04	1.697
	26.0	10.966	7.771	0.9576	1.3397	21.23	1.735
	28.0	12.138	8.341	0.9545	1.3402	23.59	1.769
	30.0	13.376	8.908	0.9514	1.3407	25.91	1.795
	32.0	14.688	9.470	0.9482	1.3411	28.15	1.814
	34.0	16.078	10.028	0.9450	1.3415	30.48	1.827
	36.0	17.556	10.580	0.9416	1.3419	32.97	1.835
	38.0	19.129	11.127	0.9382	1.3422	35.60	1.839
	40.0	20.807	11.669	0.9347	1.3425	38.60	1.837
	50.0	31.211	14.288	0.9156	1.3431	54.50	1.761
	60.0	46.816	16.749	0.8944	1.3426	74.50	1.600
	70.0	72.826	19.040	0.8715	1.3411		1.368
	80.0	124.844	21.144	0.8468	1.3385		1.128
	90.0	280.899	23.045	0.8204	1.3348		0.861
	100.0		24.710	0.7917	1.3290		0.586
Nitric acid	0.5	0.080	0.079	1.0009	1.3336	0.28	1.004
HNO_3	1.0	0.160	0.159	1.0037	1.3343	0.56	1.005
	2.0	0.324	0.320	1.0091	1.3356	1.12	1.007

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	3.0	0.491	0.483	1.0146	1.3368	1.70	1.010
	4.0	0.661	0.648	1.0202	1.3381	2.32	1.014
	5.0	0.835	0.814	1.0257	1.3394	2.96	1.018
	6.0	1.013	0.982	1.0314	1.3407	3.63	1.022
	7.0	1.194	1.152	1.0370	1.3421	4.33	1.027
	8.0	1.380	1.324	1.0427	1.3434	5.05	1.032
	9.0	1.570	1.498	1.0485	1.3447	5.81	1.038
	10.0	1.763	1.673	1.0543	1.3460	6.60	1.044
	12.0	2.164	2.030	1.0660	1.3487	8.27	1.058
	14.0	2.583	2.395	1.0780	1.3514	10.08	1.075
	16.0	3.023	2.768	1.0901	1.3541	12.04	1.094
	18.0	3.484	3.149	1.1025	1.3569	14.16	1.116
	20.0	3.967	3.539	1.1150	1.3596		1.141
	22.0	4.476	3.937	1.1277	1.3624		1.169
	24.0	5.011	4.344	1.1406	1.3652		1.199
	26.0	5.576	4.760	1.1536	1.3680		1.233
	28.0	6.172	5.185	1.1668	1.3708		1.271
	30.0	6.801	5.618	1.1801	1.3736		1.311
	32.0	7.468	6.060	1.1934	1.3763		1.354
	34.0	8.175	6.512	1.2068	1.3790		1.400
	36.0	8.927	6.971	1.2202	1.3817		1.450
	38.0	9.727	7.439	1.2335	1.3842		1.504
	40.0	10.580	7.913	1.2466	1.3867		1.561
Oxalic acid	0.5	0.056	0.056	1.0006	1.3336	0.16	1.013
$(COOH)_2$	1.0	0.112	0.111	1.0030	1.3342	0.30	1.023
	1.5	0.169	0.167	1.0054	1.3347	0.44	1.033
	2.0	0.227	0.224	1.0079	1.3353	0.57	1.044
	2.5	0.285	0.281	1.0103	1.3359	0.71	1.055
	3.0	0.343	0.337	1.0126	1.3364	0.84	1.065
	3.5	0.403	0.395	1.0150	1.3370	0.97	1.076
	4.0	0.463	0.452	1.0174	1.3375	1.09	1.086
	4.5	0.523	0.510	1.0197	1.3381		1.097
	5.0	0.585	0.568	1.0220	1.3386		1.108
	6.0	0.709	0.684	1.0265	1.3397		1.129
	7.0	0.836	0.802	1.0310	1.3407		1.150
	8.0	0.966	0.920	1.0355	1.3418		1.172
Phosphoric	0.5	0.051	0.051	1.0010	1.3335	0.12	1.010
acid	1.0	0.103	0.102	1.0038	1.3340	0.24	1.020
H_3PO_4	2.0	0.208	0.206	1.0092	1.3349	0.46	1.050
	3.0	0.316	0.311	1.0146	1.3358	0.69	1.079
	4.0	0.425	0.416	1.0200	1.3367	0.93	1.108
	5.0	0.537	0.523	1.0254	1.3376	1.16	1.138
	6.0	0.651	0.631	1.0309	1.3385	1.38	1.169
	7.0	0.768	0.740	1.0363	1.3394	1.62	1.200
	8.0	0.887	0.850	1.0418	1.3403	1.88	1.232
	9.0	1.009	0.962	1.0474	1.3413	2.16	1.267
	10.0	1.134	1.075	1.0531	1.3422	2.45	1.303
	12.0	1.392	1.304	1.0647	1.3441	3.01	1.382
	14.0	1.661	1.538	1.0765	1.3460	3.76	1.469
	16.0	1.944	1.777	1.0885	1.3480	4.45	1.565
	18.0	2.240	2.022	1.1009	1.3500	5.25	1.671
	20.0	2.551	2.273	1.1135	1.3520	6.23	1.788
	22.0	2.878	2.529	1.1263	1.3540	7.38	1.914
	24.0	3.223	2.791	1.1395	1.3561	8.69	2.049
	26.0	3.585	3.059	1.1528	1.3582	10.12	2.198

Solute	Mass %	m/mol kg^{-1}	c/mol L^{-1}	ρ/g cm^{-3}	n	Δ/°C	η/mPa s
	28.0	3.968	3.333	1.1665	1.3604	11.64	2.365
	30.0	4.373	3.614	1.1804	1.3625	13.23	2.553
	32.0	4.802	3.901	1.1945	1.3647	14.94	2.766
	34.0	5.257	4.194	1.2089	1.3669	16.81	3.001
	36.0	5.740	4.495	1.2236	1.3691	18.85	3.260
	38.0	6.254	4.803	1.2385	1.3713	21.09	3.544
	40.0	6.803	5.117	1.2536	1.3735	23.58	3.856
Potassium	0.5	0.050	0.050	1.0014	1.3335	0.18	1.009
bicarbonate	1.0	0.101	0.100	1.0046	1.3341	0.34	1.015
$KHCO_3$	2.0	0.204	0.202	1.0114	1.3353	0.67	1.027
	3.0	0.309	0.305	1.0181	1.3365	0.98	1.040
	4.0	0.416	0.409	1.0247	1.3376	1.29	1.053
	5.0	0.526	0.515	1.0310	1.3386	1.60	1.067
	6.0	0.638	0.622	1.0379	1.3397	1.91	1.081
	7.0	0.752	0.730	1.0446	1.3409	2.22	1.096
	8.0	0.869	0.840	1.0514	1.3419	2.53	1.112
	9.0	0.988	0.951	1.0581	1.3430	2.84	1.128
	10.0	1.110	1.064	1.0650	1.3441	3.16	1.145
	12.0	1.362	1.293	1.0788	1.3462	3.79	1.183
	14.0	1.626	1.528	1.0929	1.3484	4.41	1.224
	16.0	1.903	1.770	1.1073	1.3506		1.270
	18.0	2.193	2.017	1.1221	1.3528		1.319
	20.0	2.497	2.272	1.1372	1.3550		1.373
	22.0	2.817	2.533	1.1527	1.3572		1.432
	24.0	3.154	2.801	1.1685	1.3595		1.497
Potassium	0.5	0.042	0.042	1.0018	1.3336	0.15	1.000
bromide	1.0	0.085	0.084	1.0054	1.3342	0.29	0.998
KBr	2.0	0.171	0.170	1.0127	1.3354	0.59	0.994
	3.0	0.260	0.257	1.0200	1.3366	0.88	0.990
	4.0	0.350	0.345	1.0275	1.3379	1.18	0.985
	5.0	0.442	0.435	1.0350	1.3391	1.48	0.981
	6.0	0.536	0.526	1.0426	1.3403	1.78	0.977
	7.0	0.633	0.618	1.0503	1.3416	2.10	0.974
	8.0	0.731	0.711	1.0581	1.3429	2.42	0.970
	9.0	0.831	0.806	1.0660	1.3441	2.74	0.967
	10.0	0.934	0.903	1.0740	1.3454	3.07	0.964
	12.0	1.146	1.099	1.0903	1.3481	3.76	0.958
	14.0	1.368	1.302	1.1070	1.3507	4.49	0.953
	16.0	1.601	1.512	1.1242	1.3535	5.25	0.949
	18.0	1.845	1.727	1.1419	1.3562	6.04	0.946
	20.0	2.101	1.950	1.1601	1.3591	6.88	0.944
	22.0	2.370	2.179	1.1788	1.3620	7.76	0.943
	24.0	2.654	2.416	1.1980	1.3650	8.70	0.943
	26.0	2.952	2.661	1.2179	1.3680	9.68	0.944
	28.0	3.268	2.914	1.2383	1.3711	10.72	0.947
	30.0	3.601	3.175	1.2593	1.3743	11.82	0.952
	32.0	3.954	3.445	1.2810	1.3776	12.98	0.959
	34.0	4.329	3.724	1.3033	1.3809		0.968
	36.0	4.727	4.012	1.3263	1.3843		0.979
	38.0	5.150	4.311	1.3501	1.3878		0.993
	40.0	5.602	4.620	1.3746	1.3914		1.010
Potassium	0.5	0.036	0.036	1.0027	1.3339	0.18	1.013
carbonate	1.0	0.073	0.073	1.0072	1.3347	0.34	1.025
K_2CO_3	2.0	0.148	0.147	1.0163	1.3365	0.66	1.048

Solute	Mass %	m/mol kg^{-1}	c/mol L^{-1}	ρ/g cm^{-3}	n	Δ/°C	η/mPa s
	3.0	0.224	0.223	1.0254	1.3382	0.99	1.071
	4.0	0.301	0.299	1.0345	1.3399	1.32	1.094
	5.0	0.381	0.378	1.0437	1.3416	1.67	1.119
	6.0	0.462	0.457	1.0529	1.3433	2.03	1.146
	7.0	0.545	0.538	1.0622	1.3450	2.40	1.174
	8.0	0.629	0.620	1.0715	1.3467	2.77	1.204
	9.0	0.716	0.704	1.0809	1.3484	3.17	1.235
	10.0	0.804	0.789	1.0904	1.3501	3.57	1.269
	12.0	0.987	0.963	1.1095	1.3535	4.45	1.339
	14.0	1.178	1.144	1.1291	1.3569	5.39	1.414
	16.0	1.378	1.330	1.1490	1.3603	6.42	1.497
	18.0	1.588	1.523	1.1692	1.3637	7.55	1.594
	20.0	1.809	1.722	1.1898	1.3671	8.82	1.707
	24.0	2.285	2.139	1.2320	1.3739	11.96	1.978
	28.0	2.814	2.584	1.2755	1.3807	16.01	2.331
	32.0	3.405	3.057	1.3204	1.3874	21.46	2.834
	36.0	4.070	3.559	1.3665	1.3940	28.58	3.503
	40.0	4.824	4.093	1.4142	1.4006	37.55	4.360
	50.0	7.236	5.573	1.5404	1.4168		9.369
Potassium	0.5	0.067	0.067	1.0014	1.3337	0.23	1.000
chloride	1.0	0.135	0.135	1.0046	1.3343	0.46	0.999
KCl	2.0	0.274	0.271	1.0110	1.3357	0.92	0.999
	3.0	0.415	0.409	1.0174	1.3371	1.38	0.998
	4.0	0.559	0.549	1.0239	1.3384	1.85	0.997
	5.0	0.706	0.691	1.0304	1.3398	2.32	0.996
	6.0	0.856	0.835	1.0369	1.3411	2.80	0.994
	7.0	1.010	0.980	1.0434	1.3425	3.29	0.992
	8.0	1.166	1.127	1.0500	1.3438	3.80	0.990
	9.0	1.327	1.276	1.0566	1.3452	4.30	0.989
	10.0	1.490	1.426	1.0633	1.3466	4.81	0.988
	12.0	1.829	1.733	1.0768	1.3493	5.88	0.990
	14.0	2.184	2.048	1.0905	1.3521		0.994
	16.0	2.555	2.370	1.1043	1.3549		0.999
	18.0	2.944	2.701	1.1185	1.3577		1.004
	20.0	3.353	3.039	1.1328	1.3606		1.012
	22.0	3.783	3.386	1.1474	1.3635		1.024
	24.0	4.236	3.742	1.1623	1.3665		1.040
Potassium	0.5	0.090	0.089	1.0025	1.3340	0.30	1.010
hydroxide	1.0	0.180	0.179	1.0068	1.3350	0.61	1.019
KOH	2.0	0.364	0.362	1.0155	1.3369	1.24	1.038
	3.0	0.551	0.548	1.0242	1.3388	1.89	1.058
	4.0	0.743	0.736	1.0330	1.3408	2.57	1.079
	5.0	0.938	0.929	1.0419	1.3427	3.36	1.102
	6.0	1.138	1.124	1.0509	1.3445	4.14	1.126
	7.0	1.342	1.322	1.0599	1.3464	4.92	1.151
	8.0	1.550	1.524	1.0690	1.3483		1.177
	9.0	1.763	1.729	1.0781	1.3502		1.205
	10.0	1.980	1.938	1.0873	1.3520		1.233
	12.0	2.431	2.365	1.1059	1.3558		1.294
	14.0	2.902	2.806	1.1246	1.3595		1.361
	16.0	3.395	3.261	1.1435	1.3632		1.436
	18.0	3.913	3.730	1.1626	1.3670		1.521
	20.0	4.456	4.213	1.1818	1.3707		1.619
	22.0	5.027	4.711	1.2014	1.3744		1.732
	24.0	5.629	5.223	1.2210	1.3781		1.861

CONCENTRATIVE PROPERTIES OF AQUEOUS SOLUTIONS: DENSITY, REFRACTIVE INDEX, FREEZING POINT DEPRESSION, AND VISCOSITY (continued)

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	26.0	6.262	5.750	1.2408	1.3818		2.006
	28.0	6.931	6.293	1.2609	1.3854		2.170
	30.0	7.639	6.851	1.2813	1.3889		2.357
	40.0	11.882	9.896	1.3881	1.4068		3.879
	50.0	17.824	13.389	1.5024	1.4247		7.892
Potassium	0.5	0.030	0.030	1.0019	1.3337	0.11	0.999
iodide	1.0	0.061	0.061	1.0056	1.3343	0.22	0.997
KI	2.0	0.123	0.122	1.0131	1.3357	0.43	0.991
	3.0	0.186	0.184	1.0206	1.3370	0.64	0.986
	4.0	0.251	0.248	1.0282	1.3384	0.86	0.981
	5.0	0.317	0.312	1.0360	1.3397	1.08	0.976
	6.0	0.385	0.377	1.0438	1.3411	1.30	0.969
	7.0	0.453	0.443	1.0517	1.3425	1.53	0.963
	8.0	0.524	0.511	1.0598	1.3440	1.77	0.957
	9.0	0.596	0.579	1.0679	1.3454	2.01	0.951
	10.0	0.669	0.648	1.0762	1.3469	2.26	0.946
	12.0	0.821	0.790	1.0931	1.3498	2.77	0.937
	14.0	0.981	0.937	1.1105	1.3529	3.30	0.929
	16.0	1.147	1.088	1.1284	1.3560	3.87	0.921
	18.0	1.322	1.244	1.1469	1.3593	4.46	0.915
	20.0	1.506	1.405	1.1659	1.3626	5.09	0.910
	22.0	1.699	1.571	1.1856	1.3661	5.76	0.905
	24.0	1.902	1.744	1.2060	1.3696	6.46	0.901
	26.0	2.117	1.922	1.2270	1.3733	7.21	0.898
	28.0	2.343	2.106	1.2487	1.3771	8.01	0.895
	30.0	2.582	2.297	1.2712	1.3810	8.86	0.892
	32.0	2.835	2.495	1.2944	1.3851	9.76	0.891
	34.0	3.103	2.700	1.3185	1.3893	10.72	0.890
	36.0	3.388	2.913	1.3434	1.3936	11.73	0.890
	38.0	3.692	3.134	1.3692	1.3981	12.81	0.893
	40.0	4.016	3.364	1.3959	1.4027	13.97	0.897
Potassium	0.5	0.050	0.050	1.0014	1.3335	0.17	0.999
nitrate	1.0	0.100	0.099	1.0045	1.3339	0.33	0.996
KNO_3	2.0	0.202	0.200	1.0108	1.3349	0.64	0.990
	3.0	0.306	0.302	1.0171	1.3358	0.94	0.986
	4.0	0.412	0.405	1.0234	1.3368	1.22	0.983
	5.0	0.521	0.509	1.0298	1.3377	1.50	0.980
	6.0	0.631	0.615	1.0363	1.3386	1.76	0.977
	7.0	0.744	0.722	1.0428	1.3396	2.02	0.975
	8.0	0.860	0.830	1.0494	1.3405	2.27	0.973
	9.0	0.978	0.940	1.0560	1.3415	2.52	0.971
	10.0	1.099	1.051	1.0627	1.3425	2.75	0.970
	12.0	1.349	1.277	1.0762	1.3444		0.970
	14.0	1.610	1.509	1.0899	1.3463		0.972
	16.0	1.884	1.747	1.1039	1.3482		0.976
	18.0	2.171	1.991	1.1181	1.3502		0.982
	20.0	2.473	2.240	1.1326	1.3521		0.990
	22.0	2.790	2.497	1.1473	1.3541		0.999
	24.0	3.123	2.759	1.1623	1.3561		1.010
Potassium	0.5	0.032	0.032	1.0017		0.11	1.001
permanganate	1.0	0.064	0.064	1.0051		0.22	1.000
$KMnO_4$	1.5	0.096	0.096	1.0085		0.32	0.999
	2.0	0.129	0.128	1.0118		0.43	0.998
	3.0	0.196	0.193	1.0186			0.995

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	4.0	0.264	0.260	1.0254			0.992
	5.0	0.333	0.327	1.0322			0.989
	6.0	0.404	0.394	1.0390			0.985
Potassium	0.5	0.029	0.029	1.0025	1.3338	0.13	1.013
hydrogen	1.0	0.058	0.058	1.0068	1.3345	0.25	1.023
phosphate	1.5	0.087	0.087	1.0110	1.3353	0.37	1.034
K_2HPO_4	2.0	0.117	0.117	1.0153	1.3361	0.49	1.046
	2.5	0.147	0.146	1.0195	1.3368	0.61	1.057
	3.0	0.178	0.176	1.0238	1.3376	0.73	1.069
	3.5	0.208	0.207	1.0281	1.3384	0.86	1.081
	4.0	0.239	0.237	1.0324	1.3392	0.97	1.094
	4.5	0.271	0.268	1.0368	1.3399	1.10	1.107
	5.0	0.302	0.299	1.0412	1.3407	1.22	1.120
	6.0	0.366	0.362	1.0500	1.3422	1.46	1.147
	7.0	0.432	0.426	1.0590	1.3438	1.70	1.177
	8.0	0.499	0.491	1.0680	1.3453	1.95	1.209
Potassium	0.5	0.037	0.037	1.0018	1.3336	0.13	1.010
dihydrogen	1.0	0.074	0.074	1.0053	1.3342	0.25	1.019
phosphate	1.5	0.112	0.111	1.0089	1.3348	0.37	1.028
KH_2PO_4	2.0	0.150	0.149	1.0125	1.3354	0.49	1.038
	3.0	0.227	0.225	1.0197	1.3365	0.72	1.060
	4.0	0.306	0.302	1.0269	1.3377	0.96	1.083
	5.0	0.387	0.380	1.0342	1.3388	1.19	1.108
	6.0	0.469	0.459	1.0414	1.3400	1.41	1.133
	7.0	0.553	0.539	1.0486	1.3411	1.63	1.160
	8.0	0.639	0.621	1.0558	1.3422	1.84	1.187
	9.0	0.727	0.703	1.0630	1.3434	2.04	1.215
	10.0	0.816	0.786	1.0703	1.3445	2.23	1.245
Potassium	0.5	0.029	0.029	1.0022	1.3336	0.14	1.006
sulfate	1.0	0.058	0.058	1.0062	1.3343	0.26	1.011
K_2SO_4	2.0	0.117	0.116	1.0143	1.3355	0.50	1.021
	3.0	0.177	0.176	1.0224	1.3368	0.73	1.033
	4.0	0.239	0.237	1.0306	1.3380	0.95	1.045
	5.0	0.302	0.298	1.0388	1.3393	1.17	1.058
	6.0	0.366	0.360	1.0470	1.3405		1.072
	7.0	0.432	0.424	1.0553	1.3417		1.087
	8.0	0.499	0.488	1.0637	1.3428		1.102
	9.0	0.568	0.554	1.0721	1.3440		1.117
	10.0	0.638	0.620	1.0806	1.3452		1.132
1-Propanol	1.0	0.168	0.166	0.9963	1.3339	0.31	1.051
$CH_3CH_2CH_2OH$	2.0	0.340	0.331	0.9946	1.3348	0.61	1.100
	3.0	0.515	0.496	0.9928	1.3357	0.93	1.152
	4.0	0.693	0.660	0.9911	1.3366	1.24	1.208
	5.0	0.876	0.823	0.9896	1.3376	1.57	1.267
	6.0	1.062	0.987	0.9882	1.3385	1.91	1.325
	7.0	1.252	1.149	0.9868	1.3394	2.26	1.387
	8.0	1.447	1.312	0.9855	1.3404	2.61	1.449
	9.0	1.646	1.474	0.9842	1.3414	2.99	1.514
	10.0	1.849	1.635	0.9829	1.3423	3.36	1.577
	12.0	2.269	1.958	0.9804	1.3442	4.09	1.710
	14.0	2.709	2.278	0.9779	1.3460	4.91	1.849
	16.0	3.169	2.595	0.9749	1.3477	5.78	1.986
	18.0	3.652	2.911	0.9719	1.3494	6.67	2.106

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	20.0	4.160	3.223	0.9686	1.3510	7.76	2.218
	24.0	5.254	3.838	0.9612	1.3539	9.12	2.432
	28.0	6.471	4.441	0.9533	1.3566	10.17	2.612
	32.0	7.830	5.033	0.9452	1.3592	10.66	2.765
	36.0	9.359	5.613	0.9370	1.3614		2.900
	40.0	11.093	6.182	0.9288	1.3635		3.010
	60.0	24.958	8.860	0.8875	1.3734		3.186
	80.0	66.556	11.275	0.8470	1.3812		2.822
	100.0		13.368	0.8034	1.3852		2.227
2-Propanol	1.0	0.168	0.166	0.9960	1.3338	0.30	1.056
$CH_3CHOHCH_3$	2.0	0.340	0.331	0.9939	1.3346	0.60	1.112
	3.0	0.515	0.495	0.9920	1.3355	0.93	1.166
	4.0	0.693	0.659	0.9902	1.3364	1.26	1.225
	5.0	0.876	0.822	0.9884	1.3373	1.61	1.287
	6.0	1.062	0.985	0.9871	1.3382	1.96	1.352
	7.0	1.252	1.148	0.9855	1.3392	2.32	1.417
	8.0	1.447	1.310	0.9843	1.3400	2.68	1.485
	9.0	1.646	1.472	0.9831	1.3410	3.06	1.553
	10.0	1.849	1.633	0.9816	1.3420	3.48	1.629
	12.0	2.269	1.955	0.9793	1.3439	4.43	1.794
	14.0	2.709	2.276	0.9772	1.3459	5.29	1.970
	16.0	3.169	2.596	0.9751	1.3478	6.36	2.160
	18.0	3.652	2.913	0.9725	1.3496	7.40	2.352
	20.0	4.160	3.227	0.9696	1.3514	8.52	2.550
	40.0	11.093	6.191	0.9302	1.3642		
	60.0	24.958	8.809	0.8824	1.3717		
	80.0	66.556	11.103	0.8341	1.3765		
	100.0		13.058	0.7848	1.3742		
Silver	0.5	0.030	0.030	1.0027	1.3336	0.10	1.003
nitrate	1.0	0.059	0.059	1.0070	1.3342	0.20	1.005
$AgNO_3$	2.0	0.120	0.120	1.0154	1.3352	0.40	1.009
	3.0	0.182	0.181	1.0239	1.3363	0.59	1.013
	4.0	0.245	0.243	1.0327	1.3374	0.78	1.016
	5.0	0.310	0.307	1.0417	1.3385	0.96	1.020
	6.0	0.376	0.371	1.0506	1.3396	1.15	1.024
	7.0	0.443	0.437	1.0597	1.3407	1.33	1.027
	8.0	0.512	0.503	1.0690	1.3419	1.51	1.031
	9.0	0.582	0.571	1.0785	1.3431	1.69	1.035
	10.0	0.654	0.641	1.0882	1.3443	1.87	1.039
	12.0	0.803	0.783	1.1079	1.3467	2.21	1.049
	14.0	0.958	0.930	1.1284	1.3493	2.55	1.060
	16.0	1.121	1.083	1.1496	1.3519	2.86	1.072
	18.0	1.292	1.241	1.1715	1.3546		1.086
	20.0	1.472	1.406	1.1942	1.3574		1.101
	22.0	1.660	1.577	1.2177	1.3602		1.117
	24.0	1.859	1.755	1.2420	1.3632		1.135
	26.0	2.068	1.940	1.2672	1.3662		1.154
	28.0	2.289	2.132	1.2933	1.3694		1.176
	30.0	2.523	2.332	1.3204	1.3726		1.200
	32.0	2.770	2.541	1.3487	1.3760		1.227
	34.0	3.033	2.758	1.3780	1.3795		1.257
	36.0	3.311	2.985	1.4087	1.3832		1.290
	38.0	3.608	3.223	1.4407	1.3871		1.326
	40.0	3.925	3.472	1.4743	1.3911		1.366

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
Sodium	0.5	0.061	0.061	1.0008	1.3337	0.22	1.021
acetate	1.0	0.123	0.122	1.0034	1.3344	0.43	1.040
CH_3COONa	2.0	0.249	0.246	1.0085	1.3358	0.88	1.080
	3.0	0.377	0.371	1.0135	1.3372	1.34	1.124
	4.0	0.508	0.497	1.0184	1.3386	1.82	1.171
	5.0	0.642	0.624	1.0234	1.3400	2.32	1.222
	6.0	0.778	0.752	1.0283	1.3414	2.85	1.278
	7.0	0.918	0.882	1.0334	1.3428	3.40	1.337
	8.0	1.060	1.013	1.0386	1.3442	3.98	1.401
	9.0	1.206	1.145	1.0440	1.3456	4.57	1.468
	10.0	1.354	1.279	1.0495	1.3470		1.539
	12.0	1.662	1.552	1.0607	1.3498		1.688
	14.0	1.984	1.829	1.0718	1.3526		1.855
	16.0	2.322	2.112	1.0830	1.3554		2.054
	18.0	2.676	2.400	1.0940	1.3583		2.284
	20.0	3.047	2.694	1.1050	1.3611		2.567
	22.0	3.438	2.993	1.1159	1.3639		2.948
	24.0	3.849	3.297	1.1268	1.3666		3.400
	26.0	4.283	3.606	1.1377	1.3693		3.877
	28.0	4.741	3.921	1.1488	1.3720		4.388
	30.0	5.224	4.243	1.1602	1.3748		4.940
Sodium	0.5	0.060	0.060	1.0018	1.3337	0.20	1.015
bicarbonate	1.0	0.120	0.120	1.0054	1.3344	0.40	1.028
$NaHCO_3$	1.5	0.181	0.180	1.0089	1.3351	0.59	1.042
	2.0	0.243	0.241	1.0125	1.3357	0.78	1.057
	2.5	0.305	0.302	1.0160	1.3364	0.98	1.071
	3.0	0.368	0.364	1.0196	1.3370	1.16	1.086
	3.5	0.432	0.426	1.0231	1.3377	1.35	1.102
	4.0	0.496	0.489	1.0266	1.3383	1.54	1.118
	4.5	0.561	0.552	1.0301	1.3390	1.72	1.134
	5.0	0.627	0.615	1.0337	1.3396	1.90	1.151
	5.5	0.693	0.679	1.0372	1.3403	2.08	1.168
	6.0	0.760	0.743	1.0408	1.3409	2.26	1.185
Sodium	0.5	0.049	0.049	1.0021	1.3337	0.17	1.004
bromide	1.0	0.098	0.098	1.0060	1.3344	0.34	1.007
NaBr	2.0	0.198	0.197	1.0139	1.3358	0.69	1.012
	3.0	0.301	0.298	1.0218	1.3372	1.04	1.017
	4.0	0.405	0.400	1.0298	1.3386	1.39	1.022
	5.0	0.512	0.504	1.0380	1.3401	1.76	1.028
	6.0	0.620	0.610	1.0462	1.3415	2.14	1.034
	7.0	0.732	0.717	1.0546	1.3430	2.53	1.040
	8.0	0.845	0.826	1.0630	1.3445	2.93	1.046
	9.0	0.961	0.937	1.0716	1.3460	3.34	1.053
	10.0	1.080	1.050	1.0803	1.3475	3.77	1.060
	12.0	1.325	1.281	1.0981	1.3506	4.67	1.077
	14.0	1.582	1.519	1.1164	1.3538	5.65	1.096
	16.0	1.851	1.765	1.1352	1.3570	6.74	1.119
	18.0	2.133	2.020	1.1546	1.3604		1.144
	20.0	2.430	2.283	1.1745	1.3638		1.174
	22.0	2.741	2.555	1.1951	1.3673		1.207
	24.0	3.069	2.837	1.2163	1.3708		1.244
	26.0	3.415	3.129	1.2382	1.3745		1.287
	28.0	3.780	3.431	1.2608	1.3783		1.336
	30.0	4.165	3.744	1.2842	1.3822		1.395
	32.0	4.574	4.069	1.3083	1.3862		1.465

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	34.0	5.007	4.406	1.3333	1.3903		1.546
	36.0	5.467	4.755	1.3592	1.3946		1.639
	38.0	5.957	5.119	1.3860	1.3990		1.745
	40.0	6.479	5.496	1.4138	1.4035		1.866
Sodium	0.5	0.047	0.047	1.0034	1.3341	0.22	1.025
carbonate	1.0	0.095	0.095	1.0086	1.3352	0.43	1.049
Na_2CO_3	2.0	0.193	0.192	1.0190	1.3375	0.75	1.102
	3.0	0.292	0.291	1.0294	1.3397	1.08	1.159
	4.0	0.393	0.392	1.0398	1.3419	1.42	1.222
	5.0	0.497	0.495	1.0502	1.3440	1.77	1.292
	6.0	0.602	0.600	1.0606	1.3462	2.13	1.367
	7.0	0.710	0.707	1.0711	1.3483		1.448
	8.0	0.820	0.816	1.0816	1.3504		1.538
	9.0	0.933	0.927	1.0922	1.3525		1.638
	10.0	1.048	1.041	1.1029	1.3547		1.754
	11.0	1.166	1.156	1.1136	1.3568		1.884
	12.0	1.287	1.273	1.1244	1.3589		2.028
	13.0	1.410	1.392	1.1353	1.3610		2.186
	14.0	1.536	1.514	1.1463	1.3631		2.361
	15.0	1.665	1.638	1.1574	1.3652		2.551
Sodium	0.5	0.086	0.086	1.0018	1.3339	0.30	1.011
chloride	1.0	0.173	0.172	1.0053	1.3347	0.59	1.020
NaCl	2.0	0.349	0.346	1.0125	1.3365	1.19	1.036
	3.0	0.529	0.523	1.0196	1.3383	1.79	1.052
	4.0	0.713	0.703	1.0268	1.3400	2.41	1.068
	5.0	0.901	0.885	1.0340	1.3418	3.05	1.085
	6.0	1.092	1.069	1.0413	1.3435	3.70	1.104
	7.0	1.288	1.256	1.0486	1.3453	4.38	1.124
	8.0	1.488	1.445	1.0559	1.3470	5.08	1.145
	9.0	1.692	1.637	1.0633	1.3488	5.81	1.168
	10.0	1.901	1.832	1.0707	1.3505	6.56	1.193
	12.0	2.333	2.229	1.0857	1.3541	8.18	1.250
	14.0	2.785	2.637	1.1008	1.3576	9.94	1.317
	16.0	3.259	3.056	1.1162	1.3612	11.89	1.388
	18.0	3.756	3.486	1.1319	1.3648	14.04	1.463
	20.0	4.278	3.928	1.1478	1.3684	16.46	1.557
	22.0	4.826	4.382	1.1640	1.3721	19.18	1.676
	24.0	5.403	4.847	1.1804	1.3757		1.821
	26.0	6.012	5.326	1.1972	1.3795		1.990
Sodium	1.0	0.039	0.039	1.0049	1.3348	0.20	1.043
citrate	2.0	0.079	0.078	1.0120	1.3366	0.39	1.081
$(HO)C(COONa)_3$	3.0	0.120	0.118	1.0186	1.3383	0.59	1.122
	4.0	0.161	0.159	1.0260	1.3401	0.79	1.166
	5.0	0.204	0.200	1.0331	1.3419	0.97	1.210
	6.0	0.247	0.242	1.0405	1.3437	1.17	1.263
	7.0	0.292	0.284	1.0482	1.3455	1.36	1.314
	8.0	0.337	0.327	1.0557	1.3473	1.57	1.371
	9.0	0.383	0.371	1.0632	1.3491	1.77	1.427
	10.0	0.431	0.415	1.0708	1.3509	1.96	1.499
	12.0	0.528	0.505	1.0861	1.3546	2.38	1.649
	14.0	0.631	0.598	1.1019	1.3583	2.82	1.832
	16.0	0.738	0.693	1.1173	1.3618	3.27	2.045
	18.0	0.851	0.790	1.1327	1.3656	3.82	2.290
	20.0	0.969	0.891	1.1492	1.3693	4.39	2.596

Solute	Mass %	m/mol kg^{-1}	c/mol L^{-1}	ρ/g cm^{-3}	n	Δ/°C	η/mPa s
	24.0	1.224	1.099	1.1813	1.3767		3.409
	28.0	1.507	1.318	1.2151	1.3845		4.586
	32.0	1.823	1.548	1.2487	1.3923		6.541
	36.0	2.180	1.792	1.2843	1.4001		9.788
Sodium	0.5	0.126	0.125	1.0039	1.3344	0.43	1.027
hydroxide	1.0	0.253	0.252	1.0095	1.3358	0.86	1.054
NaOH	2.0	0.510	0.510	1.0207	1.3386	1.74	1.112
	3.0	0.773	0.774	1.0318	1.3414	2.64	1.176
	4.0	1.042	1.043	1.0428	1.3441	3.59	1.248
	5.0	1.316	1.317	1.0538	1.3467	4.57	1.329
	6.0	1.596	1.597	1.0648	1.3494	5.60	1.416
	7.0	1.882	1.883	1.0758	1.3520	6.69	1.510
	8.0	2.174	2.174	1.0869	1.3546	7.87	1.616
	9.0	2.473	2.470	1.0979	1.3572	9.12	1.737
	10.0	2.778	2.772	1.1089	1.3597	10.47	1.882
	12.0	3.409	3.393	1.1309	1.3648	13.42	2.201
	14.0	4.070	4.036	1.1530	1.3697	16.76	2.568
	15.0	4.412	4.365	1.1640	1.3722		2.789
	16.0	4.762	4.701	1.1751	1.3746		3.043
	18.0	5.488	5.387	1.1971	1.3793		3.698
	20.0	6.250	6.096	1.2192	1.3840		4.619
	22.0	7.052	6.827	1.2412	1.3885		5.765
	24.0	7.895	7.579	1.2631	1.3929		7.100
	26.0	8.784	8.352	1.2848	1.3971		8.744
	28.0	9.723	9.145	1.3064	1.4012		10.832
	30.0	10.715	9.958	1.3277	1.4051		13.517
	32.0	11.766	10.791	1.3488	1.4088		16.844
	34.0	12.880	11.643	1.3697	1.4123		20.751
	36.0	14.064	12.512	1.3901	1.4156		25.290
	38.0	15.324	13.398	1.4102	1.4186		30.461
	40.0	16.668	14.300	1.4299	1.4215		36.312
Sodium	0.5	0.059	0.059	1.0016	1.3336	0.20	1.004
nitrate	1.0	0.119	0.118	1.0050	1.3341	0.40	1.007
$NaNO_3$	2.0	0.240	0.238	1.0117	1.3353	0.79	1.012
	3.0	0.364	0.359	1.0185	1.3364	1.18	1.018
	4.0	0.490	0.483	1.0254	1.3375	1.56	1.025
	5.0	0.619	0.607	1.0322	1.3387	1.94	1.032
	6.0	0.751	0.734	1.0392	1.3398	2.32	1.040
	7.0	0.886	0.862	1.0462	1.3409	2.70	1.049
	8.0	1.023	0.991	1.0532	1.3421	3.08	1.059
	9.0	1.164	1.123	1.0603	1.3432	3.46	1.069
	10.0	1.307	1.256	1.0674	1.3443	3.84	1.081
	12.0	1.604	1.527	1.0819	1.3466	4.60	1.107
	14.0	1.915	1.806	1.0967	1.3489	5.37	1.138
	18.0	2.583	2.387	1.1272	1.3536	6.98	1.215
	20.0	2.941	2.689	1.1429	1.3559	7.81	1.263
	30.0	5.042	4.326	1.2256	1.3678		1.609
	40.0	7.844	6.200	1.3175	1.3802		2.226
Sodium	0.5	0.031	0.031	1.0042	1.3343	0.19	1.033
phosphate	1.0	0.062	0.062	1.0100	1.3356	0.37	1.064
Na_3PO_4	1.5	0.093	0.093	1.0158	1.3369	0.53	1.094
	2.0	0.124	0.125	1.0216	1.3381	0.67	1.126
	2.5	0.156	0.157	1.0275	1.3394	0.79	1.161
	3.0	0.189	0.189	1.0335	1.3406		1.198

Solute	Mass %	*m*/mol kg⁻¹	*c*/mol L⁻¹	ρ/g cm⁻³	*n*	Δ/°C	η/mPa s
	3.5	0.221	0.222	1.0395	1.3419		1.238
	4.0	0.254	0.255	1.0456	1.3432		1.281
	4.5	0.287	0.289	1.0517	1.3444		1.327
	5.0	0.321	0.323	1.0579	1.3457		1.375
	5.5	0.355	0.357	1.0642	1.3470		1.426
	6.0	0.389	0.392	1.0705	1.3482		1.480
	6.5	0.424	0.427	1.0768	1.3495		1.538
	7.0	0.459	0.462	1.0832	1.3507		1.598
	7.5	0.495	0.498	1.0896	1.3519		1.662
	8.0	0.530	0.535	1.0961	1.3532		1.729
Sodium hydrogen	0.5	0.035	0.035	1.0032	1.3340	0.17	1.021
phosphate	1.0	0.071	0.071	1.0082	1.3349	0.32	1.042
Na_2HPO_4	1.5	0.107	0.107	1.0131	1.3358	0.46	1.064
	2.0	0.144	0.143	1.0180	1.3368		1.088
	2.5	0.181	0.180	1.0229	1.3377		1.113
	3.0	0.218	0.217	1.0279	1.3386		1.138
	3.5	0.255	0.255	1.0328	1.3396		1.165
	4.0	0.293	0.292	1.0378	1.3405		1.193
	4.5	0.332	0.331	1.0428	1.3414		1.223
	5.0	0.371	0.369	1.0478	1.3424		1.254
	5.5	0.410	0.408	1.0528	1.3433		1.286
Sodium	0.5	0.042	0.042	1.0019	1.3336	0.14	1.018
dihydrogen	1.0	0.084	0.084	1.0056	1.3343	0.28	1.035
phosphate	1.5	0.127	0.126	1.0094	1.3349	0.42	1.051
NaH_2PO_4	2.0	0.170	0.169	1.0131	1.3356	0.56	1.068
	2.5	0.214	0.212	1.0168	1.3362	0.70	1.085
	3.0	0.258	0.255	1.0206	1.3369	0.84	1.103
	3.5	0.302	0.299	1.0244	1.3375	0.98	1.121
	4.0	0.347	0.343	1.0281	1.3382	1.12	1.140
	4.5	0.393	0.387	1.0319	1.3388	1.25	1.160
	5.0	0.439	0.432	1.0358	1.3395	1.39	1.180
	6.0	0.532	0.522	1.0434	1.3408	1.65	1.223
	7.0	0.627	0.613	1.0511	1.3421	1.89	1.270
	8.0	0.725	0.706	1.0589	1.3434	2.12	1.319
	9.0	0.824	0.800	1.0668	1.3447	2.35	1.371
	10.0	0.926	0.896	1.0747	1.3460	2.58	1.428
	12.0	1.137	1.091	1.0907	1.3486	3.06	1.552
	14.0	1.357	1.292	1.1070	1.3512	3.53	1.694
	16.0	1.588	1.499	1.1236	1.3538	4.03	1.861
	18.0	1.830	1.711	1.1404	1.3565	4.55	2.050
	20.0	2.084	1.930	1.1576	1.3592	5.10	2.283
	22.0	2.351	2.155	1.1752	1.3618		2.550
	24.0	2.632	2.387	1.1931	1.3646		2.850
	26.0	2.929	2.625	1.2113	1.3673		3.214
	28.0	3.242	2.870	1.2299	1.3700		3.682
	30.0	3.572	3.123	1.2488	1.3728		4.300
	32.0	3.923	3.383	1.2682	1.3756		5.079
	34.0	4.294	3.650	1.2879	1.3784		6.008
	36.0	4.689	3.925	1.3080	1.3812		7.098
	38.0	5.109	4.208	1.3285	1.3840		8.363
	40.0	5.557	4.499	1.3493	1.3869		9.814
Sodium	0.5	0.035	0.035	1.0027	1.3338	0.17	1.013
sulfate	1.0	0.071	0.071	1.0071	1.3345	0.32	1.026
Na_2SO_4	2.0	0.144	0.143	1.0161	1.3360	0.61	1.058

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	3.0	0.218	0.217	1.0252	1.3376	0.87	1.091
	4.0	0.293	0.291	1.0343	1.3391	1.13	1.126
	5.0	0.371	0.367	1.0436	1.3406	1.36	1.163
	6.0	0.449	0.445	1.0526	1.3420	1.56	1.202
	7.0	0.530	0.523	1.0619	1.3435		1.244
	8.0	0.612	0.603	1.0713	1.3449		1.289
	9.0	0.696	0.685	1.0808	1.3464		1.337
	10.0	0.782	0.768	1.0905	1.3479		1.390
	12.0	0.960	0.938	1.1101	1.3509		1.508
	14.0	1.146	1.114	1.1301	1.3539		1.646
	16.0	1.341	1.296	1.1503	1.3567		1.812
	18.0	1.545	1.483	1.1705	1.3595		2.005
	20.0	1.760	1.677	1.1907	1.3620		2.227
	22.0	1.986	1.875	1.2106	1.3643		2.481
Sodium	0.5	0.032	0.032	1.0024	1.3340	0.14	1.012
thiosulfate	1.0	0.064	0.064	1.0065	1.3351	0.28	1.023
$Na_2S_2O_3$	2.0	0.129	0.128	1.0148	1.3371	0.57	1.044
	3.0	0.196	0.194	1.0231	1.3392	0.84	1.066
	4.0	0.264	0.261	1.0315	1.3413	1.09	1.090
	5.0	0.333	0.329	1.0399	1.3434	1.34	1.115
	6.0	0.404	0.398	1.0483	1.3454	1.59	1.141
	7.0	0.476	0.468	1.0568	1.3475	1.83	1.169
	8.0	0.550	0.539	1.0654	1.3496	2.06	1.199
	9.0	0.626	0.611	1.0740	1.3517	2.30	1.231
	10.0	0.703	0.685	1.0827	1.3538	2.55	1.267
	12.0	0.862	0.835	1.1003	1.3581	3.06	1.345
	14.0	1.030	0.990	1.1182	1.3624	3.60	1.435
	16.0	1.205	1.150	1.1365	1.3667	4.17	1.537
	18.0	1.388	1.315	1.1551	1.3711	4.76	1.657
	20.0	1.581	1.485	1.1740	1.3756	5.37	1.798
	30.0	2.711	2.417	1.2739	1.3987		2.903
	40.0	4.216	3.498	1.3827	1.4229		5.758
Strontium	0.5	0.032	0.032	1.0027	1.3339	0.16	1.012
chloride	1.0	0.064	0.064	1.0071	1.3348	0.31	1.021
$SrCl_2$	2.0	0.129	0.128	1.0161	1.3366	0.62	1.039
	3.0	0.195	0.194	1.0252	1.3384	0.93	1.057
	4.0	0.263	0.261	1.0344	1.3402	1.26	1.076
	5.0	0.332	0.329	1.0437	1.3421	1.61	1.096
	6.0	0.403	0.399	1.0532	1.3440	1.98	1.116
	7.0	0.475	0.469	1.0628	1.3459	2.38	1.136
	8.0	0.549	0.541	1.0726	1.3478	2.80	1.157
	9.0	0.624	0.615	1.0825	1.3498	3.25	1.180
	10.0	0.701	0.689	1.0925	1.3518	3.74	1.204
	12.0	0.860	0.843	1.1131	1.3558	4.81	1.258
	14.0	1.027	1.002	1.1342	1.3599	6.03	1.317
	16.0	1.202	1.167	1.1558	1.3641	7.41	1.383
	18.0	1.385	1.338	1.1780	1.3684	8.98	1.460
	20.0	1.577	1.515	1.2008	1.3728	10.74	1.549
	22.0	1.779	1.699	1.2241	1.3772	12.74	1.650
	24.0	1.992	1.890	1.2481	1.3817	14.99	1.765
	26.0	2.216	2.087	1.2728	1.3864		1.897
	28.0	2.453	2.293	1.2983	1.3911		2.056
	30.0	2.703	2.507	1.3248	1.3961		2.245
	32.0	2.968	2.730	1.3523	1.4013		2.527

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	34.0	3.250	2.962	1.3811	1.4067		2.846
	36.0	3.548	3.205	1.4114	1.4124		3.206
Sucrose	0.5	0.015	0.015	1.0002	1.3337	0.03	1.015
$C_{12}H_{22}O_{11}$	1.0	0.030	0.029	1.0021	1.3344	0.06	1.028
	2.0	0.060	0.059	1.0060	1.3359	0.11	1.055
	3.0	0.090	0.089	1.0099	1.3373	0.17	1.084
	4.0	0.122	0.118	1.0139	1.3388	0.23	1.114
	5.0	0.154	0.149	1.0178	1.3403	0.29	1.146
	6.0	0.186	0.179	1.0218	1.3418	0.35	1.179
	7.0	0.220	0.210	1.0259	1.3433	0.42	1.215
	8.0	0.254	0.241	1.0299	1.3448	0.49	1.254
	9.0	0.289	0.272	1.0340	1.3463	0.55	1.294
	10.0	0.325	0.303	1.0381	1.3478	0.63	1.336
	12.0	0.398	0.367	1.0465	1.3509	0.77	1.429
	14.0	0.476	0.431	1.0549	1.3541	0.93	1.534
	16.0	0.556	0.497	1.0635	1.3573	1.10	1.653
	18.0	0.641	0.564	1.0722	1.3606	1.27	1.790
	20.0	0.730	0.632	1.0810	1.3639	1.47	1.945
	22.0	0.824	0.700	1.0899	1.3672	1.67	2.124
	24.0	0.923	0.771	1.0990	1.3706	1.89	2.331
	26.0	1.026	0.842	1.1082	1.3741	2.12	2.573
	28.0	1.136	0.914	1.1175	1.3776	2.37	2.855
	30.0	1.252	0.988	1.1270	1.3812	2.64	3.187
	32.0	1.375	1.063	1.1366	1.3848	2.94	3.762
	34.0	1.505	1.139	1.1464	1.3885	3.27	4.052
	36.0	1.643	1.216	1.1562	1.3922	3.63	4.621
	38.0	1.791	1.295	1.1663	1.3960	4.02	5.315
	40.0	1.948	1.375	1.1765	1.3999	4.45	6.162
	42.0	2.116	1.456	1.1868	1.4038	4.93	7.234
	44.0	2.295	1.539	1.1972	1.4078		8.596
	46.0	2.489	1.623	1.2079	1.4118		10.301
	48.0	2.697	1.709	1.2186	1.4159		12.515
	50.0	2.921	1.796	1.2295	1.4201		15.431
	60.0	4.382	2.255	1.2864	1.4419		58.487
	70.0	6.817	2.755	1.3472	1.4654		481.561
	80.0	11.686	3.299	1.4117	1.4906		
Sulfuric acid	0.5	0.051	0.051	1.0016	1.3336	0.21	1.010
H_2SO_4	1.0	0.103	0.102	1.0049	1.3342	0.42	1.019
	2.0	0.208	0.206	1.0116	1.3355	0.80	1.036
	3.0	0.315	0.311	1.0183	1.3367	1.17	1.059
	4.0	0.425	0.418	1.0250	1.3379	1.60	1.085
	5.0	0.537	0.526	1.0318	1.3391	2.05	1.112
	6.0	0.651	0.635	1.0385	1.3403	2.50	1.136
	7.0	0.767	0.746	1.0453	1.3415	2.95	1.159
	8.0	0.887	0.858	1.0522	1.3427	3.49	1.182
	9.0	1.008	0.972	1.0591	1.3439	4.08	1.206
	10.0	1.133	1.087	1.0661	1.3451	4.64	1.230
	12.0	1.390	1.322	1.0802	1.3475	5.93	1.282
	14.0	1.660	1.563	1.0947	1.3500	7.49	1.337
	16.0	1.942	1.810	1.1094	1.3525	9.26	1.399
	18.0	2.238	2.064	1.1245	1.3551	11.29	1.470
	20.0	2.549	2.324	1.1398	1.3576	13.64	1.546
	22.0	2.876	2.592	1.1554	1.3602	16.48	1.624
	24.0	3.220	2.866	1.1714	1.3628	19.85	1.706
	26.0	3.582	3.147	1.1872	1.3653	24.29	1.797
	28.0	3.965	3.435	1.2031	1.3677	29.65	1.894

Solute	Mass %	m/mol kg^{-1}	c/mol L^{-1}	ρ/g cm^{-3}	n	Δ/°C	η/mPa s
	30.0	4.370	3.729	1.2191	1.3701	36.21	2.001
	32.0	4.798	4.030	1.2353	1.3725	44.76	2.122
	34.0	5.252	4.339	1.2518	1.3749	55.28	2.255
	36.0	5.735	4.656	1.2685	1.3773		2.392
	38.0	6.249	4.981	1.2855	1.3797		2.533
	40.0	6.797	5.313	1.3028	1.3821		2.690
	42.0	7.383	5.655	1.3205	1.3846		2.872
	44.0	8.011	6.005	1.3386	1.3870		3.073
	46.0	8.685	6.364	1.3570	1.3895		3.299
	48.0	9.411	6.734	1.3759	1.3920		3.546
	50.0	10.196	7.113	1.3952	1.3945		3.826
	52.0	11.045	7.502	1.4149	1.3971		4.142
	54.0	11.969	7.901	1.4351	1.3997		4.499
	56.0	12.976	8.312	1.4558	1.4024		4.906
	58.0	14.080	8.734	1.4770	1.4050		5.354
	60.0	15.294	9.168	1.4987	1.4077		5.917
	70.0	23.790	11.494	1.6105			
	80.0	40.783	14.088	1.7272			
	90.0	91.762	16.649	1.8144			
	92.0	117.251	17.109	1.8240			
	94.0	159.734	17.550	1.8312			
	96.0	244.698	17.966	1.8355			
	98.0	499.592	18.346	1.8361			
	100.0		18.663	1.8305			
Trichloroacetic acid CCl_3COOH	0.5	0.031	0.031	1.0008	1.3337	0.11	1.011
	1.0	0.062	0.061	1.0034	1.3343	0.21	1.021
	2.0	0.125	0.123	1.0083	1.3356	0.42	1.044
	3.0	0.189	0.186	1.0133	1.3369	0.64	1.069
	4.0	0.255	0.249	1.0182	1.3381	0.86	1.096
	5.0	0.322	0.313	1.0230	1.3394	1.08	1.123
	6.0	0.391	0.377	1.0279	1.3406	1.30	1.150
	7.0	0.461	0.442	1.0328	1.3418	1.53	1.177
	8.0	0.532	0.508	1.0378	1.3431	1.76	1.204
	9.0	0.605	0.574	1.0428	1.3444	1.99	1.233
	10.0	0.680	0.641	1.0479	1.3456	2.23	1.263
	12.0	0.835	0.777	1.0583	1.3483	2.73	1.326
	14.0	0.996	0.916	1.0692	1.3510	3.26	1.393
	16.0	1.166	1.058	1.0806	1.3539	3.82	1.462
	18.0	1.343	1.203	1.0921	1.3568		1.533
	20.0	1.530	1.351	1.1035	1.3597		1.608
	24.0	1.933	1.654	1.1260	1.3652		1.768
	28.0	2.380	1.968	1.1485	1.3705		1.935
	32.0	2.880	2.294	1.1713	1.3759		2.118
	36.0	3.443	2.632	1.1947	1.3813		2.320
	40.0	4.080	2.984	1.2188	1.3868		1.543
	44.0	4.809	3.349	1.2435	1.3923		2.797
	48.0	5.650	3.726	1.2682	1.3977		3.076
Tris (hydroxymethyl)-methylamine $H_2NC(CH_2OH)_3$	0.5	0.041	0.041	0.9994	1.3337	0.08	1.014
	1.0	0.083	0.083	1.0006	1.3344	0.16	1.027
	2.0	0.168	0.166	1.0030	1.3359	0.31	1.054
	3.0	0.255	0.249	1.0054	1.3374	0.47	1.083
	4.0	0.344	0.333	1.0078	1.3388	0.64	1.115
	5.0	0.434	0.417	1.0103	1.3403	0.80	1.148
	6.0	0.527	0.502	1.0128	1.3418	0.97	1.182

Solute	Mass %	*m*/mol kg^{-1}	*c*/mol L^{-1}	ρ/g cm^{-3}	*n*	Δ/°C	η/mPa s
	7.0	0.621	0.587	1.0153	1.3433	1.15	1.218
	8.0	0.718	0.672	1.0179	1.3448	1.33	1.256
	9.0	0.816	0.758	1.0204	1.3463	1.51	1.295
	10.0	0.917	0.844	1.0230	1.3478	1.70	1.337
	12.0	1.126	1.019	1.0282	1.3508	2.08	1.427
	14.0	1.344	1.194	1.0335	1.3539	2.47	1.527
	16.0	1.572	1.372	1.0389	1.3570	2.90	1.642
	18.0	1.812	1.552	1.0443	1.3601	3.36	1.772
	20.0	2.064	1.733	1.0498	1.3633	3.85	1.920
	30.0	3.538	2.670	1.0781	1.3797		2.998
	40.0	5.503	3.657	1.1076	1.3970		5.208
Urea	0.5	0.084	0.083	0.9995	1.3337	0.16	1.007
$(NH_2)_2CO$	1.0	0.168	0.167	1.0007	1.3344	0.31	1.010
	2.0	0.340	0.334	1.0033	1.3358	0.62	1.012
	3.0	0.515	0.502	1.0058	1.3372	0.93	1.017
	4.0	0.694	0.672	1.0085	1.3387	1.24	1.025
	5.0	0.876	0.842	1.0111	1.3401	1.55	1.033
	6.0	1.063	1.013	1.0138	1.3416	1.88	1.041
	7.0	1.253	1.185	1.0165	1.3431	2.22	1.049
	8.0	1.448	1.358	1.0192	1.3446	2.56	1.057
	9.0	1.647	1.531	1.0220	1.3461	2.91	1.065
	10.0	1.850	1.706	1.0248	1.3476	3.26	1.074
	12.0	2.270	2.059	1.0304	1.3506	3.95	1.091
	14.0	2.710	2.415	1.0360	1.3537	4.66	1.109
	16.0	3.171	2.775	1.0417	1.3568	5.40	1.130
	18.0	3.655	3.139	1.0473	1.3599	6.19	1.153
	20.0	4.163	3.506	1.0530	1.3629	7.00	1.178
	22.0	4.696	3.878	1.0586	1.3661	7.81	1.205
	24.0	5.258	4.253	1.0643	1.3692	8.64	1.235
	26.0	5.850	4.632	1.0699	1.3723	9.52	1.266
	28.0	6.475	5.014	1.0756	1.3754	10.45	1.298
	30.0	7.136	5.401	1.0812	1.3785	11.40	1.332
	32.0	7.835	5.791	1.0869	1.3817	12.34	1.371
	34.0	8.577	6.185	1.0926	1.3848	13.27	1.413
	36.0	9.366	6.584	1.0984	1.3881	14.20	1.459
	38.0	10.205	6.988	1.1044	1.3913	15.11	1.509
	40.0	11.100	7.397	1.1106	1.3947	15.99	1.565
	42.0	12.057	7.812	1.1171	1.3982	16.83	1.629
	44.0	13.082	8.234	1.1239	1.4018	17.62	1.700
	46.0	14.183	8.665	1.1313	1.4056		1.780
Zinc sulfate	0.5	0.031	0.031	1.0034	1.3339	0.08	1.021
$ZnSO_4$	1.0	0.063	0.062	1.0085	1.3348	0.15	1.040
	2.0	0.126	0.126	1.0190	1.3366	0.28	1.081
	3.0	0.192	0.191	1.0296	1.3384	0.41	1.126
	4.0	0.258	0.258	1.0403	1.3403	0.53	1.175
	5.0	0.326	0.326	1.0511	1.3421	0.65	1.227
	6.0	0.395	0.395	1.0620	1.3439	0.77	1.283
	7.0	0.466	0.465	1.0730	1.3457	0.89	1.341
	8.0	0.539	0.537	1.0842	1.3475	1.01	1.403
	9.0	0.613	0.611	1.0956	1.3494	1.14	1.470
	10.0	0.688	0.686	1.1071	1.3513	1.27	1.545
	12.0	0.845	0.840	1.1308	1.3551	1.55	1.716
	14.0	1.008	1.002	1.1553	1.3590	1.89	1.918
	16.0	1.180	1.170	1.1806	1.3630	2.31	2.152

ION PRODUCT OF WATER SUBSTANCE
William L. Marshall and E. U. Franck

Pressure (bars)	Temperature (°C) 0	25	50	75	100	150	200	250	300
Saturated vapor	14.938	13.995	13.275	12.712	12.265	11.638	11.289	11.191	11.406
250	14.83	13.90	13.19	12.63	12.18	11.54	11.16	11.01	11.14
500	14.72	13.82	13.11	12.55	12.10	11.45	11.05	10.85	10.86
750	14.62	13.73	13.04	12.48	12.03	11.36	10.95	10.72	10.66
1,000	14.53	13.66	12.96	12.41	11.96	11.29	10.86	10.60	10.50
1,500	14.34	13.53	12.85	12.29	11.84	11.16	10.71	10.43	10.26
2,000	14.21	13.40	12.73	12.18	11.72	11.04	10.57	10.27	10.08
2,500	14.08	13.28	12.62	12.07	11.61	10.92	10.45	10.12	9.91
3,000	13.97	13.18	12.53	11.98	11.53	10.83	10.34	9.99	9.76
3,500	13.87	13.09	12.44	11.90	11.44	10.74	10.24	9.88	9.63
4,000	13.77	13.00	12.35	11.82	11.37	10.66	10.16	9.79	9.52
5,000	13.60	12.83	12.19	11.66	11.22	10.52	10.00	9.62	9.34
6,000	13.44	12.68	12.05	11.53	11.09	10.39	9.87	9.48	9.18
7,000	13.31	12.55	11.93	11.41	10.97	10.27	9.75	9.35	9.04
8,000	13.18	12.43	11.82	11.30	10.86	10.17	9.64	9.24	8.93
9,000	13.04	12.31	11.71	11.20	10.77	10.07	9.54	9.13	8.82
10,000	12.91	12.21	11.62	11.11	10.68	9.98	9.45	9.04	8.71

Pressure (bars)	Temperature (°C) 350	400	450	500	600	700	800	900	1000
Saturated vapor	12.30	—	—	—	—	—	—	—	—
250	11.77	19.43	21.59	22.40	23.27	23.81	24.23	24.59	24.93
500	11.14	11.88	13.74	16.13	18.30	19.29	19.92	20.39	20.80
750	10.79	11.17	11.89	13.01	15.25	16.55	17.35	17.93	18.39
1,000	10.54	10.77	11.19	11.81	13.40	14.70	15.58	16.22	16.72
1,500	10.22	10.29	10.48	10.77	11.59	12.50	13.30	13.97	14.50
2,000	9.98	9.98	10.07	10.23	10.73	11.36	11.98	12.54	12.97
2,500	9.79	9.74	9.77	9.86	10.18	10.63	11.11	11.59	12.02
3,000	9.61	9.54	9.53	9.57	9.78	10.11	10.49	10.89	11.24
3,500	9.47	9.37	9.33	9.34	9.48	9.71	10.02	10.35	10.62
4,000	9.34	9.22	9.16	9.15	9.23	9.41	9.65	9.93	10.13
5,000	9.13	8.99	8.90	8.85	8.85	8.95	9.11	9.30	9.42
6,000	8.96	8.80	8.69	8.62	8.57	8.61	8.72	8.86	8.97
7,000	8.81	8.64	8.51	8.42	8.34	8.34	8.40	8.51	8.64
8,000	8.68	8.50	8.36	8.25	8.13	8.10	8.13	8.21	8.38
9,000	8.57	8.37	8.22	8.10	7.95	7.89	7.89	7.95	8.12
10,000	8.46	8.25	8.09	7.96	7.78	7.70	7.68	7.70	7.85

Data in this table were calculated from the equation, $\log_{10} K_w^* = A + B/T + C/T^2 + D/T^3 + (E + F/T + G/T^2) \log_{10} \rho_w^*$, where $K_w^* = K_w/(\text{mol kg}^{-1})$, and $\rho_w^* = \rho_w/(\text{g cm}^{-3})$. The parameters are:

$A = -4.098$
$B = -3245.2$ K
$C = +2.2362 \times 10^5$ K^2
$D = -3.984 \times 10^7$ K^3

$E = +13.957$
$F = 1262.3$ K
$G = +8.5641 \times 10^5$ K^2

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IONIZATION CONSTANT OF NORMAL AND HEAVY WATER

This table gives the ionization constant in molality terms for H_2O and D_2O at temperatures from 0 to 100°C at the saturated vapor pressure. The quantity tabulated is $-\log K_W$, where K_W is defined by

$$K_W = m_+ \times m_-$$

and m_+ and m_- are the molalities, in mol/kg of water, for H^+ and OH^-, respectively.

REFERENCES

1. W.L. Marshall and E.U. Franck, *J. Phys. Chem. Ref. Data*, 10, 295, 1981.
2. R.E. Mesmer and D.L. Herting, *J. Solution Chem.*, 7, 901, 1978.

	$-\log K_W$	
***t*/°C**	**H_2O**	**D_2O**
0	14.938	15.972
5	14.727	15.743
10	14.528	15.527
15	14.340	15.324
20	14.163	15.132
25	13.995	14.951
30	13.836	14.779
35	13.685	14.616
40	13.542	14.462
45	13.405	14.316
50	13.275	14.176
55	13.152	14.044
60	13.034	13.918
65	12.921	13.798
70	12.814	13.683
75	12.712	13.574
80	12.613	13.470
85	12.520	13.371
90	12.428	13.276
95	12.345	13.186
100	12.265	13.099

SOLUBILITY OF SELECTED GASES IN WATER

L. H. Gevantman

The values in this table are taken almost exclusively from the International Union of Pure and Applied Chemistry "Solubility Data Series". Unless noted, they comprise evaluated data fitted to a smoothing equation. The data at each temperature are then derived from the smoothing equation which expresses the mole fraction solubility X_1 of the gas in solution as:

$$\ln X_1 = A + B/T^* + C \ln T^*$$

where

$$T^* = T/100 \text{ K}$$

All values refer to a partial pressure of the gas of 101.325 kPa (one atmosphere).

The equation constants, the standard deviation for $\ln X_1$ (except where noted), and the temperature range over which the equation applies are given in the column headed Equation constants. There are two exceptions. The equation for methane has an added term, DT^*. The equation for H_2Se and H_2S takes the form,

$$\ln X_1 = A + B/T + C \ln T + DT$$

where T is the temperature in kelvin.

Solubilities given for those gases which react with water, namely ozone, nitrogen oxides, chlorine and its oxides, carbon dioxide, hydrogen sulfide, hydrogen selenide and sulfur dioxide, are recorded as bulk solubilities; i.e., all chemical species of the gas and its reaction products with water are included.

Gas	T/K	Solubility (X_1)	Equation constants	Ref.
Hydrogen (H_2)	288.15	1.510×10^{-5}	A = –48.1611	1
M_r = 2.01588	293.15	1.455×10^{-5}	B = 55.2845	
	298.15	1.411×10^{-5}	C = 16.8893	
	303.15	1.377×10^{-5}	Std. dev. = ± 0.54%	
	308.15	1.350×10^{-5}	Temp.range = 273.15—353.15	
Deuterium (D_2)	283.15	1.675×10^{-5} ± 0.57%	Averaged experimental	1
M_r = 4.0282	288.15	1.595×10^{-5} ± 0.57%	values	
	293.15	1.512×10^{-5} ± 0.78%	Temp. range = 278.15—303.15	
	298.15	1.460×10^{-5} ± 0.52%		
	303.15	1.395×10^{-5} ± 0.37%		
Helium (He)	288.15	7.123×10^{-6}	A = –41.4611	2
A_r = 4.0026	293.15	7.044×10^{-6}	B = 42.5962	
	298.15	6.997×10^{-6}	C = 14.0094	
	303.15	6.978×10^{-6}	Std. dev. = ±0.54%	
	308.15	6.987×10^{-6}	Temp.range = 273.15—348.15	
Neon (Ne)	288.15	8.702×10^{-6}	A = –52.8573	2
A_r = 20.1797	293.15	8.395×10^{-6}	B = 61.0494	
	298.15	8.152×10^{-6}	C = 18.9157	
	303.15	7.966×10^{-6}	Std. dev. = ±0.47%	
	308.15	7.829×10^{-6}	Temp.range = 273.15—348.15	
Argon (Ar)	288.15	3.025×10^{-5}	A = –57.6661	3
A_r = 39.948	293.15	2.748×10^{-5}	B = 74.7627	
	298.15	2.519×10^{-5}	C = 20.1398	
	303.15	2.328×10^{-5}	Std. dev. = ±0.26%	
	308.15	2.169×10^{-5}	Temp.range = 273.15—348.15	
Krypton (Kr)	288.15	5.696×10^{-5}	A = –66.9928	4
A_r = 83.80	293.15	5.041×10^{-5}	B = 91.0166	
	298.15	4.512×10^{-5}	C = 24.2207	

Gas	*T*/K	Solubility (X_1)	Equation constants	Ref.
	303.15	4.079×10^{-5}	Std. dev. = ±0.32%	
	308.15	3.725×10^{-5}	Temp.range = 273.15—353.15	
Xenon (Xe)	288.15	10.519×10^{-5}	$A = -74.7398$	4
A_r = 131.29	293.15	9.051×10^{-5}	$B = 105.210$	
	298.15	7.890×10^{-5}	$C = 27.4664$	
	303.15	6.961×10^{-5}	Std. dev. = ±0.35%	
	308.15	6.212×10^{-5}	Temp.range = 273.15—348.15	
Radon-222(^{222}Rn)	288.15	2.299×10^{-4}	$A = -90.5481$	
A_r = 222	293.15	1.945×10^{-4}	$B = 130.026$	
	298.15	1.671×10^{-4}	$C = 35.0047$	
	303.15	1.457×10^{-4}	Std. dev. = ±1.02%	
	308.15	1.288×10^{-4}	Temp.range = 273.15—373.15	
Oxygen (O_2)	288.15	2.756×10^{-5}	$A = -66.7354$	5
M_r = 31.9988	293.15	2.501×10^{-5}	$B = 87.4755$	
	298.15	2.293×10^{-5}	$C = 24.4526$	
	303.15	2.122×10^{-5}	Std. dev. = ±0.36%	
	308.15	1.982×10^{-5}	Temp.range = 273.15—348.15	
Ozone (O_3)	293.15	$1.885 \times 10^{-6} \pm 10\%$	Experimental value derived	5
M_r = 47.9982		pH = 7.0	from Henry's Law Constant	
Nitrogen (N_2)	288.15	1.386×10^{-5}	$A = -67.3877$	6
M_r = 28.0134	293.15	1.274×10^{-5}	$B = 86.3213$	
	298.15	1.183×10^{-5}	$C = 24.7981$	
	303.15	1.108×10^{-5}	Std. dev. = ±0.72%	
	308.15	1.047×10^{-5}	Temp.range = 273.15—348.15	
Nitrous oxide (N_2O)	288.15	5.948×10^{-4}	$A = -60.7467$	7
M_r = 44.0129	293.15	5.068×10^{-4}	$B = 88.8280$	
	298.15	4.367×10^{-4}	$C = 21.2531$	
	303.15	3.805×10^{-4}	Std. dev. = ±1.2%	
	308.15	3.348×10^{-4}	Temp.range = 273.15—313.15	
Nitric oxide (NO)	288.15	4.163×10^{-5}	$A = -62.8086$	7
M_r = 30.0061	293.15	3.786×10^{-5}	$B = 82.3420$	
	298.15	3.477×10^{-5}	$C = 22.8155$	
	303.15	3.222×10^{-5}	Std. dev. = ±0.76%	
	308.15	3.012×10^{-5}	Temp.range = 273.15—358.15	
Carbon monoxide (CO)	288.15	2.095×10^{-5}	Derived from Henry's	8
M_r = 28.0104	293.15	1.918×10^{-5}	Law Constant Equation	
	298.15	1.774×10^{-5}	Std. dev. = ±0.043%	
	303.15	1.657×10^{-5}	Temp.range = 273.15—328.15	
	308.15	1.562×10^{-5}		
Carbon dioxide (CO_2)	288.15	8.21×10^{-4}	Derived from Henry's	9
M_r = 44.0098	293.15	7.07×10^{-4}	Law Constant Equation	
	298.15	6.15×10^{-4}	Std. dev. = ±1.1%	
	303.15	5.41×10^{-4}	Temp.range = 273.15—353.15	
	308.15	4.80×10^{-4}		
Hydrogen selenide (H_2Se)	288.15	1.80×10^{-3}	$A = 9.15$	10
M_r = 80.976	298.15	1.49×10^{-3}	$B = 974$	
	308.15	1.24×10^{-3}	$C = -3.542$	
			$D = 0.0042$	

Gas	*T*/K	Solubility (X_1)	Equation constants	Ref.
			Std. dev. = ±2.3 × 10^{-5}	
			Temp. range = 288.15—343.15	
Hydrogen sulfide (H_2S)	288.15	2.335 × 10^{-3}	*A* = –24.912	10
M_r = 34.082	293.15	2.075 × 10^{-3}	*B* = 3477	
	298.15	1.85 × 10^{-3}	*C* = 0.3993	
	303.15	1.66 × 10^{-3}	*D* = 0.0157	
	308.15	1.51 × 10^{-3}	Std. dev. = ±6.5 × 10^{-5}	
			Temp. range = 283.15—603.15	
Sulfur dioxide (SO_2)	288.15	3.45 × 10^{-2}	*A* = –25.2629	11
M_r = 64.0648	293.15	2.90 × 10^{-2}	*B* = 45.7552	
	298.15	2.46 × 10^{-2}	*C* = 5.6855	
	303.15	2.10 × 10^{-2}	Std. dev. = ±1.8%	
	308.15	1.80 × 10^{-2}	Temp.range = 278.15—328.15	
Chlorine (Cl_2)	283.15	2.48 × 10^{-3} ± 2%	Experimental data	11
M_r = 70.9054	293.15	1.88 × 10^{-3} ± 2%	Temp.range = 283.15—333.15	
	303.15	1.50 × 10^{-3} ± 2%		
	313.15	1.23 × 10^{-3} ± 2%		
Chlorine monoxide (Cl_2O)	273.15	5.25 × 10^{-1} ± 1%	Experimental data	11
M_r = 86.9048	276.61	4.54 × 10^{-1} ± 1%	Temp. range = 273.15—293.15	
	283.15	4.273 × 10^{-1} ± 1%		
	293.15	3.353 × 10^{-1} ± 1%		
Chlorine dioxide (ClO_2)	288.15	2.67 × 10^{-2}	*A* = 7.9163	11
M_r = 67.4515	293.15	2.20 × 10^{-2}	*B* = 0.4791	
	298.15	1.823 × 10^{-2}	*C* = 11.0593	
	303.15	1.513 × 10^{-2}	Std. dev. = ±4.6%	
	308.15	1.259 × 10^{-2}	Temp.range = 283.15—333.15	
Methane (CH_4)	288.15	3.122 × 10^{-5}	*A* = –115.6477	12
M_r = 16.0428	293.15	2.806 × 10^{-5}	*B* = 155.5756	
	298.15	2.552 × 10^{-5}	*C* = 65.2553	
	303.15	2.346 × 10^{-5}	*D* = –6.6170	
	308.15	2.180 × 10^{-5}	Std. dev. = ±0.056%	
			Temp.range = 273.15—328.15	
Ethane (C_2H_6)	288.15	4.556 × 10^{-5}	*A* = –90.8225	13
M_r = 30.0696	293.15	3.907 × 10^{-5}	*B* = 126.9559	
	298.15	3.401 × 10^{-5}	*C* = 34.7413	
	303.15	3.002 × 10^{-5}	Std. dev. = ±0.13%	
	308.15	2.686 × 10^{-5}	Temp.range = 273.15—323.15	
Propane (C_3H_8)	288.15	3.813 × 10^{-5}	*A* = –102.044	14
M_r = 44.097	293.15	3.200 × 10^{-5}	*B* = 144.345	
	298.15	2.732 × 10^{-5}	*C* = 39.4740	
	303.15	2.370 × 10^{-5}	Std. dev. = ±0.012%	
	308.15	2.088 × 10^{-5}	Temp.range = 273.15—347.15	
Butane (C_4H_{10})	288.15	3.274 × 10^{-5}	*A* = –102.029	14
M_r = 58.123	293.15	2.687 × 10^{-5}	*B* = 146.040	
	298.15	2.244 × 10^{-5}	*C* = 38.7599	
	303.15	1.906 × 10^{-5}	Std. dev. = ±0.026%	
	308.15	1.645 × 10^{-5}	Temp.range = 273.15—349.15	
2-Methyl propane (Isobutane)	288.15	2.333 × 10^{-5}	*A* = –129.714	14

SOLUBILITY OF SELECTED GASES IN WATER (continued)

Gas	*T*/K	Solubility (X_1)	Equation constants	Ref.
(C_4H_{10})	293.15	1.947×10^{-5}	*B* = 183.044	
M_r = 58.123	298.15	1.659×10^{-5}	*C* = 53.4651	
	303.15	1.443×10^{-5}	Std. dev. = ±0.034%	
	308.15	1.278×10^{-5}	Temp.range = 278.15—318.15	

REFERENCES

1. C. L. Young, Ed., *IUPAC Solubility Data Series*, Vol. 5/6, Hydrogen and Deuterium, Pergamon Press, Oxford, England, 1981.
2. H. L. Clever, Ed., *IUPAC Solubility Data Series*, Vol. 1, Helium and Neon, Pergamon Press, Oxford, England, 1979.
3. H. L. Clever, Ed., *IUPAC Solubility Data Series*, Vol. 4, Argon, Pergamon Press, Oxford, England, 1980.
4. H. L. Clever, Ed., *IUPAC Solubility Data Series*, Vol. 2, Krypton, Xenon and Radon, Pergamon Press, Oxford, England, 1979.
5. R. Battino, Ed., *IUPAC Solubility Data Series*, Vol. 7, Oxygen and Ozone, Pergamon Press, Oxford, England, 1981.
6. R. Battino, Ed., *IUPAC Solubility Data Series*, Vol. 10, Nitrogen and Air, Pergamon Press, Oxford, England, 1982.
7. C. L. Young, Ed., *IUPAC Solubility Data Series*, Vol. 8, Oxides of Nitrogen, Pergamon Press, Oxford, England, 1981.
8. R. W. Cargill, Ed., *IUPAC Solubility Data Series*, Vol. 43, Carbon Monoxide, Pergamon Press, Oxford, England, 1990.
9. R. Crovetto, Evaluation of Solubility Data for the System CO_2-H_2O, *J. Phys. Chem. Ref. Data*, 20, 575, 1991.
10. P. G. T. Fogg and C. L. Young, Eds., *IUPAC Solubility Data Series*, Vol. 32, Hydrogen Sulfide, Deuterium Sulfide, and Hydrogen Selenide, Pergamon Press, Oxford, England, 1988.
11. C. L. Young, Ed., *IUPAC Solubility Data Series*, Vol. 12, Sulfur Dioxide, Chlorine, Fluorine and Chlorine Oxides, Pergamon Press, Oxford, England, 1983.
12. H. L. Clever and C. L. Young, Eds., *IUPAC Solubility Data Series*, Vol. 27/28, Methane, Pergamon Press, Oxford, England, 1987.
13. W. Hayduk, Ed., *IUPAC Solubility Data Series*, Vol. 9, Ethane, Pergamon Press, Oxford, England, 1982.
14. W. Hayduk, Ed., *IUPAC Solubility Data Series*, Vol. 24, Propane, Butane and 2-Methylpropane, Pergamon Press, Oxford, England, 1986.

SOLUBILITY OF CARBON DIOXIDE IN WATER AT VARIOUS TEMPERATURES AND PRESSURES

The solubility of CO_2 in water, expressed as mole fraction of CO_2 in the liquid phase, is given for pressures up to atmospheric and temperatures of 0 to 100°C. Note that 1 standard atmosphere equals 101.325 kPa. The references give data over a wider range of temperature and pressure. The estimated accuracy is about 2%.

REFERENCES

1. Carroll, J. J., Slupsky, J. D., and Mather, A. E., *J. Phys. Chem. Ref. Data*, 20, 1201, 1991.
2. Fernandez-Prini, R. and Crovetto, R., *J. Phys. Chem. Ref. Data*, 18, 1231, 1989.
3. Crovetto, R., *J. Phys. Chem. Ref. Data*, 20, 575,1991

1000 × mole fraction of CO_2 in liquid phase

	Partial pressure of CO_2 in kPa						
***t*/°C**	**5**	**10**	**20**	**30**	**40**	**50**	**100**
0	0.067	0.135	0.269	0.404	0.538	0.671	1.337
5	0.056	0.113	0.226	0.338	0.451	0.564	1.123
10	0.048	0.096	0.191	0.287	0.382	0.477	0.950
15	0.041	0.082	0.164	0.245	0.327	0.409	0.814
20	0.035	0.071	0.141	0.212	0.283	0.353	0.704
25	0.031	0.062	0.123	0.185	0.247	0.308	0.614
30	0.027	0.054	0.109	0.163	0.218	0.271	0.541
35	0.024	0.048	0.097	0.145	0.193	0.242	0.481
40	0.022	0.043	0.087	0.130	0.173	0.216	0.431
45	0.020	0.039	0.078	0.117	0.156	0.196	0.389
50	0.018	0.036	0.071	0.107	0.142	0.178	0.354
55	0.016	0.033	0.065	0.098	0.131	0.163	0.325
60	0.015	0.030	0.060	0.090	0.121	0.150	0.300
65	0.014	0.028	0.056	0.084	0.112	0.140	0.279
70	0.013	0.026	0.052	0.079	0.105	0.131	0.261
75	0.012	0.025	0.049	0.074	0.099	0.123	0.245
80	0.012	0.023	0.047	0.070	0.093	0.116	0.232
85	0.011	0.022	0.044	0.067	0.089	0.111	0.221
90	0.011	0.021	0.042	0.064	0.085	0.106	0.211
95	0.010	0.020	0.041	0.061	0.082	0.102	0.203
100	0.010	0.020	0.039	0.059	0.079	0.098	0.196

AQUEOUS SOLUBILITY AND HENRY'S LAW CONSTANTS OF ORGANIC COMPOUNDS

The solubility in water of about 580 organic compounds, including many compounds of environmental interest, is tabulated here. Values are given at 25°C or at the nearest temperature to this where data are available. In some cases solubility values are given at other temperatures as well.

Solubility of solids is defined as the concentration of the compound in a solution that is in equilibrium with the solid phase at the specified temperature and one atmosphere pressure. For liquids whose water mixtures separate into two phases, the solubility given here is the concentration of the compound in the water-rich phase at equilibrium. In the case of gases (i.e., compounds whose vapor pressure at the specified temperature exceeds one atmosphere) the solubility is defined here as the concentration in the water phase when the partial pressure of the compound above the solution is 101.325 kPa (1 atm). Values for gases are marked with an asterisk.

All solubility values are expressed as mass percent of solute, $S = 100\,w_2$, where the mass fraction w_2 is given by $w_2 = m_2/(m_1 + m_2)$. In these equations m_2 is the mass of solute and m_1 the mass of water. This quantity is related to other common measures of solubility as follows:

Molality: $m_2 = 1000w_2/M_2(1\text{-}w_2)$

Mole fraction: $x_2 = (w_2/M_2)/\{(w_2/M_2) + (1\text{-}w_2)/M_1\}$

Mass of solute per 100 g of H_2O: $r_2 = 100w_2/(1\text{-}w_2)$

Here M_2 is the molar mass of the solute and $M_1 = 18.015$ g/mol is the molar mass of water. For small values of S the amount of substance concentration c_2 in moles per liter is approximately $10S/M_2$.

Data have been selected from evaluated sources wherever possible, in particular the *IUPAC Solubility Data Series* (References 1-4). The primary source for each value is listed in the column following the solubility values. The user is cautioned that wide variations of data are found in the literature for the lower solubility compounds.

The table also contains values of the Henry's Law constant k_H, which provides a measure of the partition of a substance between the atmosphere and the aqueous phase. Here k_H is defined as the limit of p_2/c_2 as the concentration approaches zero, where p_2 is the partial pressure of the solute above the solution and c_2 is the concentration in the solution at equilibrium (other formulations of Henry's Law are often used; see Reference 5). The values of k_H listed here are based on direct experimental measurement whenever available, but many of them are simply calculated as the ratio of the pure compound vapor pressure to the solubility. This approximation is reliable only for compounds of very low solubility. In fact, values of k_H found in the literature frequently differ by a factor of two or three, and variations over an order of magnitude are not unusual (Reference 5). Therefore the data given here should be taken only as a rough indication of the true Henry's Law constant, which is difficult to measure precisely.

All values of k_H refer to 25°C. If the vapor pressure of the compound at 25°C is greater than one atmosphere, it can be assumed that the k_H value has been calculated as $101.325/c_2$ kPa m^3/mol. The source of the Henry's Law data is given in the last column. The air-water partition coefficient (i.e., ratio of air concentration to water concentration when both are expressed in the same units) is equal to k_H/RT or $k_H/2.48$ in the units used here.

Compounds are listed by molecular formula following the Hill convention. To locate a compound by name or CAS Registry Number when the molecular formula is not known, use the table "Physical Constants of Organic Compounds" in Section 3 and its indexes to determine the molecular formula.

* Indicates a value of S for a gas at a partial pressure of 101.325 kPa (1 atm) in equilibrium with the solution.

REFERENCES

1. *Solubility Data Series, International Union of Pure and Applied Chemistry, Vol. 15,* Pergamon Press, Oxford, 1982.
2. *Solubility Data Series, International Union of Pure and Applied Chemistry, Vol. 20,* Pergamon Press, Oxford, 1985.
3. *Solubility Data Series, International Union of Pure and Applied Chemistry, Vol. 37,* Pergamon Press, Oxford, 1988.
4. *Solubility Data Series, International Union of Pure and Applied Chemistry, Vol. 38,* Pergamon Press, Oxford, 1988.
5. Mackay, D., and Shiu, W.Y., *J. Phys. Chem. Ref. Data,* 10, 1175, 1981.
6. Pearlman, R.S., and Yalkowsky, S.H., *J. Phys. Chem. Ref. Data,* 13, 975, 1984.
7. Shiu, W.Y., and Mackay, D., *J. Phys. Chem. Ref. Data,* 15, 911, 1986.
8. Varhanickova, D., Lee, S.C., Shiu, W. Y., and Mackay, D., *J. Chem. Eng. Data,* 40, 620, 1995.
9. Miller, M.M., Ghodbane, S., Wasik, S. P., Tewari, Y.B., and Martire, D.E., *J. Chem. Eng. Data,* 29, 184, 1984.
10. Riddick, J.A., Bunger, W.B., and Sakano, T.K., *Organic Solvents, Fourth Edition*, John Wiley & Sons, New York, 1986.
11. Mackay, D., Shiu, W.Y., and Ma, K.C., *Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals*, Vol. I, Lewis Publishers/CRC Press, Boca Raton, FL, 1992.
12. Mackay, D., Shiu, W.Y., and Ma, K.C., *Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals*, Vol. II, Lewis Publishers/CRC Press, Boca Raton, FL, 1992.
13. Mackay, D., Shiu, W.Y., and Ma, K.C., *Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals*, Vol. III, Lewis Publishers/CRC Press, Boca Raton, FL, 1993.
14. Horvath, A.L., *Halogenated Hydrocarbons*, Marcel Dekker, New York, 1982.
15. Howard, P.H., *Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Vol. I,* Lewis Publishers/CRC Press, Boca Raton, FL, 1989.
16. Howard, P.H., *Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Vol. II,* Lewis Publishers/CRC Press, Boca Raton, FL, 1990.
17. Banergee, S., Yalkowsky, S.H., and Valvani, S.C., *Environ. Sci. Technol.*, 14, 1227, 1980.
18. Gevantman, L., in *CRC Handbook of Chemistry and Physics, 77th Edition*, p. 6-3, CRC Press, Boca Raton, FL, 1996.
19. Wilhelm, E., Battino, R., and Wilcock, R.J., *Chem. Rev.*, 77, 219, 1977.
20. Stephenson, R.M., *J. Chem. Eng. Data,* 37, 80, 1992.
21. Stephenson, R.M., Stuart, J., and Tabak, M., *J. Chem. Eng. Data*, 29, 287, 1984.

Mol. Form.	Name	*t*/°C	*S*/mass %	Ref.	k_H/kPa m^3 mol^{-1}	Ref.
$CBrF_3$	Bromotrifluoromethane	25	0.032*	14		
CBr_3F	Tribromofluoromethane	25	0.040	14		
CBr_4	Tetrabromomethane	30	0.024	14		
$CClF_3$	Chlorotrifluoromethane	25	0.009*	10	6.9	13
CCl_2F_2	Dichlorodifluoromethane	20	0.028*	5	41	13
CCl_3F	Trichlorofluoromethane	20	0.11	5	10.2	13
CCl_4	Tetrachloromethane	25	0.065	20	2.99	13
CF_4	Tetrafluoromethane	25	0.00187*	19		
$CHBr_3$	Tribromomethane	25	0.30	5	0.047	13
$CHClF_2$	Chlorodifluoromethane	25	0.30*	10	3.0	13
$CHCl_2F$	Dichlorofluoromethane	25	0.95*	10		
$CHCl_3$	Trichloromethane	25	0.80	20	0.43	13
CHF_3	Trifluoromethane	25	0.09*	14		
CHI_3	Triiodomethane	25	0.012	14		
CH_2BrCl	Bromochloromethane	25	1.7	10	0.18	13
CH_2Br_2	Dibromomethane	25	1.14	14	0.086	13
CH_2ClF	Chlorofluoromethane	25	1.05*	14		
CH_2Cl_2	Dichloromethane	25	1.73	20	0.30	13
CH_2I_2	Diiodomethane	30	0.124	10	0.032	13
CH_3Br	Bromomethane	20	1.80*	5	0.63	13
CH_3Cl	Chloromethane	25	0.535*	5	0.98	13
CH_3F	Fluoromethane	30	0.177*	5		
CH_3I	Iodomethane	20	1.4	10	0.54	13
CH_3NO_2	Nitromethane	25	11.1	10		
CH_4	Methane	25	0.00227*	18	67.4	5
CO	Carbon monoxide	25	0.00276*	18		
CO_2	Carbon dioxide	25	0.1501	18		
CS_2	Carbon disulfide	20	0.210	10		
C_2ClF_5	Chloropentafluoroethane	25	0.006*	10	260	13
$C_2Cl_2F_4$	1,2-Dichlorotetrafluoroethane	25	0.013*	10	127	13
$C_2Cl_3F_3$	1,1,2-Trichlorotrifluoroethane	25	0.017	10	32	13
C_2Cl_4	Tetrachloroethylene	25	0.026	20	1.73	13
$C_2Cl_4F_2$	1,1,2,2-Tetrachloro-1,2-difluoroethane	25	0.012	10		
C_2Cl_6	Hexachloroethane	25	0.0050	5	0.85	13
C_2F_4	Tetrafluoroethylene	25	0.0158*	19		
C_2HCl_3	Trichloroethylene	25	0.11	5	1.03	13
C_2HCl_5	Pentachloroethane	25	0.048	5	0.25	13
C_2H_2	Acetylene	25	0.1081*	19		
$C_2H_2Br_4$	1,1,2,2-Tetrabromoethane	30	0.0651	10		
$C_2H_2Cl_2$	1,1-Dichloroethylene	25	0.040	5	2.62	13
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethylene	25	0.35	5	0.46	13
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethylene	25	0.63	5	0.96	13
$C_2H_2Cl_4$	1,1,1,2-Tetrachloroethane	25	0.11	5	0.24	13
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane	25	0.30	5	0.026	13
C_2H_3Cl	Chloroethylene	25	0.27*	5	2.68	13
$C_2H_3Cl_3$	1,1,1-Trichloroethane	25	0.072	5	1.76	13
$C_2H_3Cl_3$	1,1,2-Trichloroethane	25	0.442	5	0.092	13
C_2H_4	Ethylene	25	0.01336*	19	21.7	5
C_2H_4BrCl	1-Bromo-2-chloroethane	30	0.683	10		
$C_2H_4Br_2$	1,2-Dibromoethane	25	0.17	5	0.066	13
$C_2H_4Cl_2$	1,1-Dichloroethane	25	0.51	5	0.63	13
$C_2H_4Cl_2$	1,2-Dichloroethane	25	0.75	20	0.14	13
$C_2H_4O_2$	Methyl formate	25	23	10		
C_2H_5Br	Bromoethane	20	0.91	10	1.23	13
C_2H_5Cl	Chloroethane	20	0.57*	5	1.02	13
C_2H_5F	Fluoroethane	25	0.216*	14		
C_2H_5I	Iodoethane	30	3.88	10	0.52	13
C_2H_5NO	Acetamide	20	40.8	10		
$C_2H_5NO_2$	Nitroethane	25	4.68	10		
C_2H_6	Ethane	25	0.00568*	18	50.6	5

Mol. Form.	Name	t/°C	S/mass %	Ref.	k_H/kPa m^3 mol^{-1}	Ref.
C_2H_6O	Dimethyl ether	24	35.3*	10	0.077	13
C_2H_6OS	Dimethyl sulfoxide	25	25.3	10		
C_2H_6S	Dimethyl sulfide	25	2	10		
C_3Cl_6	Hexachloropropene	25	0.00170	14		
C_3F_6	Perfluoropropene	25	0.0194*	14		
C_3F_8	Perfluoropropane	15	0.0015*	14		
C_3H_3N	2-Propenenitrile	20	7.35	10		
C_3H_4	Propyne	25	0.364*	5	1.11	5
$C_3H_4Cl_2$	*cis*-1,3-Dichloropropene	25	0.27	5	0.24	5
$C_3H_4Cl_2$	*trans*-1,3-Dichloropropene	20	0.28	5	0.18	5
$C_3H_4Cl_2$	2,3-Dichloropropene	25	0.215	5	0.36	5
C_3H_4O	Acrolein	20	20.8	10		
C_3H_5Cl	3-Chloropropene	25	0.33	5	1.10	5
C_3H_5ClO	Epichlorohydrin	20	6.58	10	0.003	13
$C_3H_5Cl_3$	1,2,3-Trichloropropane	20	0.19	10	0.038	13
C_3H_5N	Propanenitrile	25	10.3	10		
C_3H_6	Propene	25	0.0200*	5	21.3	5
C_3H_6	Cyclopropane	25	0.0484*	19		
$C_3H_6Br_2$	1,2-Dibromopropane	25	0.143	10		
$C_3H_6Cl_2$	1,2-Dichloropropane	25	0.247	10	0.29	13
$C_3H_6N_6O_6$	Hexahydro-1,3,5-trinitro-1,3,5-triazine	25	0.0060	17		
C_3H_6O	Propanal	25	30.6	10		
C_3H_6O	Methyloxirane	20	40.5	10	0.0087	13
$C_3H_6O_2$	Ethyl formate	25	11.8	10		
$C_3H_6O_2$	Methyl acetate	20	24.5	10		
C_3H_7Br	1-Bromopropane	30	0.230	10	3.8	13
C_3H_7Br	2-Bromopropane	18	0.286	10	1.27	13
C_3H_7Cl	1-Chloropropane	20	0.271	10	1.41	13
C_3H_7Cl	2-Chloropropane	12	0.342	10		
C_3H_7F	1-Fluoropropane	14	0.386*	14		
C_3H_7F	2-Fluoropropane	15	0.366	14		
C_3H_7I	1-Iodopropane	30	0.104	10	0.93	13
C_3H_7I	2-Iodopropane	20	0.140	10		
$C_3H_7NO_2$	1-Nitropropane	25	1.50	10		
$C_3H_7NO_2$	2-Nitropropane	25	1.71	10		
C_3H_8	Propane	25	0.00669*	18	71.6	5
$C_3H_8O_2$	Dimethoxymethane	16	24.4	10		
C_4F_8	Perfluorocyclobutane	21	0.014*	14		
$C_4H_4N_2$	Succinonitrile	25	11.5	10		
C_4H_4O	Furan	25	1	10	0.54	13
C_4H_5N	Methylacrylonitrile	20	2.57	10		
C_4H_5N	Pyrrole	25	4.5	10		
C_4H_6	1,3-Butadiene	25	0.0735*	5	20.7	13
C_4H_6	1-Butyne	25	0.287*	5	1.91	5
C_4H_6O	*trans*-2-Butenal	20	15.6	10		
$C_4H_6O_2$	Methacrylic acid	20	8.9	10		
$C_4H_6O_2$	*trans*-Crotonic acid	25	9	10		
$C_4H_6O_2$	Vinyl acetate	20	2.0	10		
$C_4H_6O_2$	Methyl acrylate	25	4.94	10		
C_4H_7Cl	1-Chloro-2-methylpropene	25	0.916	5	0.12	5
C_4H_7N	Butanenitrile	20	3.3	10		
C_4H_8	1-Butene	25	0.0222*	5	25.6	13
C_4H_8	Isobutene	25	0.0263*	5	21.6	13
$C_4H_8Cl_2O$	Bis(2-chloroethyl) ether	25	1.03	20	0.003	13
C_4H_8O	*cis*-Crotonyl alcohol	20	16.6	10		
C_4H_8O	Ethyl vinyl ether	20	0.9	10		
C_4H_8O	Butanal	25	7.1	10		
C_4H_8O	Isobutanal	20	9.1	10		
C_4H_8O	2-Butanone	25	25.9	20		
$C_4H_8O_2$	2-Methylpropanoic acid	20	22.8	10		

Mol. Form.	Name	t/°C	S/mass %	Ref.	k_H/kPa m^3 mol^{-1}	Ref.
$C_4H_8O_2$	Propyl formate	22	2.05	10		
$C_4H_8O_2$	Ethyl acetate	25	8.08	10		
C_4H_9Br	1-Bromobutane	30	0.0608	10	1.2	13
C_4H_9Cl	1-Chlorobutane	20	0.11	10	1.54	13
C_4H_9Cl	1-Chloro-2-methylpropane	12	0.092	10		
C_4H_9I	1-Iodobutane	17	0.012	10	1.87	13
C_4H_{10}	Butane	25	0.00724*	18	95.9	5
C_4H_{10}	Isobutane	25	0.00535*	18	120	5
$C_4H_{10}O$	Diethyl ether	25	6.04	10	0.088	13
$C_4H_{10}O$	1-Butanol	0	10.4	1		
		25	7.4	1		
		50	6.4	1		
$C_4H_{10}O$	2-Butanol	10	23.9	1		
		25	18.1	1		
		50	14.0	1		
$C_4H_{10}O$	2-Methyl-1-propanol	0	11.5	1		
		25	8.1	1		
		50	6.5	1		
$C_4H_{10}S$	1-Butanethiol	20	0.0597	10		
$C_4H_{11}NO_2$	Diethanolamine	20	95.4	10		
$C_4H_{12}Si$	Tetramethylsilane	25	0.00196	10		
$C_5H_4O_2$	Furfural	20	8.2	10		
C_5H_6	1,3-Cyclopentadiene	25	0.068	3		
$C_5H_7NO_2$	Ethyl cyanoacetate	20	25.9	10		
C_5H_8	1,4-Pentadiene	25	0.056	3	12	5
C_5H_8	2-Methyl-1,3-butadiene	25	0.061	3	7.78	5
		50	0.076*	3		
C_5H_8	1-Pentyne	25	0.157	3	2.5	5
C_5H_8	Cyclopentene	25	0.054	3	6.56	13
$C_5H_8O_2$	Ethyl acrylate	25	1.50	10		
$C_5H_8O_2$	Methyl methacrylate	20	1.56	10		
$C_5H_8O_2$	2,4-Pentanedione	20	16.6	10		
C_5H_{10}	1-Pentene	25	0.0148	3	40.3	5
C_5H_{10}	*cis*-2-Pentene	25	0.0203	3	22.8	5
C_5H_{10}	3-Methyl-1-butene	25	0.013*	3	54.7	5
C_5H_{10}	2-Methyl-2-butene	25	0.041	3		
C_5H_{10}	Cyclopentane	25	0.0157	3	19.1	13
$C_5H_{10}O$	2-Pentanone	25	5.5	20		
$C_5H_{10}O$	3-Pentanone	25	4.72	20		
$C_5H_{10}O$	2-Methyltetrahydrofuran	25	13.9	10	0.67	13
$C_5H_{10}O_2$	Pentanoic acid	20	2.4	10		
$C_5H_{10}O_2$	3-Methylbutanoic acid	21	4.1	10		
$C_5H_{10}O_2$	Isobutyl formate	22	1.0	10		
$C_5H_{10}O_2$	Propyl acetate	20	2.3	10		
$C_5H_{10}O_2$	Isopropyl acetate	20	2.9	10		
$C_5H_{10}O_2$	Ethyl propanoate	20	1.92	10		
$C_5H_{11}Br$	1-Bromopentane	25	0.0127	10		
$C_5H_{11}Cl$	1-Chloropentane	25	0.02	10	2.37	13
C_5H_{12}	Pentane	25	0.0041	3	128	13
C_5H_{12}	Isopentane	25	0.00485	3	479	13
C_5H_{12}	Neopentane	25	0.00332*	3	220	13
$C_5H_{12}O$	1-Pentanol	0	3.1	1		
		25	2.20	1		
		50	1.8	1		
$C_5H_{12}O$	2-Pentanol	25	4.3	21		
$C_5H_{12}O$	3-Pentanol	25	5.6	21		
$C_5H_{12}O$	2-Methyl-1-butanol	25	3.0	3		
$C_5H_{12}O$	3-Methyl-1-butanol	25	2.7	1		
$C_5H_{12}O$	2-Methyl-2-butanol	25	11.0	1		
$C_5H_{12}O$	3-Methyl-2-butanol	25	5.6	1		

Mol. Form.	Name	t/°C	S/mass %	Ref.	k_H/kPa m^3 mol^{-1}	Ref.
$C_5H_{12}O$	2,2-Dimethyl-1-propanol	25	3.5	1		
$C_5H_{12}O$	Methyl *tert*-butyl ether	25	3.62	20	0.070	13
C_6Cl_6	Hexachlorobenzene	25	0.0000005	2	0.131	11
C_6HCl_5	Pentachlorobenzene	25	0.000055	2	0.085	11
C_6HCl_5O	Pentachlorophenol	25	0.0010	2		
$C_6H_2Br_4$	1,2,4,5-Tetrabromobenzene	25	0.00000434	2		
$C_6H_2Cl_4$	1,2,3,4-Tetrachlorobenzene	25	0.0000433	2	0.144	11
$C_6H_2Cl_4$	1,2,3,5-Tetrachlorobenzene	25	0.000346	2	0.59	11
$C_6H_2Cl_4$	1,2,4,5-Tetrachlorobenzene	25	0.0000606	2	0.122	11
$C_6H_2Cl_4O$	2,3,4,6-Tetrachlorophenol	25	1.8	2		
$C_6H_2Cl_4O_2$	3,4,5,6-Tetrachloro-1,2-benzenediol	25	0.071	8		
$C_6H_3Br_3$	1,2,4-Tribromobenzene	25	0.0010	2		
$C_6H_3Br_3$	1,3,5-Tribromobenzene	25	0.0000789	2		
$C_6H_3Br_3O$	2,4,6-Tribromophenol	15	0.0007	2		
$C_6H_3Cl_3$	1,2,3-Trichlorobenzene	25	0.00309	2	0.242	11
$C_6H_3Cl_3$	1,2,4-Trichlorobenzene	25	0.00379	2	0.277	11
$C_6H_3Cl_3$	1,3,5-Trichlorobenzene	25	0.000655	2	1.1	11
$C_6H_3Cl_3O$	2,4,5-Trichlorophenol	25	0.1	2		
$C_6H_3Cl_3O$	2,4,6-Trichlorophenol	25	0.04	2		
$C_6H_3Cl_3O_2$	3,4,5-Trichloro-1,2-benzenediol	25	0.051	8		
C_6H_4BrCl	1-Bromo-2-chlorobenzene	25	0.0124	2		
C_6H_4BrCl	1-Bromo-3-chlorobenzene	25	0.0118	2		
C_6H_4BrCl	1-Bromo-4-chlorobenzene	25	0.00442	2		
C_6H_4BrI	1-Bromo-4-iodobenzene	25	0.000794	2		
$C_6H_4Br_2$	*o*-Dibromobenzene	25	0.00748	2		
$C_6H_4Br_2$	*m*-Dibromobenzene	25	0.0064	2		
$C_6H_4Br_2$	*p*-Dibromobenzene	25	0.0020	2		
$C_6H_4Br_2O$	2,4-Dibromophenol	25	0.2	2		
C_6H_4ClI	1-Chloro-2-iodobenzene	25	0.00689	2		
C_6H_4ClI	1-Chloro-3-iodobenzene	25	0.00674	2		
C_6H_4ClI	1-Chloro-4-iodobenzene	25	0.00311	2		
$C_6H_4Cl_2$	*o*-Dichlorobenzene	0	0.0142	2		
		25	0.0147	2	0.244	11
		50	0.0212	2		
$C_6H_4Cl_2$	*m*-Dichlorobenzene	10	0.0103	2		
		25	0.0106	2	0.376	11
		50	0.0165	2		
$C_6H_4Cl_2$	*p*-Dichlorobenzene	10	0.00512	2		
		25	0.00829	2	0.160	11
		50	0.0167	2		
$C_6H_4Cl_2O$	2,4-Dichlorophenol	20	0.45	2		
$C_6H_4Cl_2O_2$	3,5-Dichloro-1,2-benzenediol	25	0.78	8		
$C_6H_4Cl_2O_2$	4,5-Dichloro-1,2-benzenediol	25	1.19	8		
$C_6H_4F_2$	*o*-Difluorobenzene	25	0.114	2		
$C_6H_4F_2$	*m*-Difluorobenzene	25	0.114	2		
$C_6H_4F_2$	*p*-Difluorobenzene	25	0.122	2		
$C_6H_4I_2$	*o*-Diiodobenzene	25	0.00192	2		
$C_6H_4I_2$	*m*-Diiodobenzene	25	0.000185	2		
$C_6H_4I_2$	*p*-Diiodobenzene	25	0.000893	2		
C_6H_5Br	Bromobenzene	10	0.0387	2		
		25	0.0445	2	0.21	5
		40	0.0516	2		
C_6H_5BrO	*p*-Bromophenol	25	1.86	2		
C_6H_5Cl	Chlorobenzene	10	0.0387	2		
		25	0.0495	2	0.38	11
		50	0.0882	2		
C_6H_5ClO	*o*-Chlorophenol	25	2.0	2		
C_6H_5ClO	*m*-Chlorophenol	25	2.2	2		
C_6H_5ClO	*p*-Chlorophenol	25	2.7	2		
C_6H_5F	Fluorobenzene	27	0.154	2	0.70	11

AQUEOUS SOLUBILITY AND HENRY'S LAW CONSTANTS OF ORGANIC COMPOUNDS (continued)

Mol. Form.	Name	t/°C	S/mass %	Ref.	k_H/kPa m^3 mol^{-1}	Ref.
C_6H_5I	Iodobenzene	10	0.0193	2		
		25	0.0226	2	0.078	11
		45	0.0279	2		
$C_6H_5NO_2$	Nitrobenzene	25	0.21	17		
C_6H_6	Benzene	10	0.178	3		
		25	0.177	3	0.557	11
		50	0.208	3		
C_6H_6ClN	*o*-Chloroaniline	25	0.876	10		
C_6H_6O	Phenol	25	8.66	10		
C_6H_7N	Aniline	25	3.38	10	14	15
C_6H_8	1,4-Cyclohexadiene	25	0.08	3	1.03	13
$C_6H_8N_2$	Adiponitrile	20	0.80	16		
$C_6H_8O_4$	Dimethyl maleate	25	8.0	10		
C_6H_{10}	1,5-Hexadiene	25	0.017	3		
C_6H_{10}	1-Hexyne	25	0.036	3	4.14	13
C_6H_{10}	Cyclohexene	25	0.016	3	4.57	13
$C_6H_{10}O$	Cyclohexanone	25	8.8	20		
$C_6H_{10}O$	Mesityl oxide	20	2.89	10		
$C_6H_{10}O_3$	Ethyl acetoacetate	25	12	10		
$C_6H_{11}NO$	Caprolactam	25	84.0	10		
C_6H_{12}	1-Hexene	25	0.0053	3	41.8	5
C_6H_{12}	*trans*-2-Hexene	25	0.0067	3		
C_6H_{12}	2-Methyl-1-pentene	25	0.0078	3	28.1	5
C_6H_{12}	4-Methyl-1-pentene	25	0.0048	3	63.2	5
C_6H_{12}	2,3-Dimethyl-1-butene	30	0.046	3		
C_6H_{12}	Cyclohexane	25	0.0058	3	19.4	13
C_6H_{12}	Methylcyclopentane	25	0.0043	3	36.7	5
$C_6H_{12}O$	1-Hexen-3-ol	25	2.52	1		
$C_6H_{12}O$	4-Hexen-2-ol	25	3.81	1		
$C_6H_{12}O$	Cyclohexanol	10	4.62	1		
		25	3.8	1		
		40	3.30	1		
$C_6H_{12}O$	Butyl vinyl ether	20	0.3	10		
$C_6H_{12}O$	2-Hexanone	20	1.75	10		
$C_6H_{12}O$	4-Methyl-2-pentanone	25	1.7	10		
$C_6H_{12}O_2$	Hexanoic acid	20	0.958	10		
$C_6H_{12}O_2$	Butyl acetate	20	0.68	10		
$C_6H_{12}O_2$	Isobutyl acetate	20	0.63	10		
$C_6H_{12}O_2$	*sec*-Butyl acetate	20	0.62	10		
$C_6H_{12}O_2$	Ethyl butanoate	20	0.49	10		
C_6H_{14}	Hexane	25	0.0011	3	183	13
		60	0.00136	3		
C_6H_{14}	2-Methylpentane	25	0.00137	3	176	13
C_6H_{14}	3-Methylpentane	25	0.00129	3	170	13
C_6H_{14}	2,2-Dimethylbutane	25	0.0021	3	199	13
C_6H_{14}	2,3-Dimethylbutane	25	0.0021	3	144	13
$C_6H_{14}O$	1-Hexanol	0	0.79	1		
		25	0.60	1		
		50	0.51	1		
$C_6H_{14}O$	2-Hexanol	25	1.4	1		
$C_6H_{14}O$	3-Hexanol	25	1.6	1		
$C_6H_{14}O$	Dipropyl ether	25	0.49	10	0.26	13
$C_6H_{14}O$	2-Methyl-1-pentanol	25	0.81	1		
$C_6H_{14}O$	4-Methyl-1-pentanol	25	0.76	1		
$C_6H_{14}O$	2-Methyl-2-pentanol	25	3.2	1		
$C_6H_{14}O$	3-Methyl-2-pentanol	25	1.9	1		
$C_6H_{14}O$	4-Methyl-2-pentanol	27	1.5	1		
$C_6H_{14}O$	2-Methyl-3-pentanol	25	2.0	1		
$C_6H_{14}O$	3-Methyl-3-pentanol	25	4.3	1		
$C_6H_{14}O$	2-Ethyl-1-butanol	25	1.0	1		

Mol. Form.	Name	t/°C	S/mass %	Ref.	k_H/kPa m^3 mol^{-1}	Ref.
$C_6H_{14}O$	2,2-Dimethyl-1-butanol	25	0.8	1		
$C_6H_{14}O$	Diisopropyl ether	20	1.2	10	0.26	13
$C_6H_{14}O$	2,3-Dimethyl-2-butanol	25	4.2	1		
$C_6H_{14}O$	3,3-Dimethyl-2-butanol	25	2.4	1		
$C_6H_{14}O_2$	1,1-Diethoxyethane	25	5	10		
$C_6H_{15}N$	Dipropylamine	20	2.5	10		
$C_6H_{15}N$	Triethylamine	20	5.5	10		
$C_7H_4Cl_4O$	2,3,4,6-Tetrachloro-5-methylphenol	25	0.00061	2		
$C_7H_5Cl_3$	(Trichloromethyl)benzene	5	0.0053	10		
$C_7H_5Cl_3O$	2,4,6-Trichloro-3-methylphenol	25	0.0112	2		
C_7H_5N	Benzonitrile	25	0.2	10		
C_7H_5NO	Benzoxazole	20	0.834	6		
$C_7H_6Cl_2$	(Dichloromethyl)benzene	30	0.025	10		
$C_7H_6Cl_2O$	2,6-Dichloro-4-methylphenol	25	0.0673	2		
$C_7H_6Cl_2O$	2,4-Dichloro-6-methylphenol	25	0.0283	2		
$C_7H_6N_2$	1*H*-Benzimidazole	20	0.201	6		
$C_7H_6N_2$	1*H*-Indazole	20	0.0827	6		
C_7H_6O	Benzaldehyde	20	0.3	10		
$C_7H_6O_2$	Salicylaldehyde	86	1.68	10		
C_7H_7Br	*p*-Bromotoluene	25	0.011	2		
C_7H_7Cl	(Chloromethyl)benzene	20	0.0493	10		
C_7H_7ClO	4-Chloro-2-methylphenol	25	0.68	2		
C_7H_7ClO	4-Chloro-3-methylphenol	25	0.40	2		
C_7H_7ClO	2-Chloro-6-methylphenol	25	0.36	2		
$C_7H_7NO_3$	2-Nitroanisole	30	0.619	10		
C_7H_8	Toluene	5	0.063	3		
		25	0.053	3	0.680	13
C_7H_8	1,3,5-Cycloheptatriene	25	0.064	3	0.47	13
C_7H_8	1,6-Heptadiyne	25	0.125	3		
C_7H_8O	Benzyl alcohol	20	0.08	10		
C_7H_8O	*o*-Cresol	40	3.08	10		
C_7H_8O	*m*-Cresol	40	2.51	10		
C_7H_8O	*p*-Cresol	40	2.26	10		
C_7H_8O	Anisole	25	0.19	20	0.025	13
C_7H_9N	*o*-Methylaniline	20	1.66	10		
C_7H_9N	*p*-Methylaniline	21	7.35	10		
C_7H_{12}	1-Heptyne	25	0.0094	3	4.47	13
C_7H_{12}	Cycloheptene	25	0.0066	3	4.9	13
C_7H_{12}	1-Methylyclohexene	25	0.0052	3		
C_7H_{14}	1-Heptene	25	0.032	3	40.3	13
C_7H_{14}	*trans*-2-Heptene	25	0.015	3	42.2	13
C_7H_{14}	Cycloheptane	25	0.0030	3	9.59	13
C_7H_{14}	Methylcyclohexane	25	0.00151	3	43.3	13
		50	0.0019	3		
C_7H_{14}	Ethylcyclopentane	20	0.012	3		
$C_7H_{14}O$	2-Heptanone	25	0.43	10		
$C_7H_{14}O$	3-Heptanone	20	1.43	10		
$C_7H_{14}O$	2,4-Dimethyl-3-pentanone	20	0.59	10		
$C_7H_{14}O_2$	Pentyl acetate	20	0.17	10		
$C_7H_{14}O_2$	Isopentyl acetate	20	0.2	10		
$C_7H_{14}O_2$	Ethyl 3-methylbutanoate	20	0.2	10		
C_7H_{16}	Heptane	0	0.0003	3		
		25	0.00024	3	209	13
		40	0.00025	3		
C_7H_{16}	2-Methylhexane	25	0.00025	3	346	5
C_7H_{16}	3-Methylhexane	25	0.00026	3	249	13
C_7H_{16}	2,2-Dimethylpentane	25	0.00044	3	318	5
C_7H_{16}	2,3-Dimethylpentane	25	0.00052	3	175	5
C_7H_{16}	2,4-Dimethylpentane	25	0.00042	3	323	13
C_7H_{16}	3,3-Dimethylpentane	25	0.00059	3	186	5

Mol. Form.	Name	t/°C	S/mass %	Ref.	k_H/kPa m^3 mol^{-1}	Ref.
$C_7H_{16}O$	1-Heptanol	10	0.25	1		
		25	0.174	1		
		50	0.12	1		
$C_7H_{16}O$	2-Heptanol	30	0.33	1		
$C_7H_{16}O$	3-Heptanol	25	0.43	1		
$C_7H_{16}O$	4-Heptanol	25	0.47	1		
$C_7H_{16}O$	2-Methyl-2-hexanol	25	1.0	1		
$C_7H_{16}O$	5-Methyl-2-hexanol	25	0.49	1		
$C_7H_{16}O$	3-Methyl-3-hexanol	25	1.2	1		
$C_7H_{16}O$	2,3-Dimethyl-2-pentanol	25	1.5	1		
$C_7H_{16}O$	2,4-Dimethyl-2-pentanol	25	1.3	1		
$C_7H_{16}O$	3-Ethyl-3-pentanol	25	1.7	1		
$C_7H_{16}O$	2,2-Dimethyl-3-pentanol	25	0.82	1		
$C_7H_{16}O$	2,3-Dimethyl-3-pentanol	25	1.6	1		
$C_7H_{16}O$	2,4-Dimethyl-3-pentanol	25	0.70	1		
$C_7H_{16}O$	2,3,3-Trimethyl-2-butanol	40	2.2	1		
$C_8H_4F_6$	1,3-Bis(trifluoromethyl)benzene	25	0.0041	2		
$C_8H_6N_2$	Quinoxaline	50	54	6		
C_8H_6S	Benzo[b]thiophene	20	0.0130	6		
$C_8H_7ClO_3$	3-Chloro-4-hydroxy-5-methoxybenzaldehyde	25	0.093	8		
$C_8H_7ClO_3$	2-Chloro-4-hydroxy-5-methoxybenzaldehyde	25	0.013	8		
$C_8H_7Cl_3O$	2,4,6-Trichloro-3,5-dimethylphenol	25	0.00050	2		
C_8H_7N	Indole	20	0.187	6		
C_8H_8	Styrene	25	0.025	4	0.3	15
		50	0.046	4	0.30	13
$C_8H_8N_2$	2-Methyl-1H-benzimidazole	20	0.145	6		
C_8H_8O	Acetophenone	25	0.55			
$C_8H_8O_2$	Methyl benzoate	20	0.21	10		
$C_8H_8O_3$	Methyl salicylate	30	0.74	10		
$C_8H_8O_3$	4-Hydroxy-3-methoxybenzaldehyde	25	0.247	8		
C_8H_9ClO	4-Chloro-2,5-dimethylphenol	25	0.89	2		
C_8H_9ClO	4-Chloro-2,6-dimethylphenol	25	0.52	2		
C_8H_9ClO	4-Chloro-3,5-dimethylphenol	25	0.34	2		
C_8H_{10}	Ethylbenzene	0	0.020	4		
		25	0.0169	4	0.887	11
		40	0.0200	4		
C_8H_{10}	*o*-Xylene	25	0.0173	4	0.565	13
		45	0.021	4		
C_8H_{10}	*m*-Xylene	0	0.0203	4		
		25	0.016	4	0.730	13
		40	0.022	4		
C_8H_{10}	*p*-Xylene	0	0.0160	4		
		25	0.018	4	0.578	13
		40	0.022	4		
$C_8H_{10}O$	Phenetole	25	0.12	10		
$C_8H_{10}O$	2,4-Xylenol	25	0.787	10		
$C_8H_{10}O$	3,5-Xylenol	29	0.62	10		
C_8H_{12}	4-Vinylcyclohexene	25	0.005	4		
C_8H_{14}	1-Octyne	25	0.0024	4	7.87	13
C_8H_{16}	1-Octene	25	0.00027	4	96.3	13
C_8H_{16}	Cyclooctane	25	0.00079	4	10.7	13
C_8H_{16}	Ethylcyclohexane	40	0.00066	4		
C_8H_{16}	*cis*-1,2-Dimethylcyclohexane	25	0.00060	4	36	5
C_8H_{16}	*trans*-1,4-Dimethylcyclohexane	25	0.000384	4	88.2	5
C_8H_{16}	Propylcyclopentane	25	0.00020	4	90.2	5
C_8H_{16}	1,1,3-Trimethylcyclopentane	25	0.00037	4	159	5
$C_8H_{16}O$	2-Octanone	25	0.113	10		
$C_8H_{16}O_2$	Octanoic acid	25	0.0798	10		

Mol. Form.	Name	t/°C	S/mass %	Ref.	k_H/kPa m^3 mol^{-1}	Ref.
$C_8H_{16}O_2$	Hexyl acetate	20	0.02	10		
$C_8H_{16}O_2$	sec-Hexyl acetate	20	0.13	10		
$C_8H_{16}O_2$	Isobutyl isobutanoate	20	0.5	10		
$C_8H_{17}Cl$	3-(Chloromethyl)heptane	20	0.01	10		
C_8H_{18}	Octane	25	0.000071	4	311	13
		50	0.00010	4		
C_8H_{18}	3-Methylheptane	25	0.000079	4	376	5
C_8H_{18}	2,2,4-Trimethylpentane	25	0.00022	4	307	13
C_8H_{18}	2,3,4-Trimethylpentane	25	0.00018	4	206	13
$C_8H_{18}O$	Dibutyl ether	20	0.03	10	0.48	13
$C_8H_{18}O$	1-Octanol	25	0.054	1		
$C_8H_{18}O$	2-Octanol	25	0.4	1		
$C_8H_{18}O$	2-Methyl-2-heptanol	30	0.25	1		
$C_8H_{18}O$	2-Ethyl-1-hexanol	25	0.01	1		
$C_8H_{19}N$	Dibutylamine	20	0.47	10		
$C_8H_{19}N$	2-Ethylhexylamine	20	0.25	10		
$C_8H_{20}Si$	Tetraethylsilane	25	0.0000325	10		
C_9H_7N	Quinoline	20	0.633	6		
C_9H_7N	Isoquinoline	20	0.452	6		
C_9H_9N	3-Methyl-1H-indole	20	0.050	6		
C_9H_{10}	Indan	25	0.010	4		
$C_9H_{10}O_2$	Ethyl benzoate	25	0.083	20		
C_9H_{12}	1,8-Nonadiyne	25	0.0125	4		
C_9H_{12}	Propylbenzene	25	0.0055	4	1.04	11
C_9H_{12}	Isopropylbenzene	25	0.0056	4	1.47	11
C_9H_{12}	*o*-Ethyltoluene	25	0.0093	5	0.529	13
C_9H_{12}	*p*-Ethyltoluene	25	0.0094	5	0.500	13
C_9H_{12}	1,2,3-Trimethylbenzene	25	0.0069	4	0.343	11
C_9H_{12}	1,2,4-Trimethylbenzene	25	0.0056	4	0.569	11
C_9H_{12}	1,3,5-Trimethylbenzene	25	0.00489	4	0.781	11
$C_9H_{14}O_6$	Triacetin	25	5.8	10		
C_9H_{16}	1-Nonyne	25	0.00072	4		
C_9H_{18}	1,1,3-Trimethylcyclohexane	25	0.000177	4	105	13
$C_9H_{18}O$	Diisobutyl ketone	25	0.043	10		
$C_9H_{18}O_2$	Nonanoic acid	20	0.0284	10		
C_9H_{20}	Nonane	25	0.000017	4	333	13
		50	0.000022	4		
C_9H_{20}	4-Methyloctane	25	0.0000115	4	1000	5
C_9H_{20}	2,2,5-Trimethylhexane	25	0.00008	4	246	13
$C_9H_{20}O$	3,5-Dimethyl-4-heptanol	15	0.072	1		
$C_9H_{20}O$	1-Nonanol	25	0.014	1		
$C_9H_{20}O$	2-Nonanol	15	0.026	1		
$C_9H_{20}O$	3-Nonanol	15	0.032	1		
$C_9H_{20}O$	4-Nonanol	15	0.0026	1		
$C_9H_{20}O$	5-Nonanol	15	0.0032	1		
$C_{10}H_7Cl$	1-Chloronaphthalene	25	0.00224	5		
$C_{10}H_7Cl$	2-Chloronaphthalene	25	0.00117	5		
$C_{10}H_8$	Naphthalene	10	0.0019	4		
		25	0.0031	4	0.0430	5
		50	0.0082	4		
$C_{10}H_9N$	3-Methylisoquinoline	20	0.092	6		
$C_{10}H_{10}O_4$	Dimethyl phthalate	25	0.40	15		
$C_{10}H_{14}$	Butylbenzene	25	0.0015	4	1.33	11
$C_{10}H_{14}$	*sec*-Butylbenzene	25	0.0014	4	1.89	11
$C_{10}H_{14}$	*tert*-Butylbenzene	25	0.0032	4	1.28	11
$C_{10}H_{14}$	Isobutylbenzene	25	0.0010	4	3.32	11
$C_{10}H_{14}$	*p*-Cymene	25	0.00234	4	0.80	5
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene	25	0.000348	4	2.55	11
$C_{10}H_{16}$	*d*-Limonene	0	0.00097	4		
		25	0.00138	4		

Mol. Form.	Name	*t*/°C	*S*/mass %	Ref.	k_H/kPa m^3 mol^{-1}	Ref.
$C_{10}H_{16}O$	Camphor	20	0.01	10		
$C_{10}H_{18}$	*trans*-Decahydronaphthalene	25	0.000089	4	3	13
$C_{10}H_{20}$	Pentylcyclopentane	25	0.0000115	4	185	5
$C_{10}H_{20}$	1-Decene	25	0.00057	4		
$C_{10}H_{22}$	Decane	0	0.0000015	4	479	13
$C_{10}H_{22}O$	Diisopentyl ether	20	0.02	10		
$C_{10}H_{22}O$	1-Decanol	25	0.0037	1		
$C_{11}H_{10}$	1-Methylnaphthalene	25	0.0028	4	0.0450	12
$C_{11}H_{10}$	2-Methylnaphthalene	25	0.0025	4	0.051	12
$C_{11}H_{16}$	Pentylbenzene	25	0.00105	5	1.69	11
$C_{12}Cl_{10}$	Decachlorobiphenyl	25	0.00000000012	7	0.0208	7
$C_{12}HCl_9$	2,2′,3,3′,4,5,5′,6,6′-Nonachlorobiphenyl	25	0.0000000018	7		
$C_{12}H_2Cl_8$	2,2′,3,3′5,5′,6,6′-Octachlorobiphenyl	25	0.0000003	7	0.0381	7
$C1_2H_3Cl_7$	2,2′,3,3′,4,4′,6-Heptachlorobiphenyl	25	0.0000002	7	0.0054	7
$C_{12}H_4Cl_6$	2,2′,3,3′,4,4′-Hexachlorobiphenyl	25	0.00000006	7	0.0119	7
$C_{12}H_4Cl_6$	2,2′,4,4′,6,6′-Hexachlorobiphenyl	25	0.00000007	7	0.818	7
$C_{12}H_4Cl_6$	2,2′,3,3′,6,6′-Hexachlorobiphenyl	25	0.00000008	7		
$C_{12}H_5Cl_5$	2,3,4,5,6-Pentachlorobiphenyl	25	0.0000008	7		
$C_{12}H_5Cl_5$	2,2′,4,5,5′-Pentachlorobiphenyl	25	0.000001	7	0.0355	7
$C_{12}H_6Cl_4$	2,3,4,5-Tetrachlorobiphenyl	25	0.000002	7		
$C_{12}H_6Cl_4$	2,2′,4′,5-Tetrachlorobiphenyl	25	0.0000016	9		
$C_{12}H_7Cl_3$	2,4,5-Trichlorobiphenyl	25	0.000014	7	0.0243	7
$C_{12}H_7Cl_3$	2,4,6-Trichlorobiphenyl	25	0.00002	7	0.0495	7
$C_{12}H_8Cl_2$	2,5-Dichlorobiphenyl	25	0.0002	7	0.0201	7
$C_{12}H_8Cl_2$	2,6-Dichlorobiphenyl	25	0.00014	7		
$C_{12}H_8O$	Dibenzofuran	25	0.000656	6	0.011	12
$C_{12}H_8S$	Dibenzothiophene	25	0.000103	6		
$C_{12}H_9Cl$	2-Chlorobiphenyl	25	0.00055	7	0.0701	7
$C_{12}H_9N$	Carbazole	22	0.000120	6		
$C_{12}H_{10}$	Acenaphthene	0	0.00015	4		
		25	0.00038	4	0.012	12
		50	0.00092	4		
$C_{12}H_{10}$	Biphenyl	0	0.000272	4		
		25	0.00072	4	0.028	5
		50	0.0022	4		
$C_{12}H_{10}N_2O$	*N*-Nitrosodiphenylamine	25	0.0035	17		
$C_{12}H_{10}O$	Diphenyl ether	25	0.00180	6	0.027	13
$C_{12}H_{12}$	1-Ethylnaphthalene	25	0.00101	4	0.039	12
$C_{12}H_{12}$	2-Ethylnaphthalene	25	0.00080	4	0.078	12
$C_{12}H_{12}$	1,3-Dimethylnaphthalene	25	0.0008	4		
$C_{12}H_{12}$	1,4-Dimethylnaphthalene	25	0.00114	4		
$C_{12}H_{12}$	1,5-Dimethylnaphthalene	25	0.00031	4		
$C_{12}H_{12}$	2,3-Dimethylnaphthalene	25	0.00025	4		
$C_{12}H_{12}$	2,6-Dimethylnaphthalene	25	0.00017	4		
$C_{12}H_{18}$	Hexylbenzene	25	0.00021	4		
$C_{12}H_{26}$	Dodecane	25	0.00000037	4	750	5
$C_{12}H_{26}O$	1-Dodecanol	25	0.0004	1		
$C_{12}H_{27}O_4P$	Tributyl phosphate	25	0.039	10		
$C_{13}H_9N$	Acridine	25	0.00466	6		
$C_{13}H_9N$	Benzo[f]quinoline	25	0.0079	6		
$C_{13}H_{10}$	9H-Fluorene	0	0.00007	4		
		25	0.00019	4	0.0079	12
		50	0.00063	4		
$C_{13}H_{12}$	Diphenylmethane	25	0.000141	4	0.001	12
$C_{13}H_{14}$	1,4,5-Trimethylnaphthalene	25	0.00021	4		
$C_{14}H_{10}$	Anthracene	0	0.0000022	4		
		25	0.0000062	4	0.0040	12
$C_{14}H_{10}$	Phenanthrene	10	0.000050	4		
		25	0.00011	4	0.0032	12
		50	0.00041	4		

Mol. Form.	Name	*t*/°C	*S*/mass %	Ref.	k_H/kPa m^3 mol^{-1}	Ref.
$C_{14}H_{12}$	*trans*-Stilbene	25	0.000029	4	0.040	12
$C_{14}H_{14}$	1,2-Diphenylethane	25	0.00044	6	0.017	12
$C_{14}H_{14}O$	Dibenzyl ether	35	0.0040	10		
$C_{14}H_{30}$	Tetradecane	25	0.000012	5		
$C_{14}H_{30}O$	1-Tetradecanol	25	0.000031	1		
$C_{15}H_{12}$	2-Methylanthracene	25	0.0000030	4		
$C_{15}H_{12}$	9-Methylanthracene	25	0.000026	4		
$C_{15}H_{12}$	1-Methylphenanthrene	25	0.0000269	4		
$C_{15}H_{32}O$	1-Pentadecanol	25	0.000010	1		
$C_{16}H_{10}$	Fluoranthene	25	0.000024	4	0.0010	12
$C_{16}H_{10}$	Pyrene	25	0.0000132	4	0.00092	12
		50	0.00009	4		
$C_{16}H_{14}$	9,10-Dimethylanthracene	25	0.0000056	4		
$C_{16}H_{22}O_4$	Dibutyl phthalate	25	0.00112	15		
$C_{16}H_{34}O$	1-Hexadecanol	25	0.000003	1		
$C_{17}H_{12}$	11H-Benzo[a]fluorene	25	0.0000045	4		
$C_{17}H_{12}$	11H-Benzo[b]fluorene	25	0.0000002	4		
$C_{18}H_{12}$	Benz[a]anthracene	25	0.0000011	4	0.00058	12
$C_{18}H_{12}$	Chrysene	25	0.00000019	4	0.006	12
$C_{18}H_{12}$	Naphthacene	25	0.00000006	4	0.000004	12
$C_{18}H_{12}$	Triphenylene	25	0.0000041	4	0.00001	12
$C_{18}H_{12}N_2$	2,2′-Biquinoline	24	0.000102	6		
$C_{18}H_{34}O_4$	Dibutyl sebacate	20	0.004	10		
$C_{19}H_{14}$	5-Methylchrysene	27	0.0000062	4		
$C_{19}H_{14}$	9-Methylbenz[a]anthracene	27	0.0000066	4		
$C_{19}H_{14}$	10-Methylbenz[a]anthracene	25	0.0000055	4		
$C_{20}H_{12}$	Benzo[a]pyrene	25	0.00000038	4	0.000046	12
$C_{20}H_{12}$	Perylene	25	0.00000004	4	0.000003	12
$C_{20}H_{12}$	Benzo[e]pyrene	20	0.00000046	4	0.00002	12
$C_{20}H_{13}N$	13H-Dibenzo[a,i]carbazole	24	0.00000104	6		
$C_{20}H_{14}$	1,2-Dihydrobenz[j]aceanthrylene	25	0.00000036	6		
$C_{20}H_{42}$	Eicosane	25	0.00000019	4		
$C_{21}H_{13}N$	Dibenz[a,j]acridine	25	0.000016	6		
$C_{21}H_{16}$	1,2-Dihydro-3-methylbenz[j]aceanthrylene	25	0.00000022	6		
$C_{22}H_{12}$	Benzo[ghi]perylene	25	0.000000026	4	0.000075	12
$C_{22}H_{14}$	Picene	25	0.00000025	4		
$C_{22}H_{14}$	Benzo[b]triphenylene	25	0.0000027	4		
$C_{22}H_{14}$	Dibenz[a,h]anthracene	25	0.00000006	4		
$C_{22}H_{14}$	Dibenz[a,j]anthracene	25	0.0000012	4		
$C_{22}H_{44}O_2$	Butyl stearate	25	0.2	10		
$C_{24}H_{12}$	Coronene	25	0.000000014	4		

AQUEOUS SOLUBILITY AND HENRY'S LAW CONSTANTS OF ORGANIC COMPOUNDS

The solubility in water of about 800 organic compounds, including many compounds of environmental interest, is tabulated here. Values are given at 25°C or at the nearest temperature to this where data are available. In some cases solubility values are given at other temperatures as well.

Solubility of a solid is defined as the concentration of the compound in a solution that is in equilibrium with the solid phase at the specified temperature and one atmosphere pressure. For liquids whose water mixtures separate into two phases, the solubility given here is the concentration of the compound in the water-rich phase at equilibrium. In the case of gases (i.e., compounds whose vapor pressure at the specified temperature exceeds one atmosphere) the solubility is defined here as the concentration in the water phase when the partial pressure of the compound above the solution is 101.325 kPa (1 atm). Values for gases are marked with an asterisk.

All solubility values are expressed as mass percent of solute, $S = 100\,w_2$, where the mass fraction w_2 is given by

$$w_2 = m_2/(m_1 + m_2)\ .$$

In these equations m_2 is the mass of solute and m_1 the mass of water. This quantity is related to other common measures of solubility as follows:

Molality: $m_2 = 1000w_2/M_2(1-w_2)$

Mole fraction: $x_2 = (w_2/M_2)/\{(w_2/M_2) + (1-w_2)/M_1\}$

Mass of solute per 100 g of H_2O: $r_2 = 100w_2/(1-w_2)$

Here M_2 is the molar mass of the solute and $M_1 = 18.015$ g/mol is the molar mass of water. For small values of S the amount of substance concentration c_2 in moles per liter is approximately $10S/M_2$.

Data have been selected from evaluated sources wherever possible, in particular the *IUPAC Solubility Data Series* (References 1, 2, 3, 4, 25). The primary source for each value is listed in the column following the solubility values. The user is cautioned that wide variations of data are found in the literature for the lower solubility compounds.

The table also contains values of the Henry's Law constant k_H, which provides a measure of the partition of a substance between the atmosphere and the aqueous phase. Here k_H is defined as the limit of p_2/c_2 as the concentration approaches zero, where p_2 is the partial pressure of the solute above the solution and c_2 is the solute concentration (other formulations of Henry's Law are often used; see Reference 5). The values of k_H listed here are based on direct experimental measurement whenever available, but many of them are simply calculated as the ratio of the pure compound vapor pressure to the solubility. This approximation is reliable only for compounds of very low solubility. In fact, values of k_H found in the literature frequently differ by a factor of two or three, and variations over an order of magnitude are not unusual (Reference 5). Therefore the data given here should be taken only as a rough indication of the true Henry's Law constant, which is difficult to measure precisely.

All values of k_H refer to 25°C. If the vapor pressure of the compound at 25°C is greater than one atmosphere, it can be assumed that the k_H value has been calculated as $101.325/c_2$ kPa m^3/mol. The source of the Henry's Law data is given in the last column. The air-water partition coefficient (i.e., ratio of air concentration to water concentration when both are expressed in the same units) is equal to k_H/RT or $k_H/2.48$ in the units used here.

Compounds are listed by molecular formula following the Hill convention. To locate a compound by name or CAS Registry Number when the molecular formula is not known, use the "Physical Constants of Organic Compounds" table in Section 3 and its indexes to determine the molecular formula.

* Indicates a value of S for a gas at a partial pressure of 101.325 kPa (1 atm) in equilibrium with the solution.

REFERENCES

1. *Solubility Data Series, International Union of Pure and Applied Chemistry, Vol. 15*, Pergamon Press, Oxford, 1982.
2. *Solubility Data Series, International Union of Pure and Applied Chemistry, Vol. 20*, Pergamon Press, Oxford, 1985.
3. *Solubility Data Series, International Union of Pure and Applied Chemistry, Vol. 37*, Pergamon Press, Oxford, 1988.
4. *Solubility Data Series, International Union of Pure and Applied Chemistry, Vol. 38*, Pergamon Press, Oxford, 1988.
5. Mackay, D., and Shiu, W. Y., *J. Phys. Chem. Ref. Data*, 10, 1175, 1981.
6. Pearlman, R. S., and Yalkowsky, S. H., *J. Phys. Chem. Ref. Data*, 13, 975, 1984.
7. Shiu, W. Y., and Mackay, D., *J. Phys. Chem. Ref. Data*, 15, 911, 1986.
8. Varhanickova, D., Lee, S. C., Shiu, W. Y., and Mackay, D., *J. Chem. Eng. Data*, 40, 620, 1995.
9. Miller, M. M., Ghodbane, S., Wasik, S. P., Tewari, Y. B., and Martire, D. E., *J. Chem. Eng. Data*, 29, 184, 1984.
10. Riddick, J. A., Bunger, W. B., and Sakano, T. K., *Organic Solvents, Fourth Edition*, John Wiley & Sons, New York, 1986.
11. Mackay, D., Shiu, W. Y., and Ma, K. C., *Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Vol. I*, Lewis Publishers/CRC Press, Boca Raton, FL, 1992.
12. Mackay, D., Shiu, W. Y., and Ma, K. C., *Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Vol. II*, Lewis Publishers/CRC Press, Boca Raton, FL, 1992.
13. Mackay, D., Shiu, W. Y., and Ma, K. C., *Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals, Vol. III*, Lewis Publishers/CRC Press, Boca Raton, FL, 1993.
14. Horvath, A. L., *Halogenated Hydrocarbons*, Marcel Dekker, New York, 1982.
15. Howard, P. H., *Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Vol. I*, Lewis Publishers/CRC Press, Boca Raton, FL, 1989.
16. Howard, P. H., *Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Vol. II*, Lewis Publishers/CRC Press, Boca Raton, FL, 1990.

17. Banergee, S., Yalkowsky, S. H., and Valvani, S. C., *Environ. Sci. Technol.*, 14, 1227, 1980.
18. Gevantman, L., in *CRC Handbook of Chemistry and Physics*, *82nd Edition*, Section 8, CRC Press, Boca Raton, FL, 2001.
19. Wilhelm, E., Battino, R., and Wilcock, R. J., *Chem. Rev*. 77, 219, 1977.
20. Stephenson, R. M., *J. Chem. Eng. Data*, 37, 80, 1992.
21. Stephenson, R. M., Stuart, J., and Tabak, M., *J. Chem. Eng. Data*, 29, 287, 1984.
22. Shiu, W.-Y., and Ma, K.-C, *J. Phys. Chem. Ref. Data*, 29, 41, 2000.
23. Lun, R., Varhanickova, D., Shiu, W.-Y., and Mackay, D., *J. Chem. Eng. Data,* 42, 951, 1997.
24. Huang, G.-L., Xiao, H., Chi, J., Shiu, W.-Y., and Mackay, D., *J. Chem. Eng. Data*, 45, 411, 2000.
25. Horvath, A. L., Getzen, F. W., and Maczynska, Z., *J. Phys. Chem. Ref. Data*, 28, 395, 1999.
26. Dawson, R. M. C., Elliott, D. C., Elliott, W. H., and Jones, K. M., *Data for Biochemical Research*, Third Edition, Clarendon Press, Oxford, 1986.
27. Stephen, H., and Stephen, T., *Solubilities of Organic and Inorganic Compounds*, MacMillan, New York, 1963.
28. Shiu, W.-Y., and Mackay, D., *J. Chem. Eng. Data,* 42, 27, 1997.
29. Hinz, H.-J., ed., *Thermodynamic Data for Biochemistry and Biotechnology*, Springer-Verlag, Berlin, 1986.
30. Budavari, S., ed., *The Merck Index, Twelfth Edition*, Merck & Co., Rahway, NJ, 1996.
31. Bamford, H. A., Poster, D. L., and Baker, J. E., *J. Chem. Eng. Data,* 45, 1069, 2000.

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
$CBrF_3$	Bromotrifluoromethane	25	0.032*	14		
CBr_3F	Tribromofluoromethane	25	0.040	14		
CBr_4	Tetrabromomethane	30	0.024	14		
$CClF_3$	Chlorotrifluoromethane	25	0.009*	10	6.9	13
CCl_2F_2	Dichlorodifluoromethane	20	0.028*	5	41	13
CCl_3F	Trichlorofluoromethane	20	0.11	5	10.2	13
CCl_4	Tetrachloromethane	25	0.065	20	2.99	13
CF_4	Tetrafluoromethane	25	0.00187*	19		
$CHBr_3$	Tribromomethane	25	0.30	5	0.047	13
$CHClF_2$	Chlorodifluoromethane	25	0.30*	10	3.0	13
$CHCl_2F$	Dichlorofluoromethane	25	0.95*	10		
$CHCl_3$	Trichloromethane	25	0.80	20	0.43	13
CHF_3	Trifluoromethane	25	0.09*	14		
CHI_3	Triiodomethane	25	0.012	14		
CH_2BrCl	Bromochloromethane	25	1.7	10	0.18	13
CH_2Br_2	Dibromomethane	25	1.14	14	0.086	13
CH_2ClF	Chlorofluoromethane	25	1.05*	14		
CH_2Cl_2	Dichloromethane	25	1.73	20	0.30	13
CH_2I_2	Diiodomethane	30	0.124	10	0.032	13
CH_3Br	Bromomethane	20	1.80*	5	0.63	13
CH_3Cl	Chloromethane	25	0.535*	5	0.98	13
CH_3F	Fluoromethane	30	0.177*	5		
CH_3I	Iodomethane	20	1.4	10	0.54	13
CH_3NO_2	Nitromethane	25	11.1	10		
CH_4	Methane	25	0.00227*	18	67.4	5
CO	Carbon monoxide	25	0.00276*	18		
CO_2	Carbon dioxide	25	0.1501	18		
CS_2	Carbon disulfide	20	0.210	10		
$C_2Br_2F_4$	1,2-Dibromotetrafluoroethane	25	0.00030	25		
C_2ClF_5	Chloropentafluoroethane	25	0.006*	10	260	13
$C_2Cl_2F_4$	1,2-Dichlorotetrafluoroethane	25	0.013*	10	127	13
$C_2Cl_3F_3$	1,1,2-Trichlorotrifluoroethane	25	0.017	25	32	13
C_2Cl_4	Tetrachloroethylene	0	0.024	25		
		25	0.021	25	1.73	13
		50	0.020	25		
$C_2Cl_4F_2$	1,1,2,2-Tetrachloro-1,2-difluoroethane	27	0.016	25		
C_2Cl_6	Hexachloroethane	25	0.005	25	0.85	13
C_2F_4	Tetrafluoroethylene	25	0.0158*	19		
$C_2HBrClF_3$	2-Bromo-2-chloro-1,1,1-trifluoroethane	10	0.52	25		
		25	0.41	25		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
		40	0.40	25		
$C_2HCl_2F_3$	2,2-Dichloro-1,1,1-trifluoroethane	25	0.46	25		
C_2HCl_3	Trichloroethylene	0	0.145	25		
		25	0.128	25	1.03	13
		60	0.133	25		
$C_2HCl_3O_2$	Trichloroacetic acid	25	92.3	27		
C_2HCl_5	Pentachloroethane	25	0.049	25	0.25	13
C_2H_2	Acetylene	25	0.1081*	19		
$C_2H_2Br_2Cl_2$	1,2-Dibromo-1,2-dichloroethane	20	0.070	25		
$C_2H_2Br_4$	1,1,2,2-Tetrabromoethane	0	0.052	25		
		25	0.068	25		
		50	0.106	25		
		100	0.307	25		
$C_2H_2Cl_2$	1,1-Dichloroethylene	5	0.310	25		
		25	0.242	25	2.62	13
		50	0.225	25		
		90	0.355	25		
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethylene	10	0.76	25		
		25	0.64	25	0.46	13
		40	0.66	25		
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethylene	10	0.53	25		
		25	0.45	25	0.96	13
		40	0.41	25		
$C_2H_2Cl_2F_2$	1,2-Dichloro-1,1-difluoroethane	24	0.49	25		
$C_2H_2Cl_4$	1,1,1,2-Tetrachloroethane	0	0.120	25		
		25	0.107	25	0.24	13
		50	0.123	25		
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane	5	0.302	25		
		25	0.283	25	0.026	13
		50	0.318	25		
$C_2H_2I_2$	*cis*-1,2-Diiodoethene	25	0.046	25		
$C_2H_2I_2$	*trans*-1,2-Diiodoethene	25	0.015	25		
$C_2H_2O_4$	Oxalic acid	20	8.69	27		
		80	45.8	27		
$C_2H_3Br_2Cl$	1,2-Dibromo-1-chloroethane	20	0.060	25		
$C_2H_3Br_3$	1,1,2-Tribromoethane	20	0.050	25		
C_2H_3Cl	Chloroethylene	25	0.27*	5	2.68	13
$C_2H_3Cl_2F$	1,1-Dichloro-1-fluoroethane	25	0.042	25		
$C_2H_3Cl_3$	1,1,1-Trichloroethane	0	0.134	25		
		25	0.129	25	1.76	13
		50	0.138	25		
$C_2H_3Cl_3$	1,1,2-Trichloroethane	0	0.425	25		
		25	0.459	25	0.092	13
		50	0.536	25		
$C_2H_3KO_2$	Potassium acetate	25	72.9			
$C_2H_3NaO_2$	Sodium acetate	25	33.5			
C_2H_4	Ethylene	25	0.01336*	19	21.7	5
C_2H_4BrCl	1-Bromo-2-chloroethane	30	0.683	25		
$C_2H_4Br_2$	1,2-Dibromoethane	0	0.31	25		
		25	0.39	25	0.066	13
		50	0.54	25		
		75	0.76	25		
$C_2H_4Cl_2$	1,1-Dichloroethane	0	0.62	25		
		25	0.50	25	0.63	13
		50	0.50	25		
$C_2H_4Cl_2$	1,2-Dichloroethane	0	0.92	25		
		25	0.86	25	0.14	13
		50	1.05	25		
		100	2.17	25		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
$C_2H_4O_2$	Methyl formate	25	23	10		
C_2H_5Br	Bromoethane	0	1.05	25		
		25	0.90	25	1.23	13
C_2H_5Cl	Chloroethane	0	0.45	25		
		25	0.67	25	1.02	13
C_2H_5F	Fluoroethane	25	0.216*	14		
C_2H_5I	Iodoethane	0	0.44	25		
		25	0.40	25	0.52	13
C_2H_5NO	Acetamide	20	40.8	10		
$C_2H_5NO_2$	Nitroethane	25	4.68	10		
$C_2H_5NO_2$	Methyl carbamate	15	69	27		
$C_2H_5NO_2$	Glycine	25	20.06	26		
C_2H_6	Ethane	25	0.00568*	18	50.6	5
C_2H_6O	Dimethyl ether	24	35.3*	10	0.077	13
C_2H_6OS	Dimethyl sulfoxide	25	25.3	10		
$C_2H_6O_4S$	Dimethyl sulfate	18	2.7	27		
C_2H_6S	Dimethyl sulfide	25	2	10		
C_2N_2	Cyanogen	25	0.8	30		
$C_3Br_2F_6$	1,2-Dibromo-1,1,2,3,3,3-hexafluoropropane	21	0.0068	25		
$C_3Cl_2F_6$	1,2-Dichlorohexafluoropropane	21	0.0096	25		
$C_3Cl_3F_5$	1,1,1-Trichloro-2,2,3,3,3-pentafluoropropane	21	0.0058	25		
$C_3Cl_4F_4$	1,1,1,3-Tetrachloro-2,2,3,3-tetrafluoropropane	21	0.0052	25		
C_3Cl_6	Hexachloropropene	20	0.00118	25		
C_3F_6	Perfluoropropene	25	0.0194*	14		
C_3F_8	Perfluoropropane	15	0.0015*	14		
C_3H_3N	2-Propenenitrile	20	7.35	10		
C_3H_4	Propyne	25	0.364*	5	1.11	5
$C_3H_4ClF_3$	3-Chloro-1,1,1-trifluoropropane	20	0.133	25		
$C_3H_4Cl_2$	*cis*-1,3-Dichloropropene	20	0.27	5	0.24	5
$C_3H_4Cl_2$	*trans*-1,3-Dichloropropene	20	0.28	5	0.18	5
$C_3H_4Cl_2$	2,3-Dichloropropene	25	0.215	5	0.36	5
$C_3H_4N_2O_2$	2,4-Imidazolidinedione	25	3.93	29		
C_3H_4O	Acrolein	20	20.8	10		
C_3H_5Br	3-Bromopropene	25	0.38	25		
$C_3H_5Br_2Cl$	1,2-Dibromo-3-chloropropane	20	0.123	25		
C_3H_5Cl	3-Chloropropene	25	0.40	25	1.10	5
		50	0.13	25		
C_3H_5ClO	Epichlorohydrin	20	6.58	10	0.003	13
$C_3H_5Cl_3$	1,2,3-Trichloropropane	10	0.14	25		
		25	0.20	25	0.038	13
C_3H_5N	Propanenitrile	25	10.3	10		
C_3H_6	Propene	25	0.0200*	5	21.3	5
C_3H_6	Cyclopropane	25	0.0484*	19		
C_3H_6BrCl	1-Bromo-3-chloropropane	25	0.223	25		
$C_3H_6Br_2$	1,2-Dibromopropane	25	0.143	10		
$C_3H_6Br_2$	1,3-Dibromopropane	25	0.169	25		
$C_3H_6Cl_2$	1,2-Dichloropropane	5	0.270	25		
		25	0.274	25	0.29	13
		40	0.297	25		
$C_3H_6Cl_2$	1,3-Dichloropropane	5	0.218	25		
		25	0.280	25		
$C_3H_6N_6O_6$	Hexahydro-1,3,5-trinitro-1,3,5-triazine	25	0.0060	17		
C_3H_6O	Propanal	25	30.6	10		
C_3H_6O	Methyloxirane	20	40.5	10	0.0087	13
$C_3H_6O_2$	Ethyl formate	25	11.8	10		
$C_3H_6O_2$	Methyl acetate	20	24.5	10		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
$C_3H_6O_3$	1,3,5-Trioxane	25	17.4	30		
C_3H_7Br	1-Bromopropane	0	0.298	25		
		25	0.234	25	3.8	13
C_3H_7Br	2-Bromopropane	20	0.32	25	1.27	13
C_3H_7Cl	1-Chloropropane	25	0.250	25	1.41	13
C_3H_7Cl	2-Chloropropane	0	0.44	25		
		20	0.30	25		
C_3H_7F	1-Fluoropropane	14	0.386*	14		
C_3H_7F	2-Fluoropropane	15	0.366	14		
C_3H_7I	1-Iodopropane	0	0.114	25		
		20	0.100	25	0.93	13
C_3H_7I	2-Iodopropane	0	0.167	25		
		20	0.140	25		
$C_3H_7NO_2$	1-Nitropropane	25	1.50	10		
$C_3H_7NO_2$	2-Nitropropane	25	1.71	10		
$C_3H_7NO_2$	Ethyl carbamate	15	48	27		
$C_3H_7NO_2$	Alanine	25	14.30	26		
$C_3H_7NO_2$	β-Alanine	25	47.1	26		
$C_3H_7NO_2$	Sarcosine [N-Methylglycine]	25	30.0	26		
$C_3H_7NO_3$	Serine	25	4.76	26		
$C_3H_7N_3O_2$	Glycocyamine	25	0.5	26		
C_3H_8	Propane	25	0.00669*	18	71.6	5
$C_3H_8O_2$	Dimethoxymethane	16	24.4	10		
C_4Cl_6	Hexachloro-1,3-butadiene	25	0.41	25		
C_4F_8	Perfluorocyclobutane	21	0.014*	14		
$C_4H_4N_2$	Succinonitrile	25	11.5	10		
$C_4H_4N_2O_2$	Uracil	25	0.27	29		
C_4H_4O	Furan	25	1	10	0.54	13
C_4H_5N	Methylacrylonitrile	20	2.57	10		
C_4H_5N	Pyrrole	25	4.5	10		
$C_4H_5N_3O$	Cytosine	25	0.73	29		
C_4H_6	1,3-Butadiene	25	0.0735*	5	20.7	13
C_4H_6	1-Butyne	25	0.287*	5	1.91	5
$C_4H_6BaO_4$	Barium acetate	25	44.2			
$C_4H_6N_2O_2$	2,5-Piperazinedione	25	1.64	29		
C_4H_6O	*trans*-2-Butenal	20	15.6	10		
$C_4H_6O_2$	*trans*-Crotonic acid	25	9	10		
$C_4H_6O_2$	Methacrylic acid	20	8.9	10		
$C_4H_6O_2$	Vinyl acetate	20	2.0	10		
$C_4H_6O_2$	Methyl acrylate	25	4.94	10		
$C_4H_6O_4$	Succinic acid	25	7.71	27		
		75	37.6	27		
$C_4H_6O_4$	Dimethyl oxalate	20	5.82	27		
$C_4H_6O_5$	Malic acid	25	58	27		
C_4H_7Br	4-Bromo-1-butene	25	0.076	25		
C_4H_7Cl	1-Chloro-2-methylpropene	25	0.916	5	0.12	5
C_4H_7N	Butanenitrile	20	3.3	10		
$C_4H_7NO_4$	Aspartic acid	25	0.501	26		
C_4H_8	1-Butene	25	0.0222*	5	25.6	13
C_4H_8	Isobutene	25	0.0263*	5	21.6	13
$C_4H_8Br_2$	1,4-Dibromobutane		0.035	25		
$C_4H_8Cl_2$	1,1-Dichlorobutane	25	0.050	25		
$C_4H_8Cl_2$	1,4-Dichlorobutane	25	0.16	25		
$C_4H_8Cl_2$	2,3-Dichlorobutane	20	0.056	25		
$C_4H_8Cl_2O$	Bis(2-chloroethyl) ether	25	1.03	10	0.003	13
$C_4H_8N_2O_2$	Succinamide	50	18.4	27		
$C_4H_8N_2O_3$	Asparagine	25	2.45	26		
$C_4H_8N_2O_3$	*N*-Glycylglycine	25	18.4	29		
C_4H_8O	*cis*-Crotonyl alcohol	20	16.6	10		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
C_4H_8O	Ethyl vinyl ether	20	0.9	10		
C_4H_8O	Butanal	25	7.1	10		
C_4H_8O	Isobutanal	20	9.1	10		
C_4H_8O	2-Butanone	25	25.9	20		
$C_4H_8O_2$	2-Methylpropanoic acid	20	22.8	10		
$C_4H_8O_2$	Propyl formate	22	2.05	10		
$C_4H_8O_2$	Ethyl acetate	25	8.08	10		
$C_4H_8O_2$	Methyl propanoate		6	30		
C_4H_9Br	1-Bromobutane	25	0.087	25	1.2	13
C_4H_9Br	1-Bromo-2-methylpropane	18	0.051	25		
C_4H_9Cl	1-Chlorobutane	1	0.062	25		
		25	0.087	25	1.54	13
C_4H_9Cl	2-Chlorobutane	0	0.107	25		
		25	0.092	25		
C_4H_9Cl	1-Chloro-2-methylpropane	25	0.92	25		
C_4H_9Cl	2-Chloro-2-methylpropane	15	0.29	25		
C_4H_9I	1-Iodobutane	17	0.021	10	1.87	13
$C_4H_9NO_2$	Ethyl-*N*-methyl carbamate	15	69	27		
$C_4H_9NO_2$	2-Methylalanine	25	12.0	26		
$C_4H_9NO_2$	*DL*-2-Aminobutanoic acid	25	17.4	26		
$C_4H_9NO_2$	*DL*-3-Aminobutanoic acid	25	55.6	26		
$C_4H_9NO_3$	Threonine	25	8.93	26		
$C_4H_9NO_3$	L-Homoserine	25	52.4	26		
$C_4H_9N_3O_2$	Creatine	25	1.6	26		
C_4H_{10}	Butane	25	0.00724*	18	95.9	5
C_4H_{10}	Isobutane	25	0.00535*	18	120	5
$C_4H_{10}O$	1-Butanol	0	10.4	1		
		25	7.4	1		
		50	6.4	1		
$C_4H_{10}O$	2-Butanol	10	23.9	1		
		25	18.1	1		
		50	14.0	1		
$C_4H_{10}O$	2-Methyl-1-propanol	0	11.5	1		
		25	8.1	1	0.00273	28
		50	6.5	1		
$C_4H_{10}O$	Diethyl ether	25	6.04	10	0.088	13
$C_4H_{10}O$	Methyl propyl ether	25	3.5	30		
$C_4H_{10}O_4$	1,2,3,4-Butanetetrol	20	38.0	27		
$C_4H_{10}S$	1-Butanethiol	20	0.0597	10		
$C_4H_{11}NO_2$	Diethanolamine	20	95.4	10		
$C_4H_{12}Si$	Tetramethylsilane	25	0.00196	10		
C_5Cl_8	Octachloro-1,3-pentadiene	20	0.000020	25		
C_5F_{12}	Perfluoropentane	25	0.00012	25		
$C_5H_4N_2O_4$	Orotic acid	18	0.18	26		
$C_5H_4N_4O$	Hypoxanthine	25	0.070	29		
$C_5H_4N_4O_2$	Xanthine	20	0.05	26		
$C_5H_4N_4O_3$	Uric acid	20	0.002	26		
$C_5H_4O_2$	Furfural	20	8.2	10		
$C_5H_5N_5$	Adenine	25	0.104	29		
$C_5H_5N_5O$	Guanine	25	0.0068	29		
$C_5H_5N_5O$	Isoguanine	25	0.006	26		
C_5H_6	1,3-Cyclopentadiene	25	0.068	3		
$C_5H_6N_2O_2$	Thymine	25	0.35	29		
$C_5H_7NO_2$	Ethyl cyanoacetate	20	25.9	10		
$C_5H_7N_3O$	5-Methylcytosine	25	0.45	26		
C_5H_8	1,4-Pentadiene	25	0.056	3	12	5
C_5H_8	2-Methyl-1,3-butadiene	25	0.061	3	7.78	5
		50	0.076*	3		
C_5H_8	1-Pentyne	25	0.157	3	2.5	5

Mol. Form	Name	*t*/°C	*S*/mass %	Ref.	k_H/kPa m^3mol^{-1}	Ref.
C_5H_8	Cyclopentene	25	0.054	3	6.56	13
$C_5H_8O_2$	Ethyl acrylate	25	1.50	10		
$C_5H_8O_2$	Methyl methacrylate	20	1.56	10		
$C_5H_8O_2$	2,4-Pentanedione	20	16.6	10		
$C_5H_9NO_2$	Proline	25	61.9	26		
$C_5H_9NO_3$	trans-4-Hydroxyproline	25	26.5	26		
$C_5H_9NO_4$	*DL*-Glutamic acid	25	2.30	29		
$C_5H_9NO_4$	Glutamic acid	25	0.85	26		
C_5H_{10}	1-Pentene	25	0.0148	3	40.3	5
C_5H_{10}	*cis*-2-Pentene	25	0.0203	3	22.8	5
C_5H_{10}	3-Methyl-1-butene	25	0.013*	3	54.7	5
C_5H_{10}	2-Methyl-2-butene	25	0.041	3		
C_5H_{10}	Cyclopentane	25	0.0157	3	19.1	13
$C_5H_{10}Cl_2$	2,3-Dichloro-2-methylbutane	25	0.029	25		
$C_5H_{10}Cl_2$	2,3-Dichloropentane	25	0.029	25		
$C_5H_{10}Cl_2$	1,2-Dichloropentane	25	0.029	25		
$C_5H_{10}Cl_2$	1,5-Dichloropentane	19	0.02	25		
$C_5H_{10}N_2O_3$	Glutamine	25	4.0	26		
$C_5H_{10}O$	2-Pentanone	25	5.5	20	0.00847	28
$C_5H_{10}O$	3-Pentanone	25	4.72	20		
$C_5H_{10}O$	Tetrahydropyran	25	8.02	10		
$C_5H_{10}O$	2-Methyltetrahydrofuran	25	13.9	10	0.67	13
$C_5H_{10}O_2$	Pentanoic acid	20	2.5	26		
$C_5H_{10}O_2$	3-Methylbutanoic acid	21	4.3	26		
$C_5H_{10}O_2$	Isobutyl formate	22	1.0	10		
$C_5H_{10}O_2$	Propyl acetate	20	2.3	10		
$C_5H_{10}O_2$	Isopropyl acetate	20	2.9	10		
$C_5H_{10}O_2$	Ethyl propanoate	20	1.92	10		
$C_5H_{10}O_2$	Methyl butanoate		1.6	30		
$C_5H_{11}Br$	1-Bromopentane	25	0.0127	25		
$C_5H_{11}Br$	1-Bromo-3-methylbutane	16	0.020	25		
$C_5H_{11}Cl$	1-Chloropentane	5	0.020	25		
		25	0.021	25	2.37	13
$C_5H_{11}Cl$	3-Chloropentane	25	0.025	25		
$C_5H_{11}NO_2$	Valine	25	8.13	26		
$C_5H_{11}NO_2$	L-Norvaline	25	9.7	26		
$C_5H_{11}NO_2S$	Methionine	25	5.3	26		
C_5H_{12}	Pentane	25	0.0041	3	128	13
C_5H_{12}	Isopentane	25	0.00485	3	479	13
C_5H_{12}	Neopentane	25	0.00332*	3	220	13
$C_5H_{12}O$	1-Pentanol	0	3.1	1		
		25	2.20	1		
		50	1.8	1		
$C_5H_{12}O$	2-Pentanol	25	4.3	21		
$C_5H_{12}O$	3-Pentanol	25	5.6	21		
$C_5H_{12}O$	2-Methyl-1-butanol	25	3.0	3		
$C_5H_{12}O$	3-Methyl-1-butanol	25	2.7	1		
$C_5H_{12}O$	2-Methyl-2-butanol	25	11.0	1		
$C_5H_{12}O$	3-Methyl-2-butanol	25	5.6	1		
$C_5H_{12}O$	2,2-Dimethyl-1-propanol	25	3.5	1		
$C_5H_{12}O$	Methyl *tert*-butyl ether	25	3.62		0.070	13
$C_5H_{12}O_4$	Pentaerythritol	15	5.3	30		
C_6Cl_6	Hexachlorobenzene	25	0.0000005	2	0.131	11
C_6F_{14}	Perfluorohexane	25	0.0000098	25		
C_6F_{14}	Perfluoro-2-methylpentane	25	0.000017	25		
C_6HCl_5	Pentachlorobenzene	25	0.000055	2	0.085	11
C_6HCl_5O	Pentachlorophenol	25	0.0013	24		
$C_6H_2Br_4$	1,2,4,5-Tetrabromobenzene	25	0.00000434	2		
$C_6H_2Cl_4$	1,2,3,4-Tetrachlorobenzene	25	0.0000433	2	0.144	11

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
$C_6H_2Cl_4$	1,2,3,5-Tetrachlorobenzene	25	0.000346	2	0.59	11
$C_6H_2Cl_4$	1,2,4,5-Tetrachlorobenzene	25	0.0000606	2	0.122	11
$C_6H_2Cl_4O$	2,3,4,6-Tetrachlorophenol	25	0.017	24		
$C_6H_2Cl_4O_2$	3,4,5,6-Tetrachloro-1,2-benzenediol	25	0.071	8		
$C_6H_3Br_3$	1,2,4-Tribromobenzene	25	0.0010	2		
$C_6H_3Br_3$	1,3,5-Tribromobenzene	25	0.0000789	2		
$C_6H_3Br_3O$	2,4,6-Tribromophenol	15	0.0007	2		
$C_6H_3Cl_3$	1,2,3-Trichlorobenzene	25	0.00309	2	0.242	11
$C_6H_3Cl_3$	1,2,4-Trichlorobenzene	25	0.00379	2	0.277	11
$C_6H_3Cl_3$	1,3,5-Trichlorobenzene	25	0.000655	2	1.1	11
$C_6H_3Cl_3O$	2,4,5-Trichlorophenol	25	0.1	2		
$C_6H_3Cl_3O$	2,4,6-Trichlorophenol	25	0.050	24		
$C_6H_3Cl_3O_2$	3,4,5-Trichloro-1,2-benzenediol	25	0.051	8		
$C_6H_3N_3O_7$	2,4,6-Trinitrophenol	20	1.43	27		
C_6H_4BrCl	1-Bromo-2-chlorobenzene	25	0.0124	2		
C_6H_4BrCl	1-Bromo-3-chlorobenzene	25	0.0118	2		
C_6H_4BrCl	1-Bromo-4-chlorobenzene	25	0.00442	2		
C_6H_4BrI	1-Bromo-4-iodobenzene	25	0.000794	2		
$C_6H_4Br_2$	*o*-Dibromobenzene	25	0.00748	2		
$C_6H_4Br_2$	*m*-Dibromobenzene	25	0.0064	2		
$C_6H_4Br_2$	*p*-Dibromobenzene	25	0.0020	2		
$C_6H_4Br_2O$	2,4-Dibromophenol	25	0.2	2		
C_6H_4ClI	1-Chloro-2-iodobenzene	25	0.00689	2		
C_6H_4ClI	1-Chloro-3-iodobenzene	25	0.00674	2		
C_6H_4ClI	1-Chloro-4-iodobenzene	25	0.00311	2		
$C_6H_4Cl_2$	*o*-Dichlorobenzene	0	0.0142	2		
		25	0.0147	2	0.195	28
		50	0.0212	2		
$C_6H_4Cl_2$	*m*-Dichlorobenzene	10	0.0103	2		
		25	0.0106	2	0.376	11
		50	0.0165	2		
$C_6H_4Cl_2$	*p*-Dichlorobenzene	10	0.00512	2		
		25	0.00829	2	0.244	28
		50	0.0167	2		
$C_6H_4Cl_2O$	2,4-Dichlorophenol	20	0.49	24		
$C_6H_4Cl_2O_2$	3,5-Dichloro-1,2-benzenediol	25	0.78	8		
$C_6H_4Cl_2O_2$	4,5-Dichloro-1,2-benzenediol	25	1.19	8		
$C_6H_4F_2$	*o*-Difluorobenzene	25	0.114	2		
$C_6H_4F_2$	*m*-Difluorobenzene	25	0.114	2		
$C_6H_4F_2$	*p*-Difluorobenzene	25	0.122	2		
$C_6H_4I_2$	*o*-Diiodobenzene	25	0.00192	2		
$C_6H_4I_2$	*m*-Diiodobenzene	25	0.000185	2		
$C_6H_4I_2$	*p*-Diiodobenzene	25	0.000893	2		
$C_6H_4N_2O_4$	1,2-Dinitrobenzene	20	0.21	27		
$C_6H_4N_2O_4$	1,3-Dinitrobenzene	20	2.09	27		
$C_6H_4N_2O_4$	1,4-Dinitrobenzene	20	1.30	27		
$C_6H_4O_2$	*p*-Benzoquinone	25	1.36	27		
C_6H_5Br	Bromobenzene	10	0.0387	2		
		25	0.0445	2	0.250	28
		40	0.0516	2		
C_6H_5BrO	*p*-Bromophenol	25	1.86	2		
C_6H_5Cl	Chlorobenzene	10	0.0387	2		
		25	0.0495	2	0.32	28
		50	0.0882	2		
C_6H_5ClO	*o*-Chlorophenol	25	2.0	2		
C_6H_5ClO	*m*-Chlorophenol	25	2.2	2		
C_6H_5ClO	*p*-Chlorophenol	25	2.7	2		
C_6H_5F	Fluorobenzene	27	0.154	2	0.70	11
C_6H_5I	Iodobenzene	10	0.0193	2		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
		25	0.0226	2	0.078	11
		45	0.0279	2		
$C_6H_5NO_2$	Nitrobenzene	25	0.21	17		
$C_6H_5NO_3$	2-Nitrophenol	20	0.21	27		
$C_6H_5NO_3$	3-Nitrophenol	20	2.14	27		
$C_6H_5NO_3$	4-Nitrophenol	20	1.32	27		
C_6H_6	Benzene	10	0.178	3		
		25	0.178	22	0.557	22
		50	0.208	3		
C_6H_6ClN	*o*-Chloroaniline	25	0.876	10		
$C_6H_6N_2O_2$	2-Nitroaniline	30	1.47	27		
$C_6H_6N_2O_2$	3-Nitroaniline	30	0.121	27		
$C_6H_6N_2O_2$	4-Nitroaniline	30	0.073	27		
C_6H_6O	Phenol	25	8.66	10		
$C_6H_6O_2$	*p*-Hydroquinone	25	7.42	27		
$C_6H_6O_2$	Pyrocatechol	20	31.1	27		
$C_6H_6O_2$	Resorcinol	20	63.7	27		
$C_6H_6O_3$	1,2,3-Benzenetriol	25	38.5	27		
$C_6H_6O_3$	1,3,5-Benzenetriol	20	1.12	27		
$C_6H_6O_6$	Aconitic acid	15	58.5	27		
C_6H_7N	Aniline	25	3.38	10	14	15
$C_6H_7NO_3S$	4-Aminobenzenesulfonic acid	7	0.59	27		
C_6H_8	1,4-Cyclohexadiene	25	0.08	3	1.03	13
C_6H_8ClN	Aniline hydrochloride	15	15.1	27		
$C_6H_8N_2$	Adiponitrile	20	0.80	16		
$C_6H_8N_2$	*m*-Phenylenediamine	20	19.2	27		
$C_6H_8N_2$	*p*-Phenylenediamine		1	30		
$C_6H_8O_4$	Dimethyl maleate	25	8.0	10		
$C_6H_9N_3O_2$	Histidine	25	4.17	26		
C_6H_{10}	1,5-Hexadiene	25	0.017	3		
C_6H_{10}	1-Hexyne	25	0.036	3	4.14	13
C_6H_{10}	Cyclohexene	25	0.016	3	4.57	13
$C_6H_{10}O$	Cyclohexanone	25	8.8	20		
$C_6H_{10}O$	Mesityl oxide	20	2.89	10		
$C_6H_{10}O_3$	Ethyl acetoacetate	25	12	10		
$C_6H_{10}O_4$	Adipic acid	15	1.42	27		
$C_6H_{11}NO$	Caprolactam	25	84.0	10		
C_6H_{12}	1-Hexene	25	0.0053	3	41.8	5
C_6H_{12}	*trans*-2-Hexene	25	0.0067	3		
C_6H_{12}	2-Methyl-1-pentene	25	0.0078	3	28.1	5
C_6H_{12}	4-Methyl-1-pentene	25	0.0048	3	63.2	5
C_6H_{12}	2,3-Dimethyl-1-butene	30	0.046	3		
C_6H_{12}	Cyclohexane	25	0.0058	3	19.4	13
C_6H_{12}	Methylcyclopentane	25	0.0043	3	36.7	5
$C_6H_{12}N_2O_4S$	*L*-Lanthionine	25	0.15	26		
$C_6H_{12}N_2O_4S_2$	*L*-Cystine	25	0.011	26		
$C_6H_{12}N_4$	Methenamine	12	44.8	27		
$C_6H_{12}O$	1-Hexen-3-ol	25	2.52	1		
$C_6H_{12}O$	4-Hexen-2-ol	25	3.81	1		
$C_6H_{12}O$	Butyl vinyl ether	20	0.3	10		
$C_6H_{12}O$	2-Hexanone	20	1.75	10		
$C_6H_{12}O$	4-Methyl-2-pentanone	25	1.7	10		
$C_6H_{12}O$	Cyclohexanol	10	4.62	1		
		25	3.8	1		
		40	3.30	1		
$C_6H_{12}O_2$	Hexanoic acid	20	0.97	26		
$C_6H_{12}O_2$	Isopentyl formate	22	0.3	27		
$C_6H_{12}O_2$	Butyl acetate	20	0.68	10		
$C_6H_{12}O_2$	*sec*-Butyl acetate	20	0.62	10		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
$C_6H_{12}O_2$	Isobutyl acetate	20	0.63	10		
$C_6H_{12}O_2$	Propyl propanoate	25	0.6	27		
$C_6H_{12}O_2$	Ethyl butanoate	20	0.49	10		
$C_6H_{12}O_3$	Ethylene glycol monoethyl ether acetate		14	30		
$C_6H_{12}O_3$	Paraldehyde	25	11	30		
$C_6H_{12}O_6$	*D*-Galactose	20	40.6	27		
$C_6H_{12}O_6$	α-*D*-Glucose	15	45.0	27		
		30	54.6	27		
		80	81.5	27		
$C_6H_{13}Br$	1-Bromohexane	25	0.00258	25		
$C_6H_{13}Cl$	1-Chlorohexane	5	0.0047	25		
		25	0.0064	25		
$C_6H_{13}NO_2$	Leucine	25	2.15	26		
$C_6H_{13}NO_2$	Isoleucine	25	3.31	26		
$C_6H_{13}NO_2$	L-Norleucine	25	1.5	26		
$C_6H_{13}NO_2$	Ethyl *N*-propylcarbamate	15	7.70	27		
C_6H_{14}	Hexane	25	0.0011	3	183	13
		60	0.00136	3		
C_6H_{14}	2-Methylpentane	25	0.00137	3	176	13
C_6H_{14}	3-Methylpentane	25	0.00129	3	170	13
C_6H_{14}	2,2-Dimethylbutane	25	0.0021	3	199	13
C_6H_{14}	2,3-Dimethylbutane	25	0.0021	3	144	13
$C_6H_{14}N_2O_2$	Lysine	25	0.58	26		
$C_6H_{14}N_4O_2$	Arginine	25	15.44	26		
$C_6H_{14}O$	2-Methoxy-2-methylbutane	20	1.25	27		
$C_6H_{14}O$	1-Hexanol	0	0.79	1		
		25	0.60	1		
		50	0.51	1		
$C_6H_{14}O$	2-Hexanol	25	1.4	1		
$C_6H_{14}O$	3-Hexanol	25	1.6	1		
$C_6H_{14}O$	2-Methyl-1-pentanol	25	0.81	1		
$C_6H_{14}O$	4-Methyl-1-pentanol	25	0.76	1		
$C_6H_{14}O$	2-Methyl-2-pentanol	25	3.2	1		
$C_6H_{14}O$	3-Methyl-2-pentanol	25	1.9	1		
$C_6H_{14}O$	4-Methyl-2-pentanol	27	1.5	1		
$C_6H_{14}O$	2-Methyl-3-pentanol	25	2.0	1		
$C_6H_{14}O$	3-Methyl-3-pentanol	25	4.3	1		
$C_6H_{14}O$	2-Ethyl-1-butanol	25	1.0	1		
$C_6H_{14}O$	2,2-Dimethyl-1-butanol	25	0.8	1		
$C_6H_{14}O$	2,3-Dimethyl-2-butanol	25	4.2	1		
$C_6H_{14}O$	3,3-Dimethyl-2-butanol	25	2.4	1		
$C_6H_{14}O$	Dipropyl ether	25	0.49	10	0.26	13
$C_6H_{14}O$	Diisopropyl ether	20	1.2	10	0.26	13
$C_6H_{14}O_2$	1,1-Diethoxyethane	25	5	10		
$C_6H_{14}O_6$	*D*-Mannitol	25	17.7	27		
$C_6H_{15}N$	Dipropylamine	20	2.5	10		
$C_6H_{15}N$	Triethylamine	20	5.5	10		
$C_6H_{16}ClN$	Triethylamine hydrochloride	25	57.8	27		
C_7F_{16}	Perfluoroheptane	25	0.0000013	25		
$C_7H_4ClNO_4$	3-Chloro-2-nitrobenzoic acid	25	0.047	27		
$C_7H_4ClNO_4$	5-Chloro-2-nitrobenzoic acid	25	0.96	27		
$C_7H_4Cl_4O$	2,3,4,6-Tetrachloro-5-methylphenol	25	0.00061	2		
$C_7H_4N_2O_6$	3,5-Dinitrobenzoic acid	25	0.134	27		
$C_7H_4O_6$	4-Oxo-4H-pyran-2,6-dicarboxylic acid	25	1.45	27		
$C_7H_4O_7$	3-Hydroxy-4-oxo-4H-pyran-2,6-dicarboxylic acid	25	0.84	27		
$C_7H_5BrO_2$	2-Bromobenzoic acid	25	0.185	27		
$C_7H_5BrO_2$	3-Bromobenzoic acid	25	0.040	27		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
$C_7H_5BrO_2$	4-Bromobenzoic acid	25	0.0056	27		
$C_7H_5ClO_2$	2-Chlorobenzoic acid	25	0.209	27		
$C_7H_5ClO_2$	3-Chlorobenzoic acid	25	0.040	27		
$C_7H_5ClO_2$	4-Chlorobenzoic acid	25	0.072	27		
$C_7H_5Cl_3$	(Trichloromethyl)benzene	5	0.0053	10		
$C_7H_5Cl_3O$	2,4,6-Trichloro-3-methylphenol	25	0.0112	2		
$C_7H_5FO_2$	2-Fluorobenzoic acid	25	0.72	27		
$C_7H_5FO_2$	3-Fluorobenzoic acid	25	0.15	27		
$C_7H_5FO_2$	4-Fluorobenzoic acid	25	0.12	27		
$C_7H_5IO_2$	2-Iodobenzoic acid	25	0.095	27		
$C_7H_5IO_2$	3-Iodobenzoic acid	25	0.016	27		
$C_7H_5IO_2$	4-Iodobenzoic acid	25	0.0027	27		
C_7H_5N	Benzonitrile	25	0.2	10		
C_7H_5NO	Benzoxazole	20	0.834	6		
$C_7H_5NO_3$	3-Nitrobenzaldehyde	25	0.16	27		
$C_7H_5NO_3$	4-Nitrobenzaldehyde	25	0.23	27		
$C_7H_5NO_3S$	Saccharin	25	0.40	27		
		100	4.0	27		
$C_7H_5N_3O_6$	2,4,6-Trinitrotoluene	25	0.015	27		
		100	0.015	27		
$C_7H_6Cl_2$	(Dichloromethyl)benzene	30	0.025	10		
$C_7H_6Cl_2O$	2,4-Dichloro-6-methylphenol	25	0.0283	2		
$C_7H_6Cl_2O$	2,6-Dichloro-4-methylphenol	25	0.0673	2		
$C_7H_6N_2$	1*H*-Benzimidazole	20	0.201	6		
$C_7H_6N_2$	1*H*-Indazole	20	0.0827	6		
C_7H_6O	Benzaldehyde	20	0.3	10		
$C_7H_6O_2$	Benzoic acid	25	0.34	27		
$C_7H_6O_2$	Salicylaldehyde	86	1.68	10		
$C_7H_6O_3$	4-Hydroxybenzoic acid	25	0.64	27		
		80	12.0	27		
$C_7H_6O_5$	3,4,5-Trihydroxybenzoic acid	15	0.94	27		
		100	25.0	27		
C_7H_7Br	*p*-Bromotoluene	25	0.011	2		
C_7H_7Cl	(Chloromethyl)benzene	20	0.0493	10		
C_7H_7ClO	2-Chloro-6-methylphenol	25	0.36	2		
C_7H_7ClO	4-Chloro-2-methylphenol	25	0.68	2		
C_7H_7ClO	4-Chloro-3-methylphenol	25	0.40	2		
C_7H_7NO	Benzamide	12	0.577	27		
$C_7H_7NO_2$	2-Nitrotoluene	30	0.065	27		
$C_7H_7NO_2$	3-Nitrotoluene	30	0.050	27		
$C_7H_7NO_2$	4-Nitrotoluene	30	0.044	27		
$C_7H_7NO_3$	2-Nitroanisole	30	0.169	10		
$C_7H_7NO_3$	4-Nitroanisole	30	0.059	27		
C_7H_8	Toluene	5	0.063	3		
		25	0.0531	22	0.660	22
C_7H_8	1,3,5-Cycloheptatriene	25	0.064	3	0.47	13
C_7H_8	1,6-Heptadiyne	25	0.125	3		
$C_7H_8N_2S$	Phenylthiourea	25	2.55	27		
$C_7H_8N_4O_2$	Theophylline	20	0.52	29		
C_7H_8O	*o*-Cresol	40	3.08	10		
C_7H_8O	*m*-Cresol	40	2.51	10		
C_7H_8O	*p*-Cresol	40	2.26	10		
C_7H_8O	Benzyl alcohol	20	0.08	10		
C_7H_8O	Anisole	25	0.19	20	0.025	13
C_7H_9N	*o*-Methylaniline	20	1.66	10		
C_7H_9N	*p*-Methylaniline	21	7.35	10		
$C_7H_9NO_2S$	2-Methylbenzenesulfonamide	25	0.162	27		
$C_7H_9NO_2S$	3-Methylbenzenesulfonamide	25	0.78	27		
$C_7H_9NO_2S$	4-Methylbenzenesulfonamide	25	0.316	27		

Mol. Form	Name	*t*/°C	*S*/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
C_7H_{12}	1-Heptyne	25	0.0094	3	4.47	13
C_7H_{12}	Cycloheptene	25	0.0066	3	4.9	13
C_7H_{12}	1-Methylyclohexene	25	0.0052	3		
$C_7H_{12}O_2$	Cyclohexanecarboxylic acid	15	0.201	27		
C_7H_{14}	1-Heptene	25	0.032	3	40.3	13
C_7H_{14}	*trans*-2-Heptene	25	0.015	3	42.2	13
C_7H_{14}	Cycloheptane	25	0.0030	3	9.59	13
C_7H_{14}	Methylcyclohexane	25	0.00151	3	43.3	13
		50	0.0019	3		
C_7H_{14}	Ethylcyclopentane	20	0.012	3		
$C_7H_{14}O$	1-Heptanal	11	0.124	27		
$C_7H_{14}O$	2-Heptanone	25	0.43	10	0.0171	28
$C_7H_{14}O$	3-Heptanone	20	1.43	10		
$C_7H_{14}O$	2,4-Dimethyl-3-pentanone	20	0.59	10		
$C_7H_{14}O_2$	Heptanoic acid	15	0.24	27		
$C_7H_{14}O_2$	Pentyl acetate	20	0.17	10		
$C_7H_{14}O_2$	Isopentyl acetate	20	0.2	10		
$C_7H_{14}O_2$	*sec*-Pentyl acetate	25	0.2	27		
$C_7H_{14}O_2$	Butyl propanoate	22	0.572	27		
$C_7H_{14}O_2$	Propyl butanoate	17	0.162	27		
$C_7H_{14}O_2$	Ethyl pentanoate	25	0.3	27		
$C_7H_{14}O_2$	Ethyl 3-methylbutanoate	20	0.2	10		
$C_7H_{15}Br$	1-Bromoheptane	25	0.00067	25		
$C_7H_{15}Cl$	1-Chloroheptane	25	0.00136	25		
$C_7H_{15}I$	1-Iodoheptane	25	0.00035	25		
C_7H_{16}	Heptane	0	0.0003	3		
		25	0.00024	3	209	13
		40	0.00025	3		
C_7H_{16}	2-Methylhexane	25	0.00025	3	346	5
C_7H_{16}	3-Methylhexane	25	0.00026	3	249	13
C_7H_{16}	2,2-Dimethylpentane	25	0.00044	3	318	5
C_7H_{16}	2,3-Dimethylpentane	25	0.00052	3	175	5
C_7H_{16}	2,4-Dimethylpentane	25	0.00042	3	323	13
C_7H_{16}	3,3-Dimethylpentane	25	0.00059	3	186	5
$C_7H_{16}O$	1-Heptanol	10	0.25	1		
		25	0.174	1	0.00562	28
		50	0.12	1		
$C_7H_{16}O$	2-Heptanol	30	0.33	1		
$C_7H_{16}O$	3-Heptanol	25	0.43	1		
$C_7H_{16}O$	4-Heptanol	25	0.47	1		
$C_7H_{16}O$	2-Methyl-2-hexanol	25	1.0	1		
$C_7H_{16}O$	5-Methyl-2-hexanol	25	0.49	1		
$C_7H_{16}O$	3-Methyl-3-hexanol	25	1.2	1		
$C_7H_{16}O$	3-Ethyl-3-pentanol	25	1.7	1		
$C_7H_{16}O$	2,3-Dimethyl-2-pentanol	25	1.5	1		
$C_7H_{16}O$	2,4-Dimethyl-2-pentanol	25	1.3	1		
$C_7H_{16}O$	2,2-Dimethyl-3-pentanol	25	0.82	1		
$C_7H_{16}O$	2,3-Dimethyl-3-pentanol	25	1.6	1		
$C_7H_{16}O$	2,4-Dimethyl-3-pentanol	25	0.70	1		
$C_7H_{16}O$	2,3,3-Trimethyl-2-butanol	40	2.2	1		
C_8F_{18}	Perfluorooctane	25	0.00000017	25		
$C_8H_4F_6$	1,3-Bis(trifluoromethyl)benzene	25	0.0041	2		
$C_8H_6N_2$	Quinoxaline	50	54	6		
$C_8H_6O_4$	Phthalic acid	14	0.54	27		
$C_8H_6O_4$	Isophthalic acid	25	0.013	27		
C_8H_6S	Benzo[b]thiophene	20	0.0130	6		
$C_8H_7ClO_3$	3-Chloro-4-hydroxy-5-methoxybenzaldehyde	25	0.093	8		
$C_8H_7ClO_3$	2-Chloro-4-hydroxy-5-methoxybenzaldehyde	25	0.013	8		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
$C_8H_7Cl_3O$	2,4,6-Trichloro-3,5-dimethylphenol	25	0.00050	2		
C_8H_7N	Indole	20	0.187	6		
C_8H_8	Styrene	25	0.0321	22	0.286	22
		50	0.046	4	0.30	13
$C_8H_8HgO_2$	Mercury(II) phenyl acetate		0.2	30		
$C_8H_8N_2$	2-Methyl-1H-benzimidazole	20	0.145	6		
C_8H_8O	Acetophenone	25	0.55	28	0.00108	28
$C_8H_8O_2$	*o*-Toluic acid	25	0.118	27		
$C_8H_8O_2$	*m*-Toluic acid	25	0.098	27		
$C_8H_8O_2$	*p*-Toluic acid	25	0.345	27		
$C_8H_8O_2$	Benzeneacetic acid	25	1.71	27		
$C_8H_8O_2$	Methyl benzoate	20	0.21	10		
$C_8H_8O_3$	4-Methoxybenzoic acid	25	0.023	27		
$C_8H_8O_3$	Mandelic acid	25	11.3	27		
$C_8H_8O_3$	Methyl salicylate	30	0.74	10		
$C_8H_8O_3$	4-Hydroxy-3-methoxybenzaldehyde	25	0.247	8		
C_8H_9ClO	4-Chloro-2,5-dimethylphenol	25	0.89	2		
C_8H_9ClO	4-Chloro-2,6-dimethylphenol	25	0.52	2		
C_8H_9ClO	4-Chloro-3,5-dimethylphenol	25	0.34	2		
C_8H_9NO	Acetanilide	20	0.52	27		
		70	2.7	27		
C_8H_{10}	Ethylbenzene	0	0.020	4		
		25	0.0161	22	0.843	22
		40	0.0200	4		
C_8H_{10}	*o*-Xylene	25	0.0171	22	0.551	22
		45	0.021	4		
C_8H_{10}	*m*-Xylene	0	0.0203	4		
		25	0.0161	22	0.730	22
		40	0.022	4		
C_8H_{10}	*p*-Xylene	0	0.0160	4		
		25	0.0181	22	0.690	22
		40	0.022	4		
$C_8H_{10}N_4O_2$	Caffeine	25	2.12	29		
$C_8H_{10}O$	2,4-Xylenol	25	0.787	10		
$C_8H_{10}O$	3,5-Xylenol	29	0.62	10		
$C_8H_{10}O$	Phenetole	25	0.12	10		
$C_8H_{11}N$	2,5-Dimethylaniline	20	0.66	27		
C_8H_{12}	4-Vinylcyclohexene	25	0.005	4		
C_8H_{14}	1-Octyne	25	0.0024	4	7.87	13
C_8H_{16}	1-Octene	25	0.00027	4	96.3	13
C_8H_{16}	Cyclooctane	25	0.00079	4	10.7	13
C_8H_{16}	Ethylcyclohexane	40	0.00066	4		
C_8H_{16}	*cis*-1,2-Dimethylcyclohexane	25	0.00060	4	36	5
C_8H_{16}	*trans*-1,4-Dimethylcyclohexane	25	0.000384	4	88.2	5
C_8H_{16}	Propylcyclopentane	25	0.00020	4	90.2	5
C_8H_{16}	1,1,3-Trimethylcyclopentane	25	0.00037	4	159	5
$C_8H_{16}N_2O_4S_2$	Homocystine	25	0.02	26		
$C_8H_{16}O$	2-Octanone	25	0.113	10		
$C_8H_{16}O_2$	Octanoic acid	25	0.080	26		
$C_8H_{16}O_2$	Hexyl acetate	20	0.02	10		
$C_8H_{16}O_2$	*sec*-Hexyl acetate	20	0.13	10		
$C_8H_{16}O_2$	Pentyl propanoate	20	0.1	27		
$C_8H_{16}O_2$	Isobutyl isobutanoate	20	0.5	10		
$C_8H_{16}O_2$	Ethyl hexanoate	20	0.063	27		
$C_8H_{17}Br$	1-Bromooctane	25	0.000167	25		
$C_8H_{17}Cl$	1-Chlorooctane	25	0.0345	25		
$C_8H_{17}Cl$	3-(Chloromethyl)heptane	20	0.01	10		
C_8H_{18}	Octane	25	0.000071	4	311	13
		50	0.00010	4		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
C_8H_{18}	3-Methylheptane	25	0.000079	4	376	5
C_8H_{18}	2,2,4-Trimethylpentane	25	0.00022	4	307	13
C_8H_{18}	2,3,4-Trimethylpentane	25	0.00018	4	206	13
$C_8H_{18}O$	1-Octanol	25	0.054	1		
$C_8H_{18}O$	2-Octanol	25	0.4	1		
$C_8H_{18}O$	2-Methyl-2-heptanol	30	0.25	1		
$C_8H_{18}O$	2-Ethyl-1-hexanol	25	0.01	1		
$C_8H_{18}O$	Dibutyl ether	20	0.03	10	0.48	13
$C_8H_{19}N$	Dibutylamine	20	0.47	10		
$C_8H_{19}N$	2-Ethylhexylamine	20	0.25	10		
$C_8H_{20}Si$	Tetraethylsilane	25	0.0000325	10		
$C_9H_7BrO_4$	2-(Acetyloxy)-5-bromobenzoic acid		0.07	30		
C_9H_7N	Quinoline	20	0.633	6		
C_9H_7N	Isoquinoline	20	0.452	6		
$C_9H_8O_2$	*trans*-Cinnamic acid	25	0.056	27		
$C_9H_8O_4$	2-(Acetyloxy)benzoic acid		0.25	27		
$C_9H_9I_2NO_3$	L-3,5-Diiodotyrosine	25	0.062	26		
C_9H_9N	3-Methyl-1H-indole	20	0.050	6		
$C_9H_9NO_3$	*N*-Benzoylglycine	25	0.37	29		
C_9H_{10}	Indan	25	0.010	4		
$C_9H_{10}O_2$	Ethyl benzoate	25	0.083	20		
$C_9H_{11}NO_2$	*DL*-Phenylalanine	25	1.40	29		
$C_9H_{11}NO_2$	Phenylalanine	25	2.71	26		
$C_9H_{11}NO_3$	*L*-Tyrosine	25	0.046	26		
$C_9H_{11}NO_3$	*DL*-Tyrosine	25	0.35	30		
$C_9H_{11}NO_4$	Levodopa [3-Hydroxy-*L*-tyrosine]	25	62.3	26		
C_9H_{12}	1,8-Nonadiyne	25	0.0125	4		
C_9H_{12}	Propylbenzene	25	0.0052	22	1.041	22
C_9H_{12}	Isopropylbenzene	25	0.0050	22	1.466	22
C_9H_{12}	*o*-Ethyltoluene	25	0.0093	5	0.529	13
C_9H_{12}	*p*-Ethyltoluene	25	0.0094	5	0.500	13
C_9H_{12}	1,2,3-Trimethylbenzene	25	0.0070	22	0.343	22
C_9H_{12}	1,2,4-Trimethylbenzene	25	0.0057	22	0.569	22
C_9H_{12}	1,3,5-Trimethylbenzene	25	0.0050	22	0.781	22
$C_9H_{14}N_4O_3$	Carnosine	25	24.4	26		
$C_9H_{14}O_6$	Triacetin	25	5.8	10		
C_9H_{16}	1-Nonyne	25	0.00072	4		
C_9H_{18}	1,1,3-Trimethylcyclohexane	25	0.000177	4	105	13
$C_9H_{18}O$	Diisobutyl ketone	25	0.043	10		
$C_9H_{18}O_2$	Nonanoic acid	20	0.0284	26		
$C_9H_{18}O_2$	Ethyl heptanoate	20	0.029	27		
C_9H_{20}	Nonane	25	0.000017	4	333	13
		50	0.000022	4		
C_9H_{20}	4-Methyloctane	25	0.0000115	4	1000	5
C_9H_{20}	2,2,5-Trimethylhexane	25	0.00008	4	246	13
$C_9H_{20}O$	3,5-Dimethyl-4-heptanol	15	0.072	1		
$C_9H_{20}O$	1-Nonanol	25	0.014	1		
$C_9H_{20}O$	2-Nonanol	15	0.026	1		
$C_9H_{20}O$	3-Nonanol	15	0.032	1		
$C_9H_{20}O$	4-Nonanol	15	0.0026	1		
$C_9H_{20}O$	5-Nonanol	15	0.0032	1		
$C_{10}F_{22}$	Perfluorodecane	20	0.000031	25		
$C_{10}H_7Cl$	1-Chloronaphthalene	25	0.00224	5	0.0363	28
$C_{10}H_7Cl$	2-Chloronaphthalene	25	0.00117	5	0.0335	28
$C_{10}H_8$	Naphthalene	10	0.0019	4		
		25	0.00316	22	0.043	22
		50	0.0082	4		
$C_{10}H_8O$	2-Naphthol		0.1	30		
$C_{10}H_9N$	3-Methylisoquinoline	20	0.092	6		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
$C_{10}H_{10}O_4$	Dimethyl phthalate	25	0.40	15		
$C_{10}H_{12}N_4O_5$	Inosine	20	1.6	29		
$C_{10}H_{13}N_5O_3$	2'-Deoxyadenosine	25	0.67	29		
$C_{10}H_{13}N_5O_4$	Adenosine	25	0.51	29		
$C_{10}H_{13}N_5O_5$	Guanosine	25	0.0500	29		
$C_{10}H_{14}$	Butylbenzene	25	0.00138	22	1.33	22
$C_{10}H_{14}$	*sec*-Butylbenzene	25	0.0014	4	1.89	11
$C_{10}H_{14}$	*tert*-Butylbenzene	25	0.0032	4	1.28	11
$C_{10}H_{14}$	Isobutylbenzene	25	0.0010	4	3.32	11
$C_{10}H_{14}$	*p*-Cymene	25	0.0051	23	0.80	5
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene	25	0.000348	4	2.55	11
$C_{10}H_{14}N_2O_5$	Thymidine	25	5.1	29		
$C_{10}H_{14}O$	Carvone	15	0.13	27		
$C_{10}H_{14}O$	Thymol		0.1	30		
$C_{10}H_{16}$	*d*-Limonene	0	0.00097	4		
		25	0.00138	4		
$C_{10}H_{16}O$	Camphor	20	0.01	10		
$C_{10}H_{16}O$	Carvenone	15	0.22	27		
$C_{10}H_{16}O_4$	*trans*-Camphoric acid	25	0.8	27		
$C_{10}H_{18}$	*trans*-Decahydronaphthalene	25	0.000089	4	3	13
$C_{10}H_{18}O$	Borneol	25	0.074	27		
$C_{10}H_{18}O$	α-Terpineol	15	0.20	27		
$C_{10}H_{20}$	1-Decene	25	0.00057	4		
$C_{10}H_{20}$	Pentylcyclopentane	25	0.0000115	4	185	5
$C_{10}H_{20}O_2$	Decanoic acid	20	0.015	26		
$C_{10}H_{20}O_2$	Ethyl octanoate	20	0.007	27		
$C_{10}H_{22}$	Decane	0	0.0000015	4	479	13
$C_{10}H_{22}O$	1-Decanol	25	0.0037	1		
$C_{10}H_{22}O$	Diisopentyl ether	20	0.02	10		
$C_{11}H_8O_2$	1-Naphthalenecarboxylic acid	25	0.0058	27		
$C_{11}H_{10}$	1-Methylnaphthalene	25	0.00281	22	0.045	22
$C_{11}H_{10}$	2-Methylnaphthalene	25	0.0025	4	0.051	12
$C_{11}H_{12}N_2O_2$	Tryptophan	25	1.30	26		
$C_{11}H_{16}$	Pentylbenzene	25	0.00105	5	1.69	11
$C_{11}H_{22}O_2$	Ethyl nonanoate	20	0.003	27		
$C_{12}Cl_{10}$	Decachlorobiphenyl	25	0.00000000012	7	0.0208	7
$C_{12}F_{26}$	Hexacosafluorododecane	20	0.00000096	25		
$C_{12}HCl_9$	2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl	25	0.0000000018	7		
$C_{12}H_2Cl_8$	2,2',3,3',5,5',6,6'-Octachlorobiphenyl	25	0.0000003	7	0.0381	7
$C_{12}H_3Cl_7$	2,2',3,3',4,4',6-Heptachlorobiphenyl	25	0.0000002	7	0.0054	7
$C_{12}H_4Cl_6$	2,2',3,3',4,4'-Hexachlorobiphenyl	25	0.00000006	7	0.0354	31
$C_{12}H_4Cl_6$	2,2',4,4',6,6'-Hexachlorobiphenyl	25	0.00000007	7	0.818	7
$C_{12}H_4Cl_6$	2,2',3,3',6,6'-Hexachlorobiphenyl	25	0.00000008	7		
$C_{12}H_5Cl_5$	2,3,4,5,6-Pentachlorobiphenyl	25	0.0000008	7		
$C_{12}H_5Cl_5$	2,2',4,5,5'-Pentachlorobiphenyl	25	0.000001	7	0.0421	31
$C_{12}H_6Cl_4$	2,3,4,5-Tetrachlorobiphenyl	25	0.000002	7		
$C_{12}H_6Cl_4$	2,2',4',5-Tetrachlorobiphenyl	25	0.0000016	9		
$C_{12}H_7Cl_3$	2,4,5-Trichlorobiphenyl	25	0.000014	7	0.0379	31
$C_{12}H_7Cl_3$	2,4,6-Trichlorobiphenyl	25	0.00002	7	0.0495	7
$C_{12}H_8$	Acenaphthylene	20	0.0016	28	0.012	28
$C_{12}H_8Cl_2$	2,5-Dichlorobiphenyl	25	0.0002	7	0.0201	7
$C_{12}H_8Cl_2$	2,6-Dichlorobiphenyl	25	0.00014	7		
$C_{12}H_8O$	Dibenzofuran	25	0.000656	6	0.011	12
$C_{12}H_8S$	Dibenzothiophene	25	0.000103	6		
$C_{12}H_9Cl$	2-Chlorobiphenyl	25	0.00055	7	0.0701	7
$C_{12}H_9N$	Carbazole	22	0.000120	6		
$C_{12}H_{10}$	Acenaphthene	0	0.00015	4		
		25	0.000380	22	0.01217	22
		50	0.00092	4		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
$C_{12}H_{10}$	Biphenyl	0	0.000272	4		
		25	0.00072	22	0.0280	22
		50	0.0022	4		
$C_{12}H_{10}N_2$	Azobenzene	20	0.03	27		
$C_{12}H_{10}N_2O$	*N*-Nitrosodiphenylamine	25	0.0035	17		
$C_{12}H_{10}O$	Diphenyl ether	25	0.00180	6	0.027	13
$C_{12}H_{12}$	1-Ethylnaphthalene	25	0.00101	4	0.039	12
$C_{12}H_{12}$	2-Ethylnaphthalene	25	0.00080	4	0.078	12
$C_{12}H_{12}$	1,3-Dimethylnaphthalene	25	0.0008	4		
$C_{12}H_{12}$	1,4-Dimethylnaphthalene	25	0.00114	4		
$C_{12}H_{12}$	1,5-Dimethylnaphthalene	25	0.00031	4	0.036	28
$C_{12}H_{12}$	2,3-Dimethylnaphthalene	25	0.00025	4		
$C_{12}H_{12}$	2,6-Dimethylnaphthalene	25	0.00017	4		
$C_{12}H_{18}$	Hexylbenzene	25	0.00021	4		
$C_{12}H_{22}O_{11}$	Sucrose	20	67.1	27		
		50	72.3	27		
		100	83.0	27		
$C_{12}H_{22}O_{11}$	α-Maltose	20	51.9	27		
$C_{12}H_{24}O_2$	Dodecanoic acid	20	0.0055	26		
$C_{12}H_{24}O_2$	Ethyl decanoate	20	0.0015	27		
$C_{12}H_{26}$	Dodecane	25	0.00000037	4	750	5
$C_{12}H_{26}O$	1-Dodecanol	25	0.0004	1		
$C_{12}H_{27}O_4P$	Tributyl phosphate	25	0.039	10		
$C_{13}H_9N$	Acridine	25	0.00466	6		
$C_{13}H_9N$	Benzo[f]quinoline	25	0.0079	6		
$C_{13}H_{10}$	9H-Fluorene	0	0.00007	4		
		25	0.00019	22	0.00787	22
		50	0.00063	4		
$C_{13}H_{12}$	Diphenylmethane	25	0.000141	4	0.001	12
$C_{13}H_{14}$	1,4,5-Trimethylnaphthalene	25	0.00021	4		
$C_{13}H_{26}O_2$	Tridecanoic acid	20	0.0033	26		
$C_{14}H_{10}$	Anthracene	0	0.0000022	4		
		25	0.0000045	22	0.00396	22
$C_{14}H_{10}$	Phenanthrene	10	0.000050	4		
		25	0.00011	22	0.00324	22
		50	0.00041	4		
$C_{14}H_{12}$	*trans*-Stilbene	25	0.000029	4	0.040	12
$C_{14}H_{14}$	1,2-Diphenylethane	25	0.00044	6	0.017	12
$C_{14}H_{14}O$	Dibenzyl ether	35	0.0040	10		
$C_{14}H_{28}O_2$	Tetradecanoic acid	20	0.0020	26		
$C_{14}H_{29}Cl$	1-Chlorotetradecane	25	0.0232	25		
$C_{14}H_{30}$	Tetradecane	25	0.000012	5		
$C_{14}H_{30}O$	1-Tetradecanol	25	0.000031	1		
$C_{15}H_{12}$	1-Methylphenanthrene	25	0.0000269	4		
$C_{15}H_{12}$	2-Methylanthracene	25	0.00003	22		
$C_{15}H_{12}$	9-Methylanthracene	25	0.000026	4		
$C_{15}H_{30}O_2$	Pentadecanoic acid	20	0.0012	26		
$C_{15}H_{32}O$	1-Pentadecanol	25	0.000010	1		
$C_{16}H_{10}$	Fluoranthene	25	0.000026	22	0.00096	22
$C_{16}H_{10}$	Pyrene	25	0.000013	22	0.00092	22
		50	0.00009	4		
$C_{16}H_{14}$	9,10-Dimethylanthracene	25	0.0000056	4		
$C_{16}H_{15}NO_3$	*N*-Benzoyl-*L*-phenylalanine	25	0.085	29		
$C_{16}H_{22}O_4$	Dibutyl phthalate	25	0.00112	15		
$C_{16}H_{32}O_2$	Hexadecanoic acid	20	0.00072	26		
$C_{16}H_{34}O$	1-Hexadecanol	25	0.000003	1		
$C_{17}H_{12}$	11H-Benzo[a]fluorene	25	0.0000045	4		
$C_{17}H_{12}$	11H-Benzo[b]fluorene	25	0.0000002	4		
$C_{17}H_{19}NO_3$	Morphine	20	0.015	27		

Mol. Form	Name	t/°C	S/mass %	Ref.	k_H/kPa m^{3}mol^{-1}	Ref.
$C_{17}H_{21}NO_4$	Cocaine	25	0.17	27		
$C_{17}H_{34}O_2$	Heptadecanoic acid	20	0.00042	26		
$C_{18}H_{12}$	Benzo[a]anthracene	25	0.0000011	22	0.00058	22
$C_{18}H_{12}$	Chrysene	25	0.0000002	22	0.000065	22
$C_{18}H_{12}$	Naphthacene	25	0.00000006	4	0.000004	12
$C_{18}H_{12}$	Triphenylene	25	0.0000041	4	0.00001	12
$C_{18}H_{12}N_2$	2,2'-Biquinoline	24	0.000102	6		
$C_{18}H_{21}NO_3$	Codeine	25	0.79	27		
$C_{18}H_{32}O_{16}$	Raffinose	20	12.5	27		
$C_{18}H_{34}O_4$	Dibutyl sebacate	20	0.004	10		
$C_{18}H_{36}O_2$	Octadecanoic acid	20	0.00029	26		
$C_{18}H_{38}O$	1-Octadecanol	34	0.000011	1		
$C_{19}H_{14}$	9-Methylbenz[a]anthracene	27	0.0000066	4		
$C_{19}H_{14}$	10-Methylbenz[a]anthracene	25	0.0000055	4		
$C_{19}H_{14}$	5-Methylchrysene	27	0.0000062	4		
$C_{20}H_{12}$	Perylene	25	0.00000004	4	0.000003	12
$C_{20}H_{12}$	Benzo[a]pyrene	25	0.0000003	22	0.0000465	22
$C_{20}H_{12}$	Benzo[e]pyrene	20	0.0000005	22	0.0000467	22
$C_{20}H_{12}O_5$	Fluorescein	20	0.005	27		
$C_{20}H_{13}N$	13H-Dibenzo[a,i]carbazole	24	0.00000104	6		
$C_{20}H_{14}$	1,2-Dihydrobenz[j]aceanthrylene	25	0.00000036	6		
$C_{20}H_{14}O_4$	Phenolphthalein	20	0.018	27		
$C_{20}H_{24}N_2O_2$	Quinine	25	0.057	27		
$C_{20}H_{24}N_2O_2$	Quinidine	20	0.020	27		
$C_{20}H_{42}$	Eicosane	25	0.00000019	4		
$C_{21}H_{13}N$	Dibenz[a,j]acridine	25	0.000016	6		
$C_{21}H_{16}$	1,2-Dihydro-3-methylbenz[j]aceanthrylene	25	0.00000022	6		
$C_{21}H_{22}N_2O_2$	Strychnine	20	0.013	27		
$C_{21}H_{28}O_5$	17,21-Dihydroxypregn-4-ene-3,11,20-trione	25	0.028	30		
$C_{22}H_{12}$	Benzo[ghi]perylene	25	0.000000026	4	0.000075	12
$C_{22}H_{14}$	Picene	25	0.00000025	4		
$C_{22}H_{14}$	Benzo[b]triphenylene	25	0.0000027	4		
$C_{22}H_{14}$	Dibenz[a,h]anthracene	25	0.00000006	4		
$C_{22}H_{14}$	Dibenz[a,j]anthracene	25	0.0000012	4		
$C_{22}H_{44}O_2$	Butyl stearate	25	0.2	10		
$C_{23}H_{26}N_2O_4$	Brucine	20	0.012	27		
$C_{23}H_{27}NO_8$	Narceine	13	0.078	27		
$C_{24}H_{12}$	Coronene	25	0.000000014	4		

AQUEOUS SOLUBILITY OF INORGANIC COMPOUNDS AT VARIOUS TEMPERATURES

The solubility of over 300 common inorganic compounds in water is tabulated here as a function of temperature. Solubility is defined as the concentration of the compound in a solution that is in equilibrium with a solid phase at the specified temperature. In this table the solid phase is generally the most stable crystalline phase at the temperature in question. An asterisk * on solubility values in adjacent columns indicates that the solid phase changes between those two temperatures (usually from one hydrated phase to another or from a hydrate to the anhydrous solid). In such cases the slope of the solubility vs. temperature curve may show a discontinuity.

All solubility values are expressed as mass percent of solute, $100 \cdot w_2$, where

$$w_2 = m_2/(m_1 + m_2)$$

and m_2 is the mass of solute and m_1 the mass of water. This quantity is related to other common measures of solubility as follows:

Molality: $m_2 = 1000w_2/M_2(1\text{-}w_2)$
Mole fraction: $x_2 = (w_2/M_2)/\{(w_2/\mathrm{M}_2) + (1\text{-}w_2)/M_1\}$
Mass of solute per 100 g of H_2O: $r_2 = 100w_2/(1\text{-}w_2)$

Here M_2 is the molar mass of the solute and M_1 = 18.015 g/mol is the molar mass of water.

The data in the table have been derived from the references indicated; in many cases the data have been refitted or interpolated in order to present solubility at rounded values of temperature. Where available, values were taken from the IUPAC *Solubility Data Series* (Reference 1) or the related papers in the *Journal of Physical and Chemical Reference Data* (References 2 to 5), which present carefully evaluated data.

The solubility of sparingly soluble compounds that do not appear in this table may be calculated from the data in the table “Solubility Product Constants”. Solubility of inorganic gases may be found in the table “Solubility of Selected Gases in Water”.

Compounds are listed alphabetically by chemical formula in the most commonly used form (e.g., NaCl, NH_4NO_3, etc.).

REFERENCES

1. *Solubility Data Series*, International Union of Pure and Applied Chemistry. Volumes 1 to 53 were published by Pergamon Press, Oxford, from 1979 to 1994; subsequent volumes were published by Oxford University Press, Oxford. The number following the colon is the volume number in the series.
2. Clever, H.L., and Johnston, F.J., *J. Phys. Chem. Ref. Data*, 9, 751, 1980.
3. Marcus, Y., *J. Phys. Chem. Ref. Data*, 9, 1307, 1980.
4. Clever, H.L., Johnson, S.A., and Derrick, M.E., *J. Phys. Chem. Ref. Data*, 14, 631, 1985.
5. Clever, H.L., Johnson, S.A., and Derrick, M.E., *J. Phys. Chem. Ref. Data*, 21, 941, 1992.
6. Söhnel, O., and Novotny, P., *Densities of Aqueous Solutions of Inorganic Substances*, Elsevier, Amsterdam, 1985.
7. Krumgalz, B.S., *Mineral Solubility in Water at Various Temperatures*, Israel Oceanographic and Limnological Research Ltd., Haifa, 1994.
8. Potter, R.W., and Clynne, M.A., *J. Research U.S. Geological Survey*, 6, 701, 1978; Clynne, M.A., and Potter, R.W., *J. Chem. Eng. Data,* 24, 338, 1979.
9. Marshal, W.L., and Slusher, R., *J. Phys. Chem.*, 70, 4015, 1966; Knacke, O., and Gans, W., *Zeit. Phys. Chem*., NF, 104, 41, 1977.
10. Stephen, H., and Stephen, T., *Solubilities of Inorganic and Organic Compounds, Vol. 1*, Macmillan, New York, 1963.

AQUEOUS SOLUBILITY OF INORGANIC COMPOUNDS AT VARIOUS TEMPERATURES (continued)

Compound	0°C	10°C	20°C	25°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C	Ref.
$AgBrO_3$				0.193							1.32		7
$AgClO_2$	0.17	0.31	0.47	0.55	0.64	0.82	1.02	1.22	1.44	1.66	1.88	2.11	7
$AgClO_3$				15									7
$AgClO_4$	81.6	83.0	84.2	84.8	85.3	86.3	86.9	87.5	87.9	88.3	88.6	88.8	6
$AgNO_2$	0.155			0.413									7
$AgNO_3$	55.9	62.3	67.8	70.1	72.3	76.1	79.2	81.7	83.8	85.4	86.7	87.8	6
Ag_2SO_4	0.56	0.67	0.78	0.83	0.88	0.97	1.05	1.13	1.20	1.26	1.32	1.39	7
$AlCl_3$	30.84	30.91	31.03	31.10	31.18	31.37	31.60	31.87	32.17	32.51	32.90	33.32	7
$Al(ClO_4)_3$	54.9										64.4		7
AlF_3	0.25	0.34	0.44	0.50	0.56	0.68	0.81	0.96	1.11	1.28	1.45	1.64	7
$Al(NO_3)_3$	37.0	38.2	39.9	40.8	42.0	44.5	47.3	50.4	53.8*			61.5*	6
$Al_2(SO_4)_3$	27.5			27.8	28.2	29.2	30.7	32.6	34.9	37.6	40.7	44.2	7
As_2O_3	1.19	1.48	1.80	2.01	2.27	2.86	3.43	4.11	4.89	5.77	6.72	7.71	10
$BaBr_2$	47.6	48.5	49.5	50.0	50.4	51.4	52.5	53.5	54.5	55.5	56.6	57.6	6
$Ba(BrO_3)_2$	0.285	0.442	0.656	0.788	0.935	1.30	1.74	2.27	2.90	3.61	4.40	5.25	1:14
$Ba(C_2H_3O_2)_2$	37.0			44.2									7
$BaCl_2$	23.30	24.88	26.33	27.03	27.70	29.00	30.27	31.53	32.81	34.14	35.54	37.05	8
$Ba(ClO_2)_2$	30.5			31.3								44.7	7
$Ba(ClO_3)_2$	16.90	21.23	23.66	27.50	29.43	33.16	36.69	40.05	43.04	45.90	48.70	51.17	1:14
$Ba(ClO_4)_2$	67.30	70.96	74.30	75.75	77.05	79.23	80.92	82.21	83.16	83.88	84.43	84.90	7
BaF_2		0.158		0.161									7
BaI_2	62.5	64.7	67.3	68.8	69.1	69.5	70.1	70.7	71.3	72.0	72.7	73.4	6
$Ba(IO_3)_2$	0.0182	0.0262	0.0342	0.0396	0.045*	0.058*	0.073	0.090	0.109	0.131	0.156	0.182	1:14
$Ba(NO_2)_2$	31.1	36.6	41.8	44.3	46.8	51.6	56.2	60.5	64.6	68.5	72.1	75.6	10
$Ba(NO_3)_2$	4.7	6.3	8.2	9.3	10.2	12.4	14.7	17.0	19.3	21.5	23.5	25.5	6
$Ba(OH)_2$	1.67			4.68	8.4	19	33	52	74	101			7
BaS	2.79	4.78	6.97	8.21	9.58	12.67	16.18	20.05	24.19	28.55	33.04	37.61	7
$Ba(SCN)_2$				62.6									7
$BaSO_3$				0.0011									1:26
$BeCl_2$	40.5			41.7									7
$Be(ClO_4)_2$				59.5									7
$BeSO_4$	26.69	27.58	28.61	29.22	29.90	31.51	33.39	35.50	37.78	40.21	42.72	45.28	7
$CaBr_2$	55	56	59	61	63	68	71	73					10
$CaCl_2$	36.70	39.19	42.13	44.83*	49.12*	52.85*	56.05*	56.73	57.44	58.21	59.04	59.94	8
$Ca(ClO_3)_2$	63.2	64.2	65.5	66.3	67.2	69.0	71.0	73.2	75.5*	77.4*	77.7	78.0	1:14
$Ca(ClO_4)_2$				65.3									7
CaF_2	0.0013			0.0016									10
CaI_2	64.6	66.0	67.6	68.3	69.0	70.8	72.4	74.0	76.0	78.0	79.6	81.0	7
$Ca(IO_3)_2$	0.082	0.155	0.243	0.305	0.384*	0.517*	0.590	0.652	0.811*	0.665*	0.668		1:14
$Ca(NO_2)_2$	38.6	39.5	44.5	48.6									7
$Ca(NO_3)_2$	50.1	53.1	56.7	59.0	60.9	65.4	77.8	78.1	78.2	78.3	78.4	78.5	6
$CaSO_3$			0.0059	0.0054	0.0049	0.0041	0.0035	0.0030	0.0026	0.0023	0.0020	0.0019	1:26
$CaSO_4$	0.174	0.191	0.202	0.205	0.208	0.210	0.207	0.201	0.193	0.184	0.173	0.163	9

AQUEOUS SOLUBILITY OF INORGANIC COMPOUNDS AT VARIOUS TEMPERATURES (continued)

Compound	0°C	10°C	20°C	25°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C	Ref.
$CdBr_2$	36.0	43.0	49.9	53.4	56.4	60.3*	60.3*	60.5	60.7	60.9	61.3	61.6	6
CdC_2O_4				0.0060									5
$CdCl_2$	47.2	50.1	53.2	54.6	56.3*	57.3*	57.5	57.8	58.1	58.51	58.98	59.5	6
$Cd(ClO_4)_2$				58.7								66.9	7
CdF_2		5.82	4.65	4.18	3.76								5
CdI_2	44.1	44.9	45.8	46.3	46.8	47.9	49.0	50.2	51.5	52.7	54.1	55.4	6
$Cd(IO_3)_2$				0.091									5
$Cd(NO_3)_2$	55.4	57.1	59.6	61.0	62.8	66.5	70.6	86.1	86.5	86.8	87.1	87.4	6
$CdSO_4$	43.1	43.1	43.2	43.4	43.6	44.1	43.5	42.5	41.4	40.2	38.5	36.7	6
$CdSeO_4$	42.04	40.59	39.02	38.18	37.29	35.35	33.15	30.65	27.84	24.69	21.24	17.49	5
$Ce(NO_3)_3$	57.99	59.80	61.89	63.05	64.31*	67.0*	68.6	71.1*	74.9*	79.2	80.9	83.1	1:13
$CoCl_2$	30.30	32.60	34.87	35.99	37.10	39.27	41.38	43.46	45.50	47.51	49.51	51.50	7
$Co(ClO_4)_2$	50.0			53.0									7
CoF_2				1.4									7
CoI_2	58.00	61.78	65.35	66.99	68.51	71.17	73.41	75.29	76.89	78.28	79.52	80.70	7
$Co(NO_2)_2$	0.076			0.49									7
$Co(NO_3)_2$	45.5	47.0	49.4	50.8	52.4	56.0	60.1	62.6	64.9	67.7			6
$CoSO_4$	19.9	23.0	26.1	27.7	29.2	32.3	34.4	35.9	35.5	33.2	30.6	27.8	6
$Co(SCN)_2$				50.7									7
CrO_3	62.2	62.3	62.6	62.8	63.0	63.5	64.1	64.7	65.5	66.2	67.1	67.9	6
CsBr				55.2									7
$CsBrO_3$	1.16	1.93	3.01	3.69	4.46	6.32	8.60	11.32	14.45	17.96	21.83	25.98	1:30
CsCl	61.83	63.48	64.96	65.64	66.29	67.50	68.60	69.61	70.54	71.40	72.21	72.96	1:47
$CsClO_3$	2.40	3.87	5.94	7.22	8.69	12.15	16.33	21.14	26.45	32.10	37.89	43.42	1:30
$CsClO_4$	0.79	1.01	1.51	1.96	2.57	4.28	6.55	9.29	12.41	15.80	19.39	23.07	7
CsI	30.9	37.2	43.2	45.9	48.6	53.3	57.3	60.7	63.6	65.9	67.7	69.2	6
$CsIO_3$	1.08	1.58	2.21	2.59	3.02	3.96	5.06	6.29	7.70	9.20	10.79	12.45	1:30
$CsNO_3$	8.46	13.0	18.6	21.8	25.1	32.0	39.0	45.7	51.9	57.3	62.1	66.2	6
CsOH					75								7
Cs_2SO_4	62.6	63.4	64.1	64.5	64.8	65.5	66.1	66.7	67.3	67.8	68.3	68.8	6
$CuBr_2$				55.8									7
$CuCl_2$	40.8	41.7	42.6	43.1	43.7	44.8	46.0	47.2	48.5	49.9	51.3	52.7	6
$Cu(ClO_4)_2$	54.3				59.3								7
CuF_2				0.075									7
$Cu(NO_3)_2$	45.2	49.8	56.3	59.2	61.1	62.0	63.1	64.5	65.9	67.5	69.2	71.0	6
$CuSO_4$	12.4	14.4	16.7	18.0	19.3	22.2	25.4	28.8	32.4	36.3	40.3	43.5	6
$CuSeO_4$	10.6			16.0									7
$Dy(NO_3)_3$	58.79	59.99	61.49	62.35	63.29	65.43	68.04	71.58					1:13
$Er(NO_3)_3$	61.58	63.15	64.84	65.75	66.69	68.70	70.96	73.64	77.75				1:13
$Eu(NO_3)_3$	55.2	56.7	58.5	59.4	60.4	62.5	64.6						1:13
$FeBr_2$				54.6								64.8*	7
$FeCl_2$	33.2*			39.4*								48.7*	7
$FeCl_3$	42.7	44.9	47.9	47.7	51.6	74.8	76.7	84.6	84.3	84.3	84.4	84.7	6

AQUEOUS SOLUBILITY OF INORGANIC COMPOUNDS AT VARIOUS TEMPERATURES (continued)

Compound	0°C	10°C	20°C	25°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C	Ref.
$Fe(ClO_4)_2$	63.39			67.76									7
FeF_3				5.59									7
$Fe(NO_3)_3$	40.15			46.57									7
$Fe(NO_3)_2$	41.44			46.67									7
$FeSO_4$	13.5	17.0	20.8	22.8	24.8	28.8	32.8	35.5	33.6	30.4	27.1	24.0	6
$Gd(NO_3)_3$	56.3	57.7	59.2	60.1	61.0	62.9	65.2	67.9	71.5				1:13
HIO_3	73.45	74.10	74.98	75.48	76.03	77.20	78.46	79.78	81.13	82.48	83.82	85.14	1:30
H_3BO_3	2.61	3.57	4.77	5.48	6.27	8.10	10.3	12.9	15.9	19.3	23.1	27.3	6
$HgBr_2$	0.26	0.37	0.52	0.61	0.72	0.96	1.26	1.63	2.08	2.61	3.23	3.95	4
$Hg(CN)_2$	6.57	7.83	9.33	10.2	11.1	13.1	15.5	18.2	21.2	24.6	28.3	32.3	6
$HgCl_2$	4.24	5.05	6.17	6.81	7.62	9.53	12.02	15.18	19.16	24.06	29.90	36.62	4
HgI_2			0.0041	0.0055	0.0072	0.0122	0.0199						4
$Hg(SCN)_2$				0.070									4
Hg_2Cl_2				0.0004									3
$Hg_2(ClO_4)_2$	73.8			79.8*								85.3*	7
Hg_2SO_4	0.038	0.043	0.048	0.051	0.054	0.059	0.065	0.070	0.076	0.082	0.088	0.093	4
$Ho(NO_3)_3$				63.8									1:13
KBF_4	0.28	0.34	0.45	0.55	0.75	1.38	2.09	2.82	3.58	4.34	5.12	5.90	10
KBr	35.0	37.3	39.4	40.4	41.4	43.2	44.8	46.2	47.6	48.8	49.8	50.8	6
$KBrO_3$	2.97	4.48	6.42	7.55	8.79	11.57	14.71	18.14	21.79	25.57	29.42	33.28	1:30
$KC_2H_3O_2$	68.40	70.29	72.09	72.92	73.70	75.08	76.27	77.31	78.22	79.04	79.80	80.55	7
KCl	21.74	23.61	25.39	26.22	27.04	28.59	30.04	31.40	32.66	33.86	34.99	36.05	1:47
$KClO_3$	3.03	4.67	6.74	7.93	9.21	12.06	15.26	18.78	22.65	26.88	31.53	36.65	1:30
$KClO_4$	0.70	1.10	1.67	2.04	2.47	3.54	4.94	6.74	8.99	11.71	14.94	18.67	6
KF	30.90	39.8	47.3	50.41	53.2					60.0			7
$KHCO_3$	18.62	21.73	24.92	26.6	28.13	31.32	34.46	37.51	40.45				6
$KHSO_4$	27.1	29.7	32.3	33.6	35.0	37.8	40.5	43.4	46.2	49.02	51.82	54.6	6
KH_2PO_4	11.74	14.91	18.25	19.97	21.77	25.28	28.95	32.76	36.75	40.96	45.41	50.12	1:31
KI	56.0	57.6	59.0	59.7	60.4	61.6	62.8	63.8	64.8	65.7	66.6	67.4	6
KIO_3	4.53	5.96	7.57	8.44	9.34	11.09	13.22	15.29	17.41	19.58	21.78	24.03	1:30
KIO_4	0.16	0.22	0.37	0.51	0.70	1.24	1.96	2.83	3.82	4.89	6.02	7.17	7
$KMnO_4$	2.74	4.12	5.96	7.06	8.28	11.11	14.42	18.16					6
KNO_2	73.7	74.6	75.3	75.7	76.0	76.7	77.4	78.0	78.5	79.1	79.6	80.1	6
KNO_3	12.0	17.6	24.2	27.7	31.3	38.6	45.7	52.2	58.0	63.0	67.3	70.8	6
KOH	48.7	50.8	53.2	54.7	56.1	57.9	58.6	59.5	60.6	61.8	63.1	64.6	6
KSCN	63.8	66.4	69.1	70.4	71.6	74.1	76.5	78.9	81.1	83.3	85.3	87.3	6
K_2CO_3	51.3	51.7	52.3	52.7	53.1	54.0	54.9	56.0	57.2	58.4	59.6	61.0	6
K_2CrO_4	37.1	38.1	38.9	39.4	39.8	40.5	41.3	41.9	42.6	43.2	43.8	44.3	6
$K_2Cr_2O_7$	4.30	7.12	10.9	13.1	15.5	20.8	26.3	31.7	36.9	41.5	45.5	48.9	6
K_2HAsO_4	48.5*			63.6*								79.8*	7
K_2HPO_4	57.0	59.1	61.5	62.7	64.1	67.7*		72.7*					1:31
K_2MoO_4				64.7							66.5		7
K_2SO_3	51.30	51.39	51.49	51.55	51.62	51.76	51.93	52.11	52.32	52.54	52.79	53.06	1:26

AQUEOUS SOLUBILITY OF INORGANIC COMPOUNDS AT VARIOUS TEMPERATURES (continued)

Compound	0°C	10°C	20°C	25°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C	Ref.
K_2SO_4	7.11	8.46	9.95	10.7	11.4	12.9	14.2	15.5	16.7	17.7	18.6	19.3	6
$K_2S_2O_3$	49.0*			62.3*							75.7*		7
$K_2S_2O_5$	22.1	26.7	31.1	33.1	35.2	39.0	42.6	46.0	49.1	52.0	54.6		1:26
K_2SeO_3	68.4*			68.5*								68.5*	7
K_2SeO_4	52.70	52.93	53.17	53.30	53.43	53.70	53.99	54.30	54.61	54.94	55.26	55.60	7
K_3AsO_4	51.5*			55.6*								73*	7
$K_3Fe(CN)_6$	23.9	27.6	31.1	32.8	34.3	37.2	39.6	41.7	43.5	45.0	46.1	47.0	6
K_3PO_4	44.3			51.4									7
$K_4Fe(CN)_6$	12.5	17.3	22.0	23.9	25.6	29.2	32.5	35.5	38.2	40.6	41.4	43.1	6
$LaCl_3$	49.0	48.5	48.6	48.9	49.3	50.5	52.1	54.0	56.3	58.9	61.7		6
$La(NO_3)_3$	55.0	56.9	58.9	60.0	61.1	63.6	66.3	69.9*	74.1*				1:13
LiBr	58.4	60.1	62.7	64.4	65.9	67.8	68.3	69.0	69.8	70.7	71.7	72.8	6
$LiBrO_3$	61.03	62.62	64.44	65.44	66.51	68.90	71.68*	73.24*	74.43	75.66	76.93	78.32	1:30
$LiC_2H_3O_2$	23.76	26.49	29.42	31.02	32.72	36.48	40.65	45.15	49.93	54.91	60.04	65.26	7
LiCl	40.45	42.46*	45.29*	45.81	46.25	47.30	48.47	49.78	51.27	52.98	54.98*	56.34*	1:47
$LiClO_3$	73.2	75.6*	80.8*	82.1	83.4	85.9*	87.1*	88.2	89.6	91.3	93.4	95.7	1:30
$LiClO_4$	30.1	32.6	35.5	37.0	38.6	41.9	45.5	49.2	53.2	57.2	61.3	71.4	6
LiF	0.120	0.126	0.131	0.134									7
LiH_2PO_4	55.8												7
LiI	59.4	60.5	61.7	62.3	63.0	64.3	65.8	67.3	68.8	81.3	81.7	82.6	6
$LiIO_3$				43.8									1:30
$LiNO_2$	41	45	49	51	53	56	60	63	66	68			10
$LiNO_3$	34.8	37.6	42.7	50.5	57.9	60.1	62.2	64.0	65.7	67.2	68.5	69.7	6
LiOH	10.8	10.8	11.0	11.1	11.3	11.7	12.2	12.7	13.4	14.2	15.1	16.1	6
LiSCN				54.5									7
Li_2CO_3	1.54	1.43	1.33	1.28	1.24	1.15	1.07	0.99	0.92	0.85	0.78	0.72	7
$Li_2C_2O_4$				5.87									7
Li_2HPO_3	9.07	8.40	7.77	7.47	7.18	6.64	6.16	5.71	5.30	4.91	4.53	4.16	7
Li_2SO_4	26.3	25.9	25.6	25.5	25.3	25.0	24.8	24.5	24.3	24.0	23.8	23.6	6
Li_3PO_4				0.027									1:31
$Lu(NO_3)_3$				71.1									1:13
$MgBr_2$	49.3	49.8	50.3	50.6	50.9	51.5	52.1	52.8	53.5	54.2	55.0	55.7	6
$Mg(BrO_3)_2$	43.0	45.2	48.0	49.4	51.0	54.3	57.9	61.6	65.3	69.0*	70.9*	71.7	1:14
$Mg(C_2H_3O_2)_2$	36.18	37.55	38.92	39.61									7
MgC_2O_4				0.038									7
$MgCl_2$	33.96	34.85	35.58	35.90	36.20	36.77	37.34	37.97	38.71	39.62	40.75	42.15	8
$Mg(ClO_3)_2$	53.35	54.40	56.81	58.66	60.91*	65.46*	67.33	69.27	71.01	72.44	73.48		1:14
$Mg(ClO_4)_2$	47.8	48.7	49.6	50.1	50.5	51.3	52.1						6
$MgCrO_4$	32.06*			35.39*									7
$MgCr_2O_7$				58.9						67.0			7
MgF_2				0.013									7
MgI_2	54.7	56.1	58.2	59.4	60.8	63.9	65.0	65.0	65.0	65.0	65.1	65.2	6
$Mg(IO_3)_2$	3.19*	6.70*	7.92	8.52	9.11	10.45	11.99	13.7	15.6	17.6	19.6		1:14

AQUEOUS SOLUBILITY OF INORGANIC COMPOUNDS AT VARIOUS TEMPERATURES (continued)

Compound	0°C	10°C	20°C	25°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C	Ref.
$Mg(NO_2)_2$				47									7
$Mg(NO_3)_2$	38.4	39.5	40.8	41.6	42.4	44.1	45.9	47.9	50.0	52.2	70.6	72.0	6
$MgSO_3$	0.32	0.37	0.46	0.52	0.61	0.87*	0.85*	0.76	0.69	0.64	0.62	0.60	1:26
$MgSO_4$	18.2	21.7	25.1	26.3	28.2	30.9	33.4	35.6	36.9	35.9	34.7	33.3	6
MgS_2O_3	30.7			34.1									7
$MgSeO_4$	31.4*			35.7*								47*	7
$MnBr_2$	56.00	57.72	59.39	60.19	60.96	62.41	63.75	65.01	66.19	67.32	68.42	69.50	7
$MnCl_2$	38.7	40.6	42.5	43.6	44.7	47.0	49.4	54.1	54.7	55.2	55.7	56.1	6
MnF_2	0.80*			1.01*								0.48	7
$Mn(IO_3)_2$				0.27							0.34		7
$Mn(NO_3)_2$	50.5			61.7									7
$MnSO_4$	34.6	37.3	38.6	38.9	38.9	37.7	36.3	34.6	32.8	30.8	28.8	26.7	6
NH_4Br	37.5	40.2	42.7	43.9	45.1	47.3	49.4	51.3	53.0	54.6	56.1	57.4	7
NH_4Cl	22.92	25.12	27.27	28.34	29.39	31.46	33.50	35.49	37.46	39.40	41.33	43.24	1:47
NH_4ClO_4	10.8	14.1	17.8	19.7	21.7	25.8	29.8	33.6	37.3	40.7	43.8	46.6	6
NH_4F	41.7	43.2	44.7	45.5	46.3	47.8	49.3	50.9	52.5	54.1			7
NH_4HCO_3	10.6	13.7	17.6	19.9	22.4	27.9	34.2	41.4	49.3	58.1	67.6	78.0	7
$NH_4H_2AsO_4$	25.2	29.0	32.7	34.5	36.3	39.7	43.1	46.2	49.3	52.2	55.0		7
$NH_4H_2PO_4$	17.8	22.0	26.4	28.8	31.2	36.2	41.6	47.2	53.0	59.2	65.7	72.4	7
NH_4I	60.7	62.1	63.4	64.0	64.6	65.8	66.8	67.8	68.7	69.6	70.4	71.1	6
NH_4IO_3				3.70	4.20	5.64	7.63						1:30
NH_4NO_2	55.7	59.0	64.9	68.8									7
NH_4NO_3	54.0	60.1	65.5	68.0	70.3	74.3	77.7	80.8	83.4	85.8	88.2	90.3	6
NH_4SCN				64.4					81.1				7
$(NH_4)_2C_2O_4$	2.31	3.11	4.25	4.94	5.73	7.56	9.73	12.2	15.1	18.3	21.8	25.7	7
$(NH_4)_2HPO_4$	36.4	38.2	40.0	41.0	42.0	44.1	46.2	48.5	50.9	53.3	55.9	58.6	7
$(NH_4)_2S_2O_5$	65.5	67.9	69.8	70.5	71.3	72.3	72.9	73.1					1:26
$(NH_4)_2S_2O_8$	37.00	40.45	43.84	45.49	47.11	50.25	53.28	56.23	59.13	62.00			7
$(NH_4)_2SO_3$	32.2	34.9	37.7	39.1	40.6	43.7	47.0	50.6	54.5	58.9			1:26
$(NH_4)_2SO_4$	41.3	42.1	42.9	43.3	43.8	44.7	45.6	46.6	47.5	48.5	49.5	50.5	6
$(NH_4)_2SeO_3$	49.0	51.1	53.4	54.7	56.0	58.9	62.0	65.4	69.1				7
$(NH_4)_2SeO_4$				54.02									7
$(NH_4)_3PO_4$				15.5									7
$NaBr$	44.4	45.9	47.7	48.6	49.6	51.6	53.7	54.1	54.3	54.5	54.7	54.9	6
$NaBrO_3$	20.0	23.22	26.65	28.28	29.86	32.83	35.55	38.05	40.37	42.52			1:30
$NaCHO_2$	30.8	37.9	45.7	48.7	50.6	52.0	53.5	55.0					6
$NaC_2H_3O_2$	26.5	28.8	31.8	33.5	35.5	39.9	45.1	58.3	59.3	60.5	61.7	62.9	6
$NaCl$	26.28	26.32	26.41	26.45	26.52	26.67	26.84	27.03	27.25	27.50	27.78	28.05	1:47
$NaClO$	22.7			44.4									7
$NaClO_2$				97.0*				95.3*					7
$NaClO_3$	44.27	46.67	49.3	50.1	51.2	53.6	55.5	57.0	58.5	60.5	63.3	67.1	1:30
$NaClO_4$	61.9	64.1	66.2	67.2	68.3	70.4	72.5	74.1	74.7	75.4	76.1	76.7	6
NaF	3.52	3.72	3.89	3.97	4.05	4.20	4.34	4.46	4.57	4.66	4.75	4.82	6

AQUEOUS SOLUBILITY OF INORGANIC COMPOUNDS AT VARIOUS TEMPERATURES (continued)

Compound	0°C	10°C	20°C	25°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C	Ref.
$NaHCO_3$	6.48	7.59	8.73	9.32	9.91	11.13	12.40	13.70	15.02	16.37	17.73	19.10	7
$NaHSO_4$				22.2								33.3	10
NaH_2PO_4	36.54	41.07	46.00	48.68	51.54	57.89*	61.7*	62.3*	65.9	68.7			1:31
NaI	61.2	62.4	63.9	64.8	65.7	67.7	69.8	72.0	74.7	74.8	74.9	75.1	6
$NaIO_3$	2.43	4.40	7.78*	8.65*	9.60	11.67	13.99	16.52	19.25*	21.1*	22.9	24.7	1:30
$NaIO_4$				12.62									7
$NaNO_2$	41.9	43.4	45.1	45.9	46.8	48.7	50.7	52.8	55.0	57.2	59.5	61.8	6
$NaNO_3$	42.2	44.4	46.6	47.7	48.8	51.0	53.2	55.3	57.5	59.6	61.7	63.8	6
NaOH	30	39	46	50	53	58	63	67	71	74	76	79	10
NaSCN		52.9	57.1	60.2	62.7	63.5	64.2	65.0	65.9	66.9	67.9	69.0	6
$Na_2B_4O_7$	1.23	1.71	2.50	3.07	3.82	6.02	9.7	14.9	17.1	19.9	23.5	28.0	6
Na_2CO_3	6.44	10.8	17.9	23.5	28.7	32.8	32.2	31.7	31.3	31.1	30.9	30.9	6
$Na_2C_2O_4$	2.62	2.95	3.30	3.48	3.65	4.00	4.36	4.71	5.06	5.41	5.75	6.08	6
Na_2CrO_4	22.6	32.3	44.6	46.7	46.9	48.9	51.0	53.4	55.3	55.5	55.8	56.1	6
$Na_2Cr_2O_7$	62.1	63.1	64.4	65.2	66.1	68.0	70.1	72.3	74.6	77.0	79.6	80.7	6
Na_2HAsO_4	5.6*			29.3*								67*	7
Na_2HPO_4	1.66	4.19	7.51	10.55	16.34*	35.17*	44.64*	45.20	46.81	48.78	50.52	51.53	1:31
Na_2MoO_4	30.6	38.8	39.4	39.4	39.8	40.3	41.0	41.7	42.6	43.5	44.5	45.5	6
Na_2S	11.1	13.2	15.7	17.1	18.6	22.1	26.7	28.1	30.2	33.0	36.4	41.0	6
Na_2SO_3	12.0	16.1	20.9	23.5	26.3*	27.3*	25.9	24.8	23.7	22.8	22.1	21.5	1:26
Na_2SO_4			16.13	21.94	29.22*	32.35*	31.55	30.90	30.39	30.02	29.79	29.67	8
$Na_2S_2O_3$	33.1	36.3	40.6	43.3	45.9	52.0	62.3	65.7	68.8	69.4	70.1	71.0	6
$Na_2S_2O_5$		38.4	39.5	40.0	40.6	41.8	43.0	44.2	45.5	46.8	48.1	49.5	1:26
Na_2SeO_3				47.3*								45*	7
Na_2SeO_4	11.7			36.9*								42.1*	7
Na_2WO_4	41.6	41.9	42.3	42.6	42.9	43.6	44.4	45.3	46.2	47.3	48.4	49.5	6
Na_3PO_4	4.28	7.30	10.8	12.6	14.1	16.6	22.9	28.4	32.4	37.6	40.4	43.5	6
$Na_4P_2O_7$	2.23	3.28	4.81	6.62	7.00	10.10	14.38	20.07	27.31	36.03	32.37	30.67	6
$NdCl_3$	49.0	49.3	49.7	50.0	50.4	51.2	52.2	53.3	54.5	55.8	57.1	58.5	6
$Nd(NO_3)_3$	55.76	57.49	59.37	60.38	61.43	63.69	66.27	69.47					1:13
$NiCl_2$	34.7	36.1	38.5	40.3	41.7	42.1	43.2	45.0	46.1	46.2	46.4	46.6	6
$Ni(ClO_4)_2$	51.1			52.8									7
NiF_2				2.50							2.52		7
NiI_2	55.40	57.68	59.78	60.69	61.50	62.80	63.73	64.38	64.80	65.09	65.30		7
$Ni(NO_3)_2$	44.1	46.0	48.4	49.8	51.3	54.6	58.3	61.0	63.1	65.6	67.9	69.0	6
$NiSO_4$	21.4	24.4	27.4	28.8	30.3*	32.0*	34.1	35.8	37.7	39.9	42.3	44.8	6
$Ni(SCN)_2$				35.48									7
$NiSeO_4$	21.6		26.2*									45.6*	7
$PbBr_2$	0.449	0.620	0.841	0.966	1.118	1.46	1.89						2
$PbCl_2$	0.66	0.81	0.98	1.07	1.17	1.39	1.64	1.93	2.24	2.60	2.99	3.42	2
$Pb(ClO_4)_2$				81.5									7
PbF_2		0.0603	0.0649	0.0670	0.0693								2
PbI_2	0.041	0.052	0.067	0.076	0.086	0.112	0.144	0.187	0.243	0.315			2

AQUEOUS SOLUBILITY OF INORGANIC COMPOUNDS AT VARIOUS TEMPERATURES (continued)

Compound	0°C	10°C	20°C	25°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C	Ref.
$Pb(IO_3)_2$				0.0025									7
$Pb(NO_3)_2$	28.46	32.13	35.67	37.38	39.05	42.22	45.17	47.90	50.42	52.72	54.82	56.75	2
$PbSO_4$	0.0033	0.0038	0.0042	0.0044	0.0047	0.0052	0.0058						2
$PrCl_3$	48.0	48.1	48.6	49.0	49.5	50.8	52.3	54.1	56.1	58.3			6
$Pr(NO_3)_3$	57.50	59.20	61.16	62.24	63.40*	65.7*	67.8	70.2	73.4				1:13
RbBr	47.4	50.1	52.6	53.8	54.9	57.0	58.8	60.6	62.1	63.5	64.8	65.9	6
$RbBrO_3$	0.97	1.55	2.36	2.87	3.45	4.87	6.64	8.78	11.29	14.15	17.32	20.76	1:30
RbCl	43.58	45.65	47.53	48.42	49.27	50.86	52.34	53.67	54.92	56.08	57.16	58.15	1:47
$RbClO_3$	2.10	3.38	5.14	6.22	7.45	10.35	13.85	17.93	22.53	27.57	32.96	38.60	1:30
$RbClO_4$	1			1.5								17	7
RbF			75										7
$RbHCO_3$			53.7										7
RbI	55.8	58.6	61.1	62.3	63.4	65.4	67.2	68.8	70.3	71.6	72.7	73.8	6
$RbIO_3$	1.09	1.53	2.07	2.38	2.74	3.52	4.41	5.42	6.52	7.74	9.00	10.36	1:30
$RbNO_3$	16.4	25.0	34.6	39.4	44.2	53.1	60.8	67.2	72.2	76.1	79.0	81.2	6
RbOH					63.4								7
Rb_2CrO_4	38.27			43.26									7
Rb_2SO_4	27.3	30.0	32.5	33.7	34.8	36.9	38.7	40.3	41.8	43.0	44.1	44.9	6
$SbCl_3$	85.7			90.8									7
SbF_3	79.4			83.1									7
$Sc(NO_3)_3$	57.0	59.3	61.6	62.8	63.9	66.2	68.5						1:13
$Sm(NO_3)_3$	54.83	56.33	58.08	59.05	60.08	62.38	65.05*	68.1*	70.8	74.2			1:13
$SmCl_3$		48.0	48.2	48.4	48.6	49.2	50.0						6
$SnCl_2$	46	64											7
SnI_2			0.97									3.87	7
$SrBr_2$	46.0	48.3	50.6	51.7	52.9	55.2	57.6	59.9	62.3	64.6	66.8	69.0	6
$Sr(BrO_3)_2$	18.53	22.00	25.39	27.02	28.59	31.55	34.21	36.57	38.64*	40.2*	40.8	41.0	1:14
$SrCl_2$	31.94	32.93	34.43	35.37	36.43	38.93	41.94	45.44*	46.81*	47.69	48.70	49.87	8
$Sr(ClO_2)_2$	13.0	13.6	14.1	14.3	14.5	14.9	15.3	15.6	15.9				7
$Sr(ClO_3)_2$	63.29	63.42	63.64	63.77	63.93	64.29	64.70	65.16	65.65	66.18	66.74	67.31	1:14
$Sr(ClO_4)_2$	70.04*			75.35*		78.44*							7
SrF_2	0.011			0.021									7
SrI_2	62.5	62.8	63.5	63.9	64.5	65.8	67.3	69.0	70.8	72.7	74.7	79.2	6
$Sr(IO_3)_2$	0.102	0.126	0.152	0.165	0.179	0.206	0.233	0.259	0.284	0.307	0.328	0.346	1:14
$Sr(MnO_4)_2$	2.5												7
$Sr(NO_2)_2$					41.9	44.3						58.6	7
$Sr(NO_3)_2$	28.2	34.6	41.0	44.5	47.0	47.4	47.9	48.4	48.9	49.5	50.1	50.7	6
$Sr(OH)_2$	0.9			2.2									7
$SrSO_3$				0.0015									1:26
$SrSO_4$				0.0135									7
SrS_2O_3	8.8	13.2	17.7	20.0	22.2	26.8							7
$Tb(NO_3)_3$			60.6	61.02									1:13
Tl_2SO_4	2.65	3.56	4.61	5.19	5.80	7.09	8.46	9.89	11.33	12.77	14.18	15.53	6

AQUEOUS SOLUBILITY OF INORGANIC COMPOUNDS AT VARIOUS TEMPERATURES (continued)

Compound	0°C	10°C	20°C	25°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C	100°C	Ref.
$Tm(NO_3)_3$				67.9									1:13
$UO_2(NO_3)_2$	49.52	51.82	54.42	55.85	57.55	61.59	67.07						1:55
$Y(NO_3)_3$	55.57	56.93	58.75	59.86	61.11*	63.3*	64.9	67.9	72.5				1:13
$Yb(NO_3)_3$				70.5									1:13
$ZnBr_2$	79.3	80.1	81.8	83.0	84.1	85.6	85.8	86.1	86.3	86.6	86.8	87.1	6
ZnC_2O_4		0.0010	0.0019	0.0026									5
$ZnCl_2$		76.6	79.0	80.3	81.4	81.8	82.4	83.0	83.7	84.4	85.2	86.0	6
$Zn(ClO_4)_2$	44.29*			46.27*			48.70						7
ZnF_2				1.53									5
ZnI_2	81.1	81.2	81.3	81.4	81.5	81.7	82.0	82.3	82.6	83.0	83.3	83.7	6
$Zn(IO_3)_2$			0.58	0.64	0.69	0.77	0.82						5
$Zn(NO_3)_2$	47.8	50.8	54.4	54.6	58.5	79.1	80.1	87.5	89.9				6
$ZnSO_3$			0.1786	0.1790	0.1794	0.1803	0.1812						5
$ZnSO_4$	29.1	32.0	35.0	36.6	38.2	41.3	43.0	42.1	41.0	39.9	38.8	37.6	6
$ZnSeO_4$	33.06	34.98	37.38	38.79	40.34								5

SOLUBILITY PRODUCT CONSTANTS

The solubility product constant K_{sp} is a useful parameter for calculating the aqueous solubility of sparingly soluble compounds under various conditions. It may be determined by direct measurement or calculated from the standard Gibbs energies of formation $\Delta_f G°$ of the species involved at their standard states. Thus if $K_{sp} = [M^+]^m [A^-]^n$ is the equilibrium constant for the reaction

$$M_mA_n(s) \rightleftharpoons mM^+(aq) + nA^-(aq),$$

where M_mA_n is the slightly soluble substance and M^+ and A^- are the ions produced in solution by the dissociation of M_mA_n, then the Gibbs energy change is

$$\Delta G° = m\,\Delta_f G°\,(M^+,aq) + n\;\Delta_f G°\,(A^-,aq) - \Delta_f G°\,(M_mA_n, s)$$

The solubility product constant is calculated from the equation

$$\ln K_{sp} = -\Delta\, G°/RT$$

The first table below gives selected values of K_{sp} at 25°C. Many of these have been calculated from standard state thermodynamic data in References 1 and 2; other values are taken from publications of the IUPAC Solubility Data Project (References 3 to 7).

The above formulation is not convenient for treating sulfides because the S^{-2} ion is usually not present in significant concentrations (see Reference 8). This is due to the hydrolysis reaction

$$S^{-2} + H_2O \rightleftharpoons HS^- + OH^-$$

which is strongly shifted to the right except in very basic solutions. Furthermore, the equilibrium constant for this reaction, which depends on the second ionization constant of H_2S, is poorly known. Therefore it is more useful in the case of sulfides to define a different solubility product K_{spa} based on the reaction

$$M_mS_n(s) + 2H^+ \rightleftharpoons mM^+ + nH_2S\ (aq)$$

Values of K_{spa} , taken from Reference 8, are given for several sulfides in the auxiliary table following the main table. Additional discussion of sulfide equilibria may be found in References 7 and 9.

REFERENCES

1. Wagman, D.D., Evans, W.H., Parker, V.B., Schumm, R.H., Halow, I., Bailey, S.M., Churney, K.L., and Nuttall, R L., *The NBS Tables of Chemical Thermodynamic Properties, J. Phys. Chem. Ref. Data*, Vol. 11, Suppl. 2, 1982.
2. Garvin, D., Parker, V.B., and White, H.J., *CODATA Thermodynamic Tables*, Hemisphere, New York, 1987.
3. *Solubility Data Series* (53 Volumes), International Union of Pure and Applied Chemistry, Pergamon Press, Oxford, 1979—1992.
4. Clever, H.L., and Johnston, F.J., *J. Phys. Chem. Ref. Data*, 9, 751, 1980.
5. Marcus, Y., *J. Phys. Chem. Ref. Data*, 9, 1307, 1980.
6. Clever, H.L., Johnson, S.A., and Derrick, M.E., *J. Phys. Chem. Ref. Data*, 14, 631, 1985.
7. Clever, H.L., Johnson, S.A., and Derrick, M.E., *J. Phys. Chem. Ref. Data*, 21, 941, 1992.
8. Myers, R.J., *J. Chem. Educ*., 63, 687, 1986.
9. Licht, S., *J. Electrochem. Soc*.,135, 2971, 1988.

Compound	Formula	K_{sp}
Aluminum phosphate	$AlPO_4$	$9.84 \cdot 10^{-21}$
Barium bromate	$Ba(BrO_3)_2$	$2.43 \cdot 10^{-4}$
Barium carbonate	$BaCO_3$	$2.58 \cdot 10^{-9}$
Barium chromate	$BaCrO_4$	$1.17 \cdot 10^{-10}$
Barium fluoride	BaF_2	$1.84 \cdot 10^{-7}$
Barium hydroxide octahydrate	$Ba(OH)_2 \cdot 8H_2O$	$2.55 \cdot 10^{-4}$
Barium iodate	$Ba(IO_3)_2$	$4.01 \cdot 10^{-9}$
Barium iodate monohydrate	$Ba(IO_3)_2 \cdot H_2O$	$1.67 \cdot 10^{-9}$
Barium molybdate	$BaMoO_4$	$3.54 \cdot 10^{-8}$
Barium nitrate	$Ba(NO_3)_2$	$4.64 \cdot 10^{-3}$
Barium selenate	$BaSeO_4$	$3.40 \cdot 10^{-8}$
Barium sulfate	$BaSO_4$	$1.08 \cdot 10^{-10}$
Barium sulfite	$BaSO_3$	$5.0 \cdot 10^{-10}$
Beryllium hydroxide	$Be(OH)_2$	$6.92 \cdot 10^{-22}$
Bismuth arsenate	$BiAsO_4$	$4.43 \cdot 10^{-10}$

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SOLUBILITY PRODUCT CONSTANTS (continued)

Compound	Formula	K_{sp}
Bismuth iodide	BiI_3	$7.71 \cdot 10^{-19}$
Cadmium arsenate	$Cd_3(AsO_4)_2$	$2.2 \cdot 10^{-33}$
Cadmium carbonate	$CdCO_3$	$1.0 \cdot 10^{-12}$
Cadmium fluoride	CdF_2	$6.44 \cdot 10^{-3}$
Cadmium hydroxide	$Cd(OH)_2$	$7.2 \cdot 10^{-15}$
Cadmium iodate	$Cd(IO_3)_2$	$2.5 \cdot 10^{-8}$
Cadmium oxalate trihydrate	$CdC_2O_4 \cdot 3H_2O$	$1.42 \cdot 10^{-8}$
Cadmium phosphate	$Cd_3(PO_4)_2$	$2.53 \cdot 10^{-33}$
Calcium carbonate (calcite)	$CaCO_3$	$3.36 \cdot 10^{-9}$
Calcium fluoride	CaF_2	$3.45 \cdot 10^{-11}$
Calcium hydroxide	$Ca(OH)_2$	$5.02 \cdot 10^{-6}$
Calcium iodate	$Ca(IO_3)_2$	$6.47 \cdot 10^{-6}$
Calcium iodate hexahydrate	$Ca(IO_3)_2 \cdot 6H_2O$	$7.10 \cdot 10^{-7}$
Calcium molybdate	$CaMoO_4$	$1.46 \cdot 10^{-8}$
Calcium oxalate monohydrate	$CaC_2O_4 \cdot H_2O$	$2.32 \cdot 10^{-9}$
Calcium phosphate	$Ca_3(PO_4)_2$	$2.07 \cdot 10^{-33}$
Calcium sulfate	$CaSO_4$	$4.93 \cdot 10^{-5}$
Calcium sulfate dihydrate	$CaSO_4 \cdot 2H_2O$	$3.14 \cdot 10^{-5}$
Calcium sulfite hemihydrate	$CaSO_3 \cdot 0.5H_2O$	$3.1 \cdot 10^{-7}$
Cesium perchlorate	$CsClO_4$	$3.95 \cdot 10^{-3}$
Cesium periodate	$CsIO_4$	$5.16 \cdot 10^{-6}$
Cobalt(II) arsenate	$Co_3(AsO_4)_2$	$6.80 \cdot 10^{-29}$
Cobalt(II) hydroxide (blue)	$Co(OH)_2$	$5.92 \cdot 10^{-15}$
Cobalt(II) iodate dihydrate	$Co(IO_3)_2 \cdot 2H_2O$	$1.21 \cdot 10^{-2}$
Cobalt(II) phosphate	$Co_3(PO_4)_2$	$2.05 \cdot 10^{-35}$
Copper(I) bromide	$CuBr$	$6.27 \cdot 10^{-9}$
Copper(I) chloride	$CuCl$	$1.72 \cdot 10^{-7}$
Copper(I) cyanide	$CuCN$	$3.47 \cdot 10^{-20}$
Copper(I) iodide	CuI	$1.27 \cdot 10^{-12}$
Copper(I) thiocyanate	$CuSCN$	$1.77 \cdot 10^{-13}$
Copper(II) arsenate	$Cu_3(AsO_4)_2$	$7.95 \cdot 10^{-36}$
Copper(II) iodate monohydrate	$Cu(IO_3)_2 \cdot H_2O$	$6.94 \cdot 10^{-8}$
Copper(II) oxalate	CuC_2O_4	$4.43 \cdot 10^{-10}$
Copper(II) phosphate	$Cu_3(PO_4)_2$	$1.40 \cdot 10^{-37}$
Europium(III) hydroxide	$Eu(OH)_3$	$9.38 \cdot 10^{-27}$
Gallium(III) hydroxide	$Ga(OH)_3$	$7.28 \cdot 10^{-36}$
Iron(II) carbonate	$FeCO_3$	$3.13 \cdot 10^{-11}$
Iron(II) fluoride	FeF_2	$2.36 \cdot 10^{-6}$
Iron(II) hydroxide	$Fe(OH)_2$	$4.87 \cdot 10^{-17}$
Iron(III) hydroxide	$Fe(OH)_3$	$2.79 \cdot 10^{-39}$
Iron(III) phosphate dihydrate	$FePO_4 \cdot 2H_2O$	$9.91 \cdot 10^{-16}$
Lanthanum iodate	$La(IO_3)_3$	$7.50 \cdot 10^{-12}$
Lead(II) bromide	$PbBr_2$	$6.60 \cdot 10^{-6}$
Lead(II) carbonate	$PbCO_3$	$7.40 \cdot 10^{-14}$
Lead(II) chloride	$PbCl_2$	$1.70 \cdot 10^{-5}$
Lead(II) fluoride	PbF_2	$3.3 \cdot 10^{-8}$
Lead(II) hydroxide	$Pb(OH)_2$	$1.43 \cdot 10^{-20}$
Lead(II) iodate	$Pb(IO_3)_2$	$3.69 \cdot 10^{-13}$
Lead(II) iodide	PbI_2	$9.8 \cdot 10^{-9}$
Lead(II) selenate	$PbSeO_4$	$1.37 \cdot 10^{-7}$
Lead(II) sulfate	$PbSO_4$	$2.53 \cdot 10^{-8}$
Lithium carbonate	Li_2CO_3	$8.15 \cdot 10^{-4}$
Lithium fluoride	LiF	$1.84 \cdot 10^{-3}$
Lithium phosphate	Li_3PO_4	$2.37 \cdot 10^{-11}$
Magnesium carbonate	$MgCO_3$	$6.82 \cdot 10^{-6}$
Magnesium carbonate trihydrate	$MgCO_3 \cdot 3H_2O$	$2.38 \cdot 10^{-6}$
Magnesium carbonate pentahydrate	$MgCO_3 \cdot 5H_2O$	$3.79 \cdot 10^{-6}$
Magnesium fluoride	MgF_2	$5.16 \cdot 10^{-11}$
Magnesium hydroxide	$Mg(OH)_2$	$5.61 \cdot 10^{-12}$
Magnesium oxalate dihydrate	$MgC_2O_4 \cdot 2H_2O$	$4.83 \cdot 10^{-6}$

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SOLUBILITY PRODUCT CONSTANTS (continued)

Compound	Formula	K_{sp}
Magnesium phosphate	$Mg_3(PO_4)_2$	$1.04 \cdot 10^{-24}$
Manganese(II) carbonate	$MnCO_3$	$2.24 \cdot 10^{-11}$
Manganese(II) iodate	$Mn(IO_3)_2$	$4.37 \cdot 10^{-7}$
Manganese(II) oxalate dihydrate	$MnC_2O_4 \cdot 2H_2O$	$1.70 \cdot 10^{-7}$
Mercury(I) bromide	Hg_2Br_2	$6.40 \cdot 10^{-23}$
Mercury(I) carbonate	Hg_2CO_3	$3.6 \cdot 10^{-17}$
Mercury(I) chloride	Hg_2Cl_2	$1.43 \cdot 10^{-18}$
Mercury(I) fluoride	Hg_2F_2	$3.10 \cdot 10^{-6}$
Mercury(I) iodide	Hg_2I_2	$5.2 \cdot 10^{-29}$
Mercury(I) oxalate	$Hg_2C_2O_4$	$1.75 \cdot 10^{-13}$
Mercury(I) sulfate	Hg_2SO_4	$6.5 \cdot 10^{-7}$
Mercury(I) thiocyanate	$Hg_2(SCN)_2$	$3.2 \cdot 10^{-20}$
Mercury(II) bromide	$HgBr_2$	$6.2 \cdot 10^{-20}$
Mercury(II) iodide	HgI_2	$2.9 \cdot 10^{-29}$
Neodymium carbonate	$Nd_2(CO_3)_3$	$1.08 \cdot 10^{-33}$
Nickel(II) carbonate	$NiCO_3$	$1.42 \cdot 10^{-7}$
Nickel(II) hydroxide	$Ni(OH)_2$	$5.48 \cdot 10^{-16}$
Nickel(II) iodate	$Ni(IO_3)_2$	$4.71 \cdot 10^{-5}$
Nickel(II) phosphate	$Ni_3(PO_4)_2$	$4.74 \cdot 10^{-32}$
Palladium(II) thiocyanate	$Pd(SCN)_2$	$4.39 \cdot 10^{-23}$
Potassium hexachloroplatinate	K_2PtCl_6	$7.48 \cdot 10^{-6}$
Potassium perchlorate	$KClO_4$	$1.05 \cdot 10^{-2}$
Potassium periodate	KIO_4	$3.71 \cdot 10^{-4}$
Praseodymium hydroxide	$Pr(OH)_3$	$3.39 \cdot 10^{-24}$
Radium iodate	$Ra(IO_3)_2$	$1.16 \cdot 10^{-9}$
Radium sulfate	$RaSO_4$	$3.66 \cdot 10^{-11}$
Rubidium perchlorate	$RbClO_4$	$3.00 \cdot 10^{-3}$
Scandium fluoride	ScF_3	$5.81 \cdot 10^{-24}$
Scandium hydroxide	$Sc(OH)_3$	$2.22 \cdot 10^{-31}$
Silver(I) acetate	$AgCH_3COO$	$1.94 \cdot 10^{-3}$
Silver(I) arsenate	Ag_3AsO_4	$1.03 \cdot 10^{-22}$
Silver(I) bromate	$AgBrO_3$	$5.38 \cdot 10^{-5}$
Silver(I) bromide	$AgBr$	$5.35 \cdot 10^{-13}$
Silver(I) carbonate	Ag_2CO_3	$8.46 \cdot 10^{-12}$
Silver(I) chloride	$AgCl$	$1.77 \cdot 10^{-10}$
Silver(I) chromate	Ag_2CrO_4	$1.12 \cdot 10^{-12}$
Silver(I) cyanide	$AgCN$	$5.97 \cdot 10^{-17}$
Silver(I) iodate	$AgIO_3$	$3.17 \cdot 10^{-8}$
Silver(I) iodide	AgI	$8.52 \cdot 10^{-17}$
Silver(I) oxalate	$Ag_2C_2O_4$	$5.40 \cdot 10^{-12}$
Silver(I) phosphate	Ag_3PO_4	$8.89 \cdot 10^{-17}$
Silver(I) sulfate	Ag_2SO_4	$1.20 \cdot 10^{-5}$
Silver(I) sulfite	Ag_2SO_3	$1.50 \cdot 10^{-14}$
Silver(I) thiocyanate	$AgSCN$	$1.03 \cdot 10^{-12}$
Strontium arsenate	$Sr_3(AsO_4)_2$	$4.29 \cdot 10^{-19}$
Strontium carbonate	$SrCO_3$	$5.60 \cdot 10^{-10}$
Strontium fluoride	SrF_2	$4.33 \cdot 10^{-9}$
Strontium iodate	$Sr(IO_3)_2$	$1.14 \cdot 10^{-7}$
Strontium iodate monohydrate	$Sr(IO_3)_2 \cdot H_2O$	$3.77 \cdot 10^{-7}$
Strontium iodate hexahydrate	$Sr(IO_3)_2 \cdot 6H_2O$	$4.55 \cdot 10^{-7}$
Strontium sulfate	$SrSO_4$	$3.44 \cdot 10^{-7}$
Thallium(I) bromate	$TlBrO_3$	$1.10 \cdot 10^{-4}$
Thallium(I) bromide	$TlBr$	$3.71 \cdot 10^{-6}$
Thallium(I) chloride	$TlCl$	$1.86 \cdot 10^{-4}$
Thallium(I) chromate	Tl_2CrO_4	$8.67 \cdot 10^{-13}$
Thallium(I) iodate	$TlIO_3$	$3.12 \cdot 10^{-6}$
Thallium(I) iodide	TlI	$5.54 \cdot 10^{-8}$
Thallium(I) thiocyanate	$TlSCN$	$1.57 \cdot 10^{-4}$
Thallium(III) hydroxide	$Tl(OH)_3$	$1.68 \cdot 10^{-44}$
Tin(II) hydroxide	$Sn(OH)_2$	$5.45 \cdot 10^{-27}$

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SOLUBILITY PRODUCT CONSTANTS (continued)

Compound	Formula	K_{sp}
Yttrium carbonate	$Y_2(CO_3)_3$	$1.03 \cdot 10^{-31}$
Yttrium fluoride	YF_3	$8.62 \cdot 10^{-21}$
Yttrium hydroxide	$Y(OH)_3$	$1.00 \cdot 10^{-22}$
Yttrium iodate	$Y(IO_3)_3$	$1.12 \cdot 10^{-10}$
Zinc arsenate	$Zn_3(AsO_4)_2$	$2.8 \cdot 10^{-28}$
Zinc carbonate	$ZnCO_3$	$1.46 \cdot 10^{-10}$
Zinc carbonate monohydrate	$ZnCO_3 \cdot H_2O$	$5.42 \cdot 10^{-11}$
Zinc fluoride	ZnF_2	$3.04 \cdot 10^{-2}$
Zinc hydroxide	$Zn(OH)_2$	$3 \cdot 10^{-17}$
Zinc iodate dihydrate	$Zn(IO_3)_2 \cdot 2H_2O$	$4.1 \cdot 10^{-6}$
Zinc oxalate dihydrate	$ZnC_2O_4 \cdot 2H_2O$	$1.38 \cdot 10^{-9}$
Zinc selenide	ZnSe	$3.6 \cdot 10^{-26}$
Zinc selenite monohydrate	$ZnSeO_3 \cdot H_2O$	$1.59 \cdot 10^{-7}$

Sulfides

Compound	Formula	K_{spa}
Cadmium sulfide	CdS	$8 \cdot 10^{-7}$
Copper(II) sulfide	CuS	$6 \cdot 10^{-16}$
Iron(II) sulfide	FeS	$6 \cdot 10^{2}$
Lead(II) sulfide	PbS	$3 \cdot 10^{-7}$
Manganese(II) sulfide (green)	MnS	$3 \cdot 10^{7}$
Mercury(II) sulfide (red)	HgS	$4 \cdot 10^{-33}$
Mercury(II) sulfide (black)	HgS	$2 \cdot 10^{-32}$
Silver(I) sulfide	Ag_2S	$6 \cdot 10^{-30}$
Tin(II) sulfide	SnS	$1 \cdot 10^{-5}$
Zinc sulfide (sphalerite)	ZnS	$2 \cdot 10^{-4}$
Zinc sulfide (wurtzite)	ZnS	$3 \cdot 10^{-2}$

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SOLUBILITY CHART

Abbreviations: **W**, soluble in water; **A**, insoluble in water but soluble in acids; **w**, sparingly soluble in water but soluble in acids; a, insoluble in water and only sparingly soluble in acids; **I,** insoluble in water and acids; **d**, decomposes in water. ***** Indicates two modifications of the salt

No.		Al	NH_4	Sb	Ba	Bi	Cd	Ca	Cr	Co	Cu	Au (I)	Au (II)	H	Fe (II)	Fe (III)
1	Acetate $—(C_2H_3O_2)$	W $Al(—)_3$	W $NH_4(—)$		W $Ba(—)_2$	W $Bi(—)_3$	W $Cd(—)_2$	W $Ca(—)_2$	W $Cr(—)_3$	W $Co(—)_2$	W $Cu(—)_2$	W	W	W $C_2H_4O_2$	$Fe(—)_2$	$Fe_2(—)_6$
2	Arsenate $—(AsO_4)$	a $Al(—)$	W $(NH_4)_3(—)$	A $Sb(—)$	w $Ba_3(—)_2$	A $Bi(—)$	A $Cd_3(—)_2$	w $Ca_3(—)_2$		A $Co_3(—)_2$	A $Cu_3(—)_2$			W H_3AsO_4	A $Fe_3(—)_2$	A $Fe(—)$
3	Arsenite $—(AsO_3)$		W NH_4AsO_2	A $Sb(—)$				w $Ca_3(—)_2$		A $Co_3H_6(—)_4$	A $CuH(—)$					
4	Benzoate $—(C_7H_5O_2)$		W $NH_4(—)$		W $Ba(—)_2$	A $Bi(—)_3$	W $Cd(—)_2$	W $Ca(—)_2$		W $Co(—)_2$	w $Cu(—)_2$			W $C_7H_6O_2$	W $Fe(—)_2$	A $Fe_2(—)_6$
5	Bromide	W $AlBr_2$	W NH_4Br	d $SbBr_3$	W $BaBr_2$	d $BiBr_3$	W $CdBr_2$	W $CaBr_2$	W(I)* $CrBr_3$	W $CoBr_2$	W $CuBr_2$	w AuBr	W $AuBr_3$	W HBr	W $FeBr_2$	W $FeBr_3$
6	Carbonate		W $(NH_4)_2CO_3$		w $BaCO_3$		A $CdCO_3$	w $CaCO_3$	W $CrCO_3$	A $CoCO_3$					w $FeCO_3$	
7	Chlorate $—(ClO_3)$	W $Al(—)_3$	W $NH_4(—)$		W $Ba(—)_2$	W $Bi(—)_3$	W $Cd(—)_2$	W $Ca(—)_2$		W $Co(—)_2$	W $Cu(—)_2$			W $HClO_3$	W $Fe(—)_2$	W $Fe(—)_3$
8	Chloride	W $AlCl_3$	W NH_4Cl	W $SbCl_3$	W $BaCl_2$	d $BiCl_3$	W $CdCl_2$	W $CaCl_2$	I $CrCl_3$	W $CoCl_2$	W $CuCl_2$	w AuCl	W $AuCl_3$	W HCl	W $FeCl_2$	W $FeCl_3$
9	Chromate $—(CrO_4)$		W $(NH_4)_2(—)$		A $Ba(—)$		A $Cd(—)$	W $Ca(—)$		A $Co(—)$						A $Fe_2(—)_3$
10	Citrate $—(C_6H_5O_7)$	W $Al(—)$	W $(NH_4)_3(—)$		w $Ba_3(—)_2$	A $Bi(—)$	A $Cd_3(—)_2$	w $Ca_3(—)_2$		w $Co_3(—)_2$				W $C_6H_8O_7$		W $Fe(—)$
11	Cyanide		W NH_4CN		W $Ba(CN)_2$	w $Bi(CN)_3$	W $Cd(CN)_2$	W $Ca(CN)_2$	A $Cr(CN)_3$	A $Co(CN)_2$	A $Cu(CN)_2$	w AuCN	W $Au(CN)_3$	W HCN	a $Fe(CN)_2$	
12	Ferricy'de $—(Fe(CN)_6)$		W $(NH_4)_3(—)$		w $Ba_3(—)_2$		A $Cd_3(—)_2$	W $Ca_3(—)_2$		I $Co_3(—)_2$	I $Cu_3(—)_2$			W $H_3(—)$	I $Fe_3(—)_2$	
13	Ferrocy'de $—(Fe(CN)_6)$	w $Al_4(—)_3$	W $(NH_4)_4(—)$		W $Ba_2(—)$		A $Cd_2(—)$	W $Ca_2(—)$		I $Co_2(—)$	I $Cu_2(—)$			W $H_4(—)$	I $Fe_2(—)$	a $Fe_4(—)_3$
14	Fluoride	W AlF_3	W NH_4F	W SbF_3	w BaF_2	W BiF_3	W CdF_2	w CaF_2	W(a)* CrF_3	W CoF_2	w CuF_2			W HF	w FeF_2	w FeF_3
15	Formate $—(CHO_2)$	W $Al(—)_3$	W $NH_4(—)$		W $Ba(—)_2$	W $Bi(—)_3$	W $Cd(—)_2$	W $Ca(—)_2$		W $Co(—)_2$	W $Cu(—)_2$			W CH_2O_2	W $Fe(—)_2$	W $Fe(—)_3$
16	Hydroxide	A $Al(OH)_3$	W NH_4OH		W $Ba(OH)_2$	A $Bi(OH)_3$	A $Cd(OH)_2$	W $Ca(OH)_2$	A $Cr(OH)_3$	A $Co(OH)_2$	A $Cu(OH)_2$	W AuOH	A $Au(OH)_3$		A $Fe(OH)_2$	A $Fe(OH)_3$
17	Iodide	W AlI_3	W NH_4I	d SbI_3	W BaI_2	A BiI_3	W CdI_2	W CaI_2	W CrI_3	W CoI_2	a CuI	a AuI	a AuI_3	W HI	W FeI_2	W FeI_3
18	Nitrate	W $Al(NO_3)_3$	W NH_4NO_3		W $Ba(NO_3)_2$	d $Bi(NO_3)_3$	W $Cd(NO_3)_2$	W $Ca(NO_3)_2$	W $Cr(NO_3)_3$	W $Co(NO_3)_2$	W $Cu(NO_3)_2$			W HNO_3	W $Fe(NO_3)_2$	W $Fe(NO)_3$
19	Oxalate $—(C_2O_4)$	A $Al_2(—)_3$	W $(NH_4)_2(—)$		w $Ba(—)$	A $Bi_2(—)_3$	w $Cd(—)$	A $Ca(—)$	W $Cr(—)$	A $Co(—)$	A $Cu(—)$			W $C_2H_2O_4$	A $Fe(—)$	W $Fe_2(—)_3$
20	Oxide	a Al_2O_3		w Sb_2O_3	W BaO	A Bi_2O_3	A CdO	w CaO	a Cr_2O_3	A CoO	A CuO	Au_2O	A Au_2O_3	W H_2O_2	A FeO	A Fe_2O_3
21	Phosphate	A $AlPO_4$	W $NH_4H_2PO_4$		A $Ba_3(PO_4)_2$	A $BiPO_4$	A $Cd_3(PO_4)_2$	w $Ca_3(PO_4)_2$	w $Cr_2(PO_4)_2$	A $Co_3(PO_4)_2$	A $Cu_3(PO_4)_2$		H_3PO_4	W $Fe_3(PO_4)_2$	A $FePO_4$	w
22	Silicate, $—(SiO_3)$	I $Al_2(—)_3$			W $Ba(—)$		A $Cd(—)$	w $Ca(—)$		A Co_2SiO_4	A $Cu(—)$			I H_2SiO_3		
23	Sulfate	W $Al_2(SO_4)_3$	W $(NH_4)_2SO_4$	A $Sb_2(SO_4)_3$	a $BaSO_4$	d $Bi_2(SO_4)_3$	W $CdSO_4$	w $CaSO_4$	W(I)* $Cr_2(SO_4)_3$	W $CoSO_4$	W $CuSO_4$			W H_2SO_4	W $FeSO_4$	w $Fe(SO_4)_3$
24	Sulfide	d Al_2S_3	W $(NH_4)_2S$	A Sb_2S_3	d BaS	A Bi_2S_3	A CdS	w CaS	d Cr_2S_3	A CoS	A CuS	I Au_2S	I Au_2S_3	W H_2S	A FeS	d Fe_2S_3
25	Tartrate $—(C_4H_4O_6)$	w $Al_2(—)_3$	W $(NH_4)_2(—)$	W $Sb_2(—)_3$	w $Ba(—)$	A $Bi_2(—)_3$	A $Cd(—)$	w $Ca(—)$	d	A $Co(—)$	A $Cu(—)$	I	I	W $C_4H_6O_6$	A $Fe(—)$	d $Fe_2(—)_3$

SOLUBILITY CHART (continued)

No.		Al	NH₄	Sb	Ba	Bi	Cd	Ca	Cr	Co	Cu	Au (I)	Au (II)	H	Fe (II)	Fe (III)
26	Thiocy'te		W NH_4CNS		W $Ba(CNS)_2$			W $Ca(CNS)$		W $Co(CNS)_2$	d $CuCNS$			W $CNSH$	W $Fe(CNS)_2$	W $Fe(CNS)_3$

No.		Pb	Mg	Mn	Hg (I)	Hg (II)	Ni	K	Pt	Ag	Na	Sn (IV)	Sn (II)	Sr	Zn
1	Acetate —$(C_2H_3O_2)$	W $Pb(—)_2$	W $Mg(—)_2$	W $Mn(—)_2$	w $Hg(—)$	W $Hg(—)_2$	W $Ni(—)_2$	W $K(—)$		w $Ag(—)$	W $Na(—)$	W $Sn(—)_4$	d $Sn(—)_2$	W $Sr(—)_2$	W $Zn(—)_2$
2	Arsenate —(AsO_4)	A $PbH(—)$	A $Mg_3(—)$	w $MnH(—)$	A $Hg_3(—)$	w $Hg_3(—)_2$	A $Ni_3(—)_2$	W $K_3(—)$		A $Ag_3(—)$	W $Na_3(—)$			w $SrH(—)$	A $Zn_3(—)_2$
3	Arsenite —(AsO_3)		W $Mg_3(—)_2$	A $Mn_3H_6(—)_4$	A $Hg_3(—)$	A $Hg_3(—)$	A $Ni_3H_6(—)_4$	W K_3AsO_3		A $Ag_3(—)$	W $Na_2H(—)$		A $Sn_3(—)_2$	w $Sr_3(—)_2$	
4	Benzoate —$(C_7H_5O_2)$	w $Pb(—)_2$	W $Mg(—)_2$	W $Mn(—)_2$	A $Hg_2(—)_2$	w $Hg(—)_2$	w $Ni(—)_2$	W $K(—)$		w $Ag(—)$	W $Na(—)$				W $Zn(—)_2$
5	Bromide	W $PbBr_2$	W $MgBr_2$	W $MnBr_2$	A $HgBr$	W $HgBr_2$	W $NiBr_2$	W KBr	w $PtBr_4$	a $AgBr$	W $NaBr$	W $SnBr_4$	W $SnBr_2$	W $SrBr_2$	W $ZnBr_2$
6	Carbonate	A $PbCO_3$	w $MgCO_3$	w $MnCO_3$	A Hg_2CO_3		w $NiCO_3$	W K_2CO_3		A Ag_2CO_3	W Na_2CO_3			w $SrCO_3$	w $ZnCO_3$
7	Chlorate —(ClO_3)	W $Pb(—)_2$	W $Mg(—)_2$	W $Mn(—)_2$	W $Hg(—)$	W $Hg(—)_2$	W $Ni(—)_2$	W $K(—)$		W $Ag(—)$	W $Na(—)$		W $Sn(—)_2$	W $Sr(—)_2$	W $Zn(—)_2$
8	Chloride	W $PbCl_2$	W $MgCl_2$	W $MnCl_2$	a $HgCl$	W $HgCl_2$	W $NiCl_2$	W KCl	W $PtCl_4$	a $AgCl$	W $NaCl$	W $SnCl_4$	W $SnCl_2$	W $SrCl_2$	W $ZnCl_2$
9	Chromate —(CrO_4)	A $Pb(—)$	W $Mg(—)$		w $Hg_2(—)$	w $Hg(—)$	A $Ni(—)$	W $K_2(—)$		w $Ag_2(—)$	W $Ma_2(—)$	W $Sn(—)_2$	A $Sn(—)$	w $Sr(—)$	w $Zn(—)$
10	Citrate —$(C_6H_5O_7)$	W $Pb_3(—)_2$	W $Mg_3(—)_2$	w $MnH(—)$	w $Hg_3(—)$		W $Ni_3(—)_2$	W $K_3(—)$		w $Ag_3(—)$	W $Na_3(—)$			A $SrH(—)$	w $Zn_3(—)_2$
11	Cyanide	w $Pb(CN)_2$	W $Mg(CN)_2$		A $HgCN$	W $Hg(CN)_2$	a $Ni(CN)_2$	W KCN	I $Pt(CN)_2$	a $AgCN$	W $NaCN$			W $Sr(CN)_2$	A $Zn(CN)_2$
12	Ferricy'de —$Fe(CN)_6$	w $Pb_3(—)_2$	W $Mg_3(—)_2$			A $Hg_3(—)_2$	I $Ni_3(—)_2$	W $K_3(—)$		I $Ag_3(—)$	W $Na_3(—)$		A $Sn_3(—)_2$	W $Sr_3(—)_2$	A $Zn_3(—)_2$
13	Ferrocy'de —$Fe(CN)_6$	a $Pb_2(—)$	W $Mg_2(—)$	A $Mn_2(—)$		I $Hg_2(—)$	I $Ni_2(—)$	W $K_4(—)$		I $Ag_4(—)$	W $Na_4(—)$		a $Sn_2(—)$	W $Sr_2(—)$	I $Zn_2(—)$
14	Fluoride	w PbF_2	w MgF_2	A MnF_2	d HgF	d HgF_2	w NiF_2	W KF	W PtF_4	W AgF	W NaF	W SnF_4	W SnF_2	w SrF_2	w ZnF_2
15	Formate —(CHO_2)	W $Pb(—)_2$	W $Mg(—)_2$	W $Mn(—)_2$	w $Hg(—)$	W $Hg(—)_2$	W $Ni(—)_2$	W $K(—)$		W $Ag(—)$	W $Na(—)$			W $Sr(—)_2$	W $Zn(—)_2$
16	Hydroxide	w $Pb(OH)_2$	A $Mg(OH)_2$	A $Mn(OH)_2$		A $Hg(OH)_2$	w $Ni(OH)_2$	W KOH	A $Pt(OH)_4$		W $NaOH$	w $Sn(OH)_4$	A $Sn(OH)_2$	W $Sr(OH)_2$	A $Zn(OH)_2$
17	Iodide	w PbI_2	W MgI_2	W MnI_2	A HgI	w HgI_2	W NiI_2	W KI	I PtI_2	I AgI	W NaI	d SnI_4	W SnI_2	W SrI_2	W ZnI_2
18	Nitrate	W $Pb(NO_3)_2$	W $Mg(NO_3)_2$	W $Mn(NO_3)_2$	W $HgNO_3$	W $Hg(NO_3)_2$	W $Ni(NO_3)_2$	W KNO_3	W $Pt(NO_3)_4$	W $AgNO_3$	W $NaNO_3$		d $Sn(NO_3)_2$	W $Sr(NO_3)_2$	W $Zn(NO_3)_2$
19	Oxalate —(C_2O_4)	A $Pb(—)$	w $Mg(—)$	w $Mn(—)$	a $Hg_2(—)$	A $Hg(—)$	A $Ni(—)$	W $K_2(—)$		a $Ag_2(—)$	W $Na_2(—)$		A $Sn(—)$	w $Sr(—)$	A $Zn(—)$
20	Oxide	w PbO	A MgO	A MnO	A Hg_2O	w HgO	A NiO	W K_2O	A PtO	w Ag_2O	d Na_2O	A SnO_2	A SnO	W SrO	w ZnO
21	Phosphate	A $Pb_3(PO_4)_2$	w $Mg_3(PO_4)_2$	w $Mn_3(PO_4)_2$	A Hg_3PO_4	A $Hg_3(PO_4)_2$	A $Ni_3(PO_4)_2$	W K_3PO_4		A Ag_3PO_4	W Na_3PO_4		A $Sn_3(PO_4)$	A $Sr_3(PO_4)_2$	A $Zn_3(PO_4)_2$
22	Silicate —(SiO_3)	A $Pb(—)$	A $Mg(—)$	I $Mn(—)$				W $K_2(—)$			W $Na_2(—)$			A $Sr(—)$	A $Zn(—)$
23	Sulfate	w $PbSO_4$	W $MgSO_4$	W $MnSO_4$	w Hg_2SO_4	d $HgSO_4$	W $NiSO_4$	W K_2SO_4	W $Pt(SO_4)_2$	w Ag_2SO_4	W Na_2SO_4	W $Sn(SO_4)_2$	W $SnSO_4$	w $SrSO_4$	W $ZnSO_4$

SOLUBILITY CHART (continued)

No.		Pb	Mg	Mn	Hg (I)	Hg (II)	Ni	K	Pt	Ag	Na	Sn (IV)	Sn (II)	Sr	Zn
24	Sulfide	**A**	**d**	**A**	**I**	**I**	**A**	**W**	**I**	**A**	**W**	**A**	**A**	**W**	**A**
		PbS	MgS	MnS	Hg_2S	HgS	NiS	K_2S	PtS	Ag_2S	Na_2S	SnS_2	SnS	SrS	ZnS
25	Tartrate	**A**	**w**	**w**	**I**	**I**	**A**	**W**	**I**	**A**	**W**	**A**	**A**	**W**	**A**
	—($C_4H_4O_6$)	Pb(—)	Mg(—)	Mn(—)	Hg_2(—)		Ni(—)	K_2(—)		Ag_2(—)	Na_2(—)		Sn(—)	Sr(—)	Zn(—)
26	Thiocy’te	**w**	**W**	**W**	**A**	**w**		**W**		**I**	**W**			**W**	**W**
		$Pb(CNS)_2$	$Mg(CNS)_2$	$Mn(CNS)_2$	HgCNS	$Hg(CNS)_2$		KCNS		AgCNS	NaCNS			$Sr(CNS)_2$	$Zn(CNS)_2$

REDUCTION OF WEIGHINGS IN AIR TO VACUO

When the mass M of a body is determined in air, a correction is necessary for the buoyancy of the air. The corrected mass is given by $M + kM/1000$, where k is a function of the material used for the weights, given by

$$k = 1000\rho_{air}(1/\rho_{body} - 1/\rho_{weight})$$

and ρ is density. The table below is computed for an air density of 0.0012 g/cm^3 and for densities of three common weights: platinum-iridium (21.6 g/cm^3), brass (8.5 g/cm^3), and aluminum or quartz (2.65 g/cm^3).

REFERENCES

1. Kaye, G. W. C., and Laby, T. H., *Tables of Physical and Chemical Constants, 16th Edition*, pp. 25-28, Longman, London, 1995.
2. Giacomo, P., *Metrologia* 18, 33, 1982.
3. Davis, R. S., *Metrologia* 29, 67, 1992.

Density of body (g/cm^3)	**Value of *k* for weights of: Pt-Ir**	**Brass**	**Quartz or Al**
0.5	2.34	2.26	1.95
0.6	1.94	1.86	1.55
0.7	1.66	1.57	1.26
0.8	1.44	1.36	1.05
0.9	1.28	1.19	0.88
1.0	1.14	1.06	0.75
1.1	1.04	0.95	0.64
1.2	0.94	0.86	0.55
1.3	0.87	0.78	0.47
1.4	0.80	0.72	0.40
1.5	0.74	0.66	0.35
1.6	0.69	0.61	0.30
1.7	0.65	0.56	0.25
1.8	0.61	0.53	0.21
1.9	0.58	0.49	0.18
2.0	0.54	0.46	0.15
2.5	0.42	0.34	0.03
3.0	0.34	0.26	-0.05
4.0	0.24	0.16	-0.15
6.0	0.14	0.06	-0.25
8.0	0.09	0.01	-0.30
10.0	0.06	-0.02	-0.33
15.0	0.02	-0.06	-0.37
20.0	0.00	-0.08	-0.39
22.0	0.00	-0.09	-0.40

For a more accurate calculation, use the following values of the density of air (assuming 50% relative humidity and 0.04% CO_2):

	Air temperature		
***P*/kPa**	**10°C**	**20°C**	**30°C**
85	0.001043	0.001005	0.000968
90	0.001105	0.001065	0.001025
95	0.001166	0.001124	0.001083
100	0.001228	0.001184	0.001140
105	0.001290	0.001243	0.001198

Formulas for calculating the density of air over more extended ranges of temperature, pressure, and humidity may be found in the references.

VOLUME OF ONE GRAM OF WATER

The following table, which is designed for gravimetric calibration of volumetric apparatus, gives the specific volume of water at standard atmospheric pressure as a function of temperature.

REFERENCE

Marsh, K. N., Editor, *Recommended Reference Materials for the Realization of Physicochemical Properties*, pp. 25-27, Blackwell Scientific Publications, Oxford, 1987.

t/°C	Volume of 1 g H_2O in cm^3	t/°C	Volume of 1 g H_2O in cm^3	t/°C	Volume of 1 g H_2O in cm^3
10	1.0002980	17	1.0012246	24	1.0027079
11	1.0003928	18	1.0014044	25	1.0029607
12	1.0005007	19	1.0015952	26	1.0032234
13	1.0006212	20	1.0017969	27	1.0034956
14	1.0007542	21	1.0020092	28	1.0037771
15	1.0008992	22	1.0022320	29	1.0040679
16	1.0010561	23	1.0024649	30	1.0043679

PROPERTIES OF CARRIER GASES FOR GAS CHROMATOGRAPHY

The following is a list of carrier gases sometimes used in gas chromatography, with properties relevant to the design of chromatographic systems. All data refer to normal atmospheric pressure (101.325 kPa).

M_r : Molecular weight (relative molar mass)
ρ_{25} : Density at 25°C in g/L
λ : Thermal conductivity in mW/m °C
η : Viscosity in µPa s (equal to 10^{-3} cp)
c_p : Specific heat at 25°C in J/g °C

REFERENCES

1. Lide, D. R., and Kehiaian, H. V., *CRC Handbook of Thermophysical and Thermochemical Data*, CRC Press, Boca Raton, FL, 1994.
2. Bruno, T. J., and Svoronos, P. D. N., *CRC Handbook of Basic Tables for Chemical Analysis*, CRC Press, Boca Raton, FL, 1989

			At 25°C		At 250°C		
Gas	M_r	ρ_{25} g L^{-1}	λ mW/m °C	η µPa s	λ mW/m °C	η µPa s	c_p(25 °C) J/g °C
Hydrogen	2.016	0.0824	185.9	8.9	280	13.1	14.3
Helium	4.003	0.1636	154.6	19.9	230	29.5	5.20
Argon	39.95	1.6329	17.8	22.7	27.7	35.3	0.521
Nitrogen	28.01	1.1449	25.9	17.9	39.6	26.8	1.039
Oxygen	32.00	1.3080	26.2	20.7	42.6	31.8	0.919
Carbon monoxide	28.01	1.1449	24.8	17.8	40.7	26.5	1.039
Carbon dioxide	44.01	1.7989	16.7	14.9	35.5	24.9	0.843
Sulfur hexafluoride	146.05	5.9696	13.1	28.1	15.3	24.8	0.664
Methane	16.04	0.6556	34.5	11.1	75.0	17.6	2.23
Ethane	30.07	1.2291	20.9	9.4	57.7	15.5	1.75
Ethylene	28.05	1.1465	20.5	10.3	53.8	17.2	1.53
Propane	44.10	1.8025	17.9	8.3	49.2	14.0	1.67

SOLVENTS FOR ULTRAVIOLET SPECTROPHOTOMETRY

This table lists some solvents commonly used for sample preparation for ultraviolet spectrophotometry. The properties given are:

λ_c: cutoff wavelength, below which the solvent absorption becomes excessive.
ε: dielectric constant (relative permittivity); the temperature in °C is given as a superscript.
t_b: normal boiling point.

REFERENCES

1. Bruno, T. J., and Svoronos, P. D. N., *CRC Handbook of Basic Tables for Chemical Analysis*, CRC Press, Boca Raton, FL, 1989.
2. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series,* IV/6, *Static Dielectric Constants of Pure Liquids and Binary Liquid Mixtures,* Springer-Verlag, Heidelberg, 1991.

Name	λ_c/nm	ε	t_b/°C
Acetic acid	260	6.20^{20}	117.9
Acetone	330	21.01^{20}	56.0
Acetonitrile	190	36.64^{20}	81.6
Benzene	280	2.28^{20}	80.0
2-Butanol	260	17.26^{20}	99.5
Butyl acetate	254	5.07^{20}	126.1
Carbon disulfide	380	2.63^{20}	46
Carbon tetrachloride	265	2.24^{20}	76.8
1-Chlorobutane	220	7.28^{20}	78.6
Chloroform	245	4.81^{20}	61.1
Cyclohexane	210	2.02^{20}	80.7
1,2-Dichloroethane	226	10.42^{20}	83.5
Dichloromethane	235	8.93^{25}	40
Diethyl ether	218	4.27^{20}	34.5
N,*N*-Dimethylacetamide	268	38.85^{21}	165
N,*N*-Dimethylformamide	270	38.25^{20}	153
Dimethyl sulfoxide	265	47.24^{20}	189
1,4-Dioxane	215	2.22^{20}	101.5
Ethanol	210	25.3^{20}	78.2
Ethyl acetate	255	6.08^{20}	77.1
Ethylene glycol dimethyl ether	240	7.30^{24}	85
Ethylene glycol monoethyl ether	210	13.38^{25}	135
Ethylene glycol monomethyl ether	210	17.2^{25}	124.1
Glycerol	207	46.53^{20}	290
Heptane	197	1.92^{20}	98.5
Hexadecane	200	2.05^{20}	286.8
Hexane	210	1.89^{20}	68.7
Methanol	210	33.0^{20}	64.6
Methylcyclohexane	210	2.02^{20}	100.9
Methyl ethyl ketone	330	18.56^{20}	79.5
Methyl isobutyl ketone	335	13.11^{20}	116.5
2-Methyl-1-propanol	230	17.93^{20}	107.8
N-Methyl-2-pyrrolidone	285	32.55^{20}	202
Nitromethane	380	37.27^{20}	101.1
Pentane	210	1.84^{20}	36.0
Pentyl acetate	212	4.79^{20}	149.2
1-Propanol	210	20.8^{20}	97.2
2-Propanol	210	20.18^{20}	82.3
Pyridine	330	13.26^{20}	115.2
Tetrachloroethylene	290	2.27^{30}	121.3
Tetrahydrofuran	220	7.52^{22}	65
Toluene	286	2.38^{23}	110.6
1,1,2-Trichloro-1,2,2-trifluoroethane	231	2.41^{25}	47.7
2,2,4-Trimethylpentane	215	1.94^{20}	99.2
Water	191	80.10^{20}	100.0
o-Xylene	290	2.56^{20}	144.5
m-Xylene	290	2.36^{20}	139.1
p-Xylene	290	2.27^{20}	138.3

^{13}C CHEMICAL SHIFTS OF USEFUL NMR SOLVENTS

The following table gives the expected carbon-13 chemical shifts, relative to tetramethylsilane, for various useful NMR solvents. In some solvents, slight changes can occur with change of concentration.[2,3]

REFERENCES

1. Bruno, T. J. and Svoronos, P. D. N., *CRC Handbook of Basic Tables for Chemical Analysis*, CRC Press, Boca Raton, FL, 1989.
2. Silverstein, R. M., Bassler, G. C., and Morrill, T. C., *Spectrometric Identification of Organic Compounds*, John Wiley & Sons, Now York, 1981.
3. Rahman, A. U., *Nuclear Magnetic Resonance. Basic Principles*, Springer-Verlag, New York, 1986.
4. Pretsch, E., Clerc, T., Seibl, J., and Simon, W., *Spectral Data for Structure Determination of Organic Compounds, Second Edition*, Springer-Verlag, Heidelberg, 1989.

Solvent	**Formula**	**Chemical shift (ppm)**
Acetic acid-d_4	CD_3COOD	20.0 (CD_3) 205.8 (C=O)
Acetone	$(CH_3)_2C{=}O$	30.7 (CH_3) 206.7 (C=O)
Acetone-d_6	$(CD_3)_2C{=}O$	29.2 (CD_3) 204.1 (C=O)
Acetonitrile-d_3	$CD_3C{\equiv}N$	1.3 (CD_3) 117.1 ($C{\equiv}N$)
Benzene	C_6H_6	128.5
Benzene-d_6	C_6D_6	128.4
Carbon disulfide	CS_2	192.3
Carbon tetrachloride	CCl_4	96.0
Chloroform	$CHCl_3$	77.2
Chloroform-d_3	$CDC1_3$	77.05
Cyclohexane-d_{12}	C_6D_{12}	27.5
Dichloromethane-d_2	CD_2C1_2	53.6
Dimethylformamide-d_7	$(CD_3)_2NCDO$	31 (CD_3) 36 (CD_3) 162.4 (C=O)
Dimethylsulfoxide-d_6	$(CD_3)_2S{=}O$	39.6
Dioxane-d_8	$C_4D_3O_2$	67.4
Formic acid-d_2	DCOOD	165.5
Methanol-d_4	CD_3OD	49.3
Nitromethane-d_3	CD_3NO_2	57.3
Pyridine	C_5H_5N	123.6 (C_3) 135.7 (C_4) 149.8 (C_2)
Pyridine-d_5	C_5D_5N	123.9 (C_3) 135.9 (C_4) 150.2 (C_2)
1,1,2,2-Tetrachloroethane-d_2	$CDC1_2CDC1_2$	75.5
Tetrahydrofuran-d_8	C_4D_8O	25.8 (C_2) 67.9 (C_1)
Trichlorofluoromethane	$CFC1_3$	117.6

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MASS SPECTRAL PEAKS OF COMMON ORGANIC SOLVENTS

The strongest peaks in the mass spectra of 200 important solvents are listed in this table. The *e*/*m* value for each peak is followed by the relative intensity in parentheses, with the strongest peak assigned an intensity of 100. The peaks for each compound are listed in order of decreasing intensity. Solvents are listed in alphabetical order by common name.

Data on the physical properties of the same compounds may be found in Section 15 in the table "Properties of Common Laboratory Solvents".

REFERENCES

1. NIST/EPA/NIH Mass Spectral Database, National Institute of Standards and Technology, Gaithersburg, MD, 20899.
2. Lide, D.R., and Milne, G.W.A., Editors, *Handbook of Data on Organic Compounds, Third Edition*, CRC Press, Boca Raton, FL, 1994. (Also available as a CD ROM database.)

MASS SPECTRAL PEAKS OF COMMON ORGANIC SOLVENTS (continued)

Compound	*e*/*m* (intensity)								
Acetal (1,1-Diethoxyethane)	44(100)	43(92)	29(77)	31(76)	45(74)	27(52)	72(48)	73(23)	28(17)	46(15)
Acetic acid	43(100)	45(87)	60(57)	15(42)	42(14)	29(13)	14(13)	28(7)	18(6)	16(6)
Acetone	43(100)	15(34)	58(23)	27(9)	14(9)	42(8)	26(7)	29(5)	28(5)	39(4)
Acetonitrile	41(100)	40(46)	39(13)	14(9)	38(6)	28(4)	26(4)	25(3)	42(2)	27(2)
Acetylacetone	43(100)	85(31)	100(20)	27(12)	42(10)	29(10)	41(7)	39(7)	31(5)	26(5)
Acrylonitrile	53(100)	26(85)	52(79)	51(34)	27(13)	50(8)	25(7)	38(5)	54(3)	37(3)
Adiponitrile	41(100)	68(50)	54(42)	40(21)	55(20)	27(17)	39(16)	28(13)	52(7)	42(6)
Allyl alcohol	57(100)	31(34)	29(32)	28(31)	58(25)	39(22)	27(20)	30(16)	32(14)	26(11)
Allylamine	30(100)	56(80)	28(76)	57(33)	39(21)	29(20)	27(18)	26(13)	41(8)	18(8)
2-Aminoisobutanol	58(100)	41(18)	18(17)	42(13)	28(11)	56(10)	30(10)	29(8)	43(6)	59(5)
Benzal chloride	125(100)	127(32)	160(14)	89(13)	162(9)	63(9)	126(8)	62(7)	105(5)	39(5)
Benzaldehyde	51(100)	77(81)	50(55)	106(44)	105(43)	52(26)	78(16)	39(13)	27(10)	74(8)
Benzene	78(100)	77(20)	52(19)	51(17)	50(15)	39(12)	79(6)	76(5)	74(4)	38(4)
Benzonitrile	103(100)	76(34)	50(13)	104(9)	75(7)	51(7)	77(5)	52(4)	39(4)	74(3)
Benzyl chloride	91(100)	126(20)	65(14)	92(9)	39(9)	63(8)	128(6)	45(6)	89(5)	125(3)
Bromochloromethane	49(100)	130(67)	128(52)	51(31)	93(23)	81(20)	79(20)	95(17)	132(16)	47(8)
Bromoform (Tribromomethane)	173(100)	171(50)	175(49)	93(22)	91(22)	79(18)	81(17)	94(13)	92(13)	254(11)
Butyl acetate	43(100)	56(34)	41(17)	27(16)	29(15)	73(11)	61(10)	28(7)	55(6)	39(6)
Butyl alcohol	31(100)	56(81)	41(62)	43(60)	27(50)	42(31)	29(31)	28(17)	39(16)	55(12)
sec-Butyl alcohol	45(100)	31(22)	27(22)	59(20)	29(18)	43(13)	41(12)	44(8)	18(8)	28(5)
tert-Butyl alcohol	59(100)	31(33)	41(22)	43(18)	29(13)	27(11)	57(10)	42(4)	60(3)	28(3)
Butylamine	30(100)	73(10)	28(5)	41(3)	27(3)	18(3)	44(2)	42(2)	31(2)	29(2)
tert-Butylamine	58(100)	41(21)	42(15)	18(9)	30(8)	15(8)	39(7)	57(6)	28(6)	59(4)
Butyl methyl ketone	43(100)	58(60)	57(17)	100(16)	29(15)	41(13)	85(8)	27(8)	71(7)	59(5)
p-*tert*-Butyltoluene	133(100)	105(38)	41(23)	148(18)	93(16)	91(14)	115(13)	134(11)	39(11)	116(10)
γ-Butyrolactone	28(100)	42(74)	29(48)	27(33)	41(27)	56(25)	86(24)	26(18)	85(10)	39(10)
Caprolactam	55(100)	113(87)	30(81)	56(66)	84(60)	85(57)	42(51)	41(33)	28(26)	43(17)
Carbon disulfide	76(100)	32(22)	44(17)	78(9)	38(6)	28(5)	77(3)	64(1)	46(1)	39(1)
Carbon tetrachloride	117(100)	119(98)	121(31)	82(24)	47(23)	84(16)	35(14)	49(8)	28(8)	36(6)
1-Chloro-1,1-difluoroethane	65(100)	45(31)	85(14)	31(10)	64(8)	44(7)	35(6)	26(6)	87(5)	81(4)
Chlorobenzene	112(100)	77(63)	114(33)	51(29)	50(14)	75(8)	113(7)	78(5)	76(5)	28(4)
Chloroform	83(100)	85(64)	47(35)	35(19)	48(16)	49(12)	87(10)	37(6)	50(5)	84(4)
Chloropentafluoroethane	85(100)	69(61)	31(38)	87(32)	50(17)	35(8)	119(6)	66(4)	100(3)	47(3)
Cumene (Isopropylbenzene)	105(100)	120(25)	77(13)	51(12)	79(10)	106(9)	39(9)	27(8)	103(6)	91(5)
Cyclohexane	56(100)	84(71)	41(70)	27(37)	55(36)	39(35)	42(30)	69(23)	28(18)	43(14)
Cyclohexanol	57(100)	44(68)	41(68)	39(51)	32(40)	43(38)	31(32)	42(22)	67(18)	82(16)
Cyclohexanone	55(100)	42(85)	41(34)	27(33)	98(31)	39(27)	69(26)	70(20)	43(14)	28(14)
Cyclohexylamine	56(100)	43(23)	28(17)	99(10)	70(8)	57(6)	30(6)	93(5)	54(4)	41(4)
Cyclopentane	42(100)	70(30)	55(29)	41(29)	39(22)	27(15)	40(7)	29(5)	28(4)	43(3)
Cyclopentanone	55(100)	28(50)	84(42)	41(38)	56(29)	27(24)	39(19)	42(15)	26(9)	29(7)
p-Cymene (1-Methyl-4-isopropylbenzene)	119(100)	91(42)	134(33)	39(27)	41(20)	117(18)	65(18)	77(17)	27(16)	120(15)
cis-Decalin	67(100)	81(87)	41(81)	138(67)	96(62)	82(62)	39(50)	55(45)	27(44)	95(42)
trans-Decalin	41(100)	68(91)	67(88)	82(67)	27(65)	96(61)	95(55)	138(51)	81(51)	29(51)

MASS SPECTRAL PEAKS OF COMMON ORGANIC SOLVENTS (continued)

Compound	*e*/*m* (intensity)								
Diacetone alcohol	43(100)	59(41)	58(17)	101(10)	41(9)	31(9)	83(6)	56(6)	55(6)	29(6)
1,2-Dibromoethane	27(100)	107(77)	109(72)	26(24)	28(10)	81(5)	79(5)	25(5)	95(4)	93(4)
Dibromofluoromethane	111(100)	113(98)	192(29)	43(16)	41(16)	190(15)	194(14)	81(9)	79(9)	122(7)
Dibromomethane	174(100)	93(96)	95(84)	172(53)	176(50)	91(11)	81(9)	79(9)	94(5)	65(5)
1,2-Dibromotetrafluoroethane	179(100)	181(97)	129(34)	131(33)	100(17)	31(13)	260(12)	50(8)	69(7)	262(6)
Dibutylamine	86(100)	72(52)	30(48)	44(40)	29(31)	57(24)	41(21)	73(15)	28(15)	43(13)
o-Dichlorobenzene	146(100)	148(64)	111(38)	75(23)	113(12)	74(12)	50(11)	150(10)	73(9)	147(7)
1,1-Dichloroethane (Ethylidene dichloride)	63(100)	27(71)	65(31)	26(19)	83(11)	85(7)	61(7)	35(6)	98(5)	62(5)
1,2-Dichloroethane (Ethylene dichloride)	62(100)	27(91)	49(40)	64(32)	26(31)	63(19)	98(14)	51(13)	61(12)	100(9)
1,1-Dichloroethylene	61(100)	96(61)	98(38)	63(32)	26(16)	60(15)	62(7)	25(7)	100(6)	35(6)
cis-1,2-Dichloroethylene	61(100)	96(73)	98(47)	63(32)	26(30)	60(21)	25(13)	35(12)	62(9)	100(8)
trans-1,2-Dichloroethylene	61(100)	96(67)	98(43)	26(34)	63(32)	60(24)	25(15)	62(10)	100(7)	47(7)
Dichloroethyl ether	93(100)	63(74)	27(38)	95(32)	65(24)	31(9)	49(4)	28(4)	94(3)	62(3)
Dichloromethane (Methylene chloride)	49(100)	84(64)	86(39)	51(31)	47(14)	48(8)	88(6)	50(3)	85(2)	83(2)
1,2-Dichloropropane	63(100)	62(71)	27(57)	41(49)	39(32)	65(31)	76(27)	64(25)	49(13)	77(12)
1,2-Dichlorotetrafluoroethane	85(100)	135(52)	87(33)	137(17)	101(9)	31(9)	103(6)	100(6)	50(5)	69(4)
Diethanolamine	30(100)	74(82)	28(77)	56(69)	18(50)	42(46)	29(36)	27(34)	45(30)	43(19)
Diethylamine	30(100)	58(81)	44(28)	73(18)	29(18)	28(17)	72(12)	42(11)	27(11)	59(4)
Diethyl carbonate	29(100)	45(70)	31(53)	27(39)	91(24)	28(15)	63(11)	26(10)	30(6)	43(5)
Diethylene glycol	45(100)	75(23)	31(20)	44(16)	27(14)	76(12)	29(12)	43(11)	42(9)	41(4)
Diethylene glycol dimethyl ether (Diglyme)	59(100)	58(43)	31(34)	29(32)	45(28)	28(19)	89(15)	43(9)	27(5)	60(4)
Diethylene glycol monoethyl ether (Carbitol)	45(100)	59(56)	72(37)	73(22)	60(14)	31(13)	75(11)	44(9)	104(8)	103(7)
Diethylene glycol monoethyl ether acetate	43(100)	29(51)	31(42)	45(40)	59(24)	72(18)	44(10)	73(9)	42(9)	30(6)
Diethylene glycol monomethyl ether	45(100)	31(42)	59(41)	29(38)	28(32)	58(21)	43(14)	27(13)	44(11)	32(10)
Diethylenetriamine	44(100)	73(59)	30(35)	19(18)	56(16)	28(16)	27(16)	42(11)	99(8)	43(8)
Diethyl ether	31(100)	29(63)	59(40)	27(35)	45(33)	74(23)	15(17)	43(9)	28(9)	26(9)
Diisobutyl ketone (Isovalerone)	57(100)	85(82)	41(46)	43(39)	58(33)	28(30)	26(30)	39(22)	42(12)	142(11)
Diisopropyl ether	45(100)	43(39)	87(15)	41(12)	59(10)	27(8)	39(4)	69(3)	42(3)	31(3)
N,*N*-Dimethylacetamide	44(100)	87(69)	43(46)	45(23)	42(19)	72(15)	15(11)	30(8)	28(5)	88(4)
Dimethylamine	44(100)	45(81)	18(32)	28(30)	43(19)	42(15)	15(9)	46(5)	41(5)	27(5)
Dimethyl disulfide	94(100)	45(63)	79(59)	46(38)	47(26)	15(18)	48(14)	61(12)	64(11)	96(9)
N,*N*-Dimethylformamide	73(100)	44(86)	42(36)	30(22)	28(20)	29(8)	43(7)	72(6)	58(5)	74(4)
Dimethyl sulfoxide	63(100)	78(70)	15(40)	45(35)	29(16)	61(13)	46(12)	31(11)	48(10)	47(10)
1,4-Dioxane	28(100)	29(37)	88(31)	58(24)	31(17)	15(17)	27(15)	30(13)	43(11)	26(9)
1,3-Dioxolane	73(100)	29(56)	44(53)	45(28)	28(21)	43(20)	27(13)	31(7)	74(5)	42(3)
Dipentene	68(100)	93(50)	67(44)	94(22)	39(22)	107(18)	92(18)	53(18)	136(16)	79(16)
Epichlorohydrin	57(100)	27(39)	29(32)	49(25)	31(22)	62(18)	28(16)	92(1)		

MASS SPECTRAL PEAKS OF COMMON ORGANIC SOLVENTS (continued)

Compound	*e/m* (intensity)								
Ethanolamine (Glycinol)	30(100)	18(30)	28(15)	42(7)	31(6)	17(6)	61(5)	15(5)	43(3)	29(3)
Ethyl acetate	43(100)	29(46)	27(33)	45(32)	61(28)	28(25)	42(18)	73(11)	88(10)	70(10)
Ethyl acetoacetate	43(100)	29(24)	88(18)	28(16)	85(14)	27(12)	42(11)	60(9)	130(6)	45(6)
Ethyl alcohol	31(100)	45(44)	46(18)	27(18)	29(15)	43(14)	30(6)	42(3)	19(3)	14(3)
Ethylamine	30(100)	28(32)	44(20)	45(19)	27(13)	15(10)	42(9)	29(8)	41(5)	40(5)
Ethylbenzene	91(100)	106(31)	51(14)	39(10)	77(8)	65(8)	105(7)	92(7)	78(7)	27(6)
Ethyl bromide (Bromoethane)	108(100)	110(97)	29(62)	27(51)	28(35)	26(14)	93(6)	32(6)	95(5)	81(5)
Ethyl chloride (Cloroethane)	64(100)	28(91)	29(84)	27(75)	66(32)	26(28)	49(25)	51(8)	63(6)	65(4)
Ethylene carbonate	29(100)	44(62)	43(54)	88(40)	30(16)	28(11)	45(7)	58(6)	42(6)	73(4)
Ethylenediamine (1,2-Ethane-diamine)	30(100)	18(13)	42(6)	43(5)	27(5)	44(4)	29(4)	17(4)	15(4)	41(3)
Ethylene glycol	31(100)	33(35)	29(13)	32(11)	43(6)	27(5)	28(4)	62(3)	30(3)	44(2)
Ethylene glycol diethyl ether	31(100)	59(71)	29(58)	45(43)	27(33)	74(27)	43(15)	15(14)	28(12)	44(10)
Ethylene glycol dimethyl ether	45(100)	60(13)	29(13)	90(7)	58(6)	31(5)	28(5)	43(4)	59(3)	46(2)
Ethylene glycol monobutyl ether	57(100)	45(38)	29(35)	41(31)	87(16)	27(12)	56(11)	31(9)	75(7)	28(7)
Ethylene glycol monoethyl ether (Cellosolve)	31(100)	29(52)	59(50)	27(27)	45(26)	72(14)	43(14)	15(14)	28(8)	26(6)
Ethylene glycol monoethyl ether acetate	43(100)	31(34)	59(31)	72(28)	44(25)	29(24)	45(12)	27(11)	15(11)	87(7)
Ethylene glycol monomethyl ether	45(100)	31(15)	29(14)	28(11)	47(9)	76(6)	43(6)	58(4)	46(4)	27(4)
Ethylene glycol monomethyl ether acetate	43(100)	45(48)	58(42)	29(10)	42(4)	31(4)	73(3)	27(3)	59(2)	26(2)
Ethyl formate	31(100)	28(73)	27(51)	29(38)	45(34)	26(17)	74(11)	43(9)	47(8)	56(4)
Furan	68(100)	39(64)	40(9)	38(9)	42(6)	29(6)	37(5)	69(4)	34(2)	67(1)
Furfural	39(100)	96(55)	95(52)	38(38)	29(35)	37(29)	40(11)	97(9)	50(7)	42(7)
Furfuryl alcohol	98(100)	41(65)	39(59)	81(55)	53(53)	97(51)	42(49)	69(39)	70(36)	29(28)
Glycerol	61(100)	43(90)	31(57)	44(54)	29(38)	18(32)	27(12)	42(11)	60(10)	45(10)
Heptane	43(100)	41(56)	29(49)	57(47)	27(46)	71(45)	56(27)	42(26)	39(23)	70(18)
1-Heptanol	41(100)	70(87)	56(86)	31(78)	43(72)	29(70)	55(67)	27(65)	42(54)	69(41)
Hexane	57(100)	43(78)	41(77)	29(61)	27(57)	56(45)	42(39)	39(27)	28(16)	86(14)
1-Hexanol (Caproyl alcohol)	56(100)	43(78)	31(74)	41(71)	27(64)	29(59)	55(58)	42(53)	39(37)	69(27)
Hexylene glycol	59(100)	43(61)	56(25)	45(17)	41(16)	57(13)	42(13)	85(11)	61(10)	31(10)
Hexyl methyl ketone	43(100)	58(79)	41(56)	59(52)	71(49)	27(46)	29(36)	39(27)	57(18)	55(17)
Isobutyl acetate	43(100)	56(26)	73(15)	41(10)	29(5)	71(3)	57(3)	39(3)	27(3)	86(2)
Isobutyl alcohol	43(100)	33(73)	31(72)	41(66)	42(60)	27(43)	29(18)	39(17)	28(8)	74(6)
Isobutylamine	30(100)	28(9)	41(6)	73(5)	27(5)	39(4)	29(3)	15(3)	58(2)	56(2)
Isopentyl acetate	43(100)	70(49)	55(38)	61(15)	42(15)	41(14)	27(12)	87(11)	29(10)	73(9)
Isophorone	82(100)	39(20)	138(17)	54(13)	27(12)	41(10)	53(8)	83(7)	29(7)	55(6)
Isopropyl acetate	43(100)	61(17)	41(14)	87(9)	59(8)	27(8)	42(7)	39(4)	45(3)	44(2)
Isopropyl alcohol	45(100)	43(19)	27(17)	29(12)	41(7)	31(6)	19(6)	42(5)	44(4)	59(3)
Isoquinoline	129(100)	102(26)	51(20)	128(18)	50(11)	130(10)	75(10)	76(9)	103(8)	74(7)
d-Limonene (Citrene)	68(100)	93(50)	67(49)	41(22)	94(21)	79(21)	39(21)	136(20)	53(19)	121(16)
2,6-Lutidine (2,6-Dimethyl-pyridine)	107(100)	39(39)	106(29)	66(22)	92(18)	65(18)	38(12)	27(11)	79(9)	63(9)

MASS SPECTRAL PEAKS OF COMMON ORGANIC SOLVENTS (continued)

Compound	*e*/*m* (intensity)									
Mesitylene (1,3,5-Trimethyl-benzene)	105(100)	120(64)	119(15)	77(13)	39(11)	106(9)	91(9)	51(8)	27(7)	121(6)
Mesityl oxide	55(100)	83(89)	43(73)	29(42)	98(36)	39(32)	27(28)	53(11)	41(10)	56(5)
Methyl acetate	43(100)	74(52)	28(38)	42(19)	59(17)	44(8)	32(8)	29(6)	31(4)	75(2)
Methylal (Dimethoxymethane)	45(100)	75(61)	29(59)	31(13)	30(6)	15(6)	47(5)	76(2)	46(2)	44(2)
Methyl alcohol	31(100)	29(72)	32(67)	15(42)	28(12)	14(10)	30(9)	13(6)	12(3)	16(2)
Methylamine	30(100)	31(87)	28(56)	29(19)	32(15)	15(12)	27(9)			
Methyl benzoate	105(100)	77(81)	51(45)	136(24)	50(18)	106(8)	78(6)	28(6)	39(5)	27(5)
Methylcyclohexane	83(100)	55(82)	41(60)	98(44)	42(35)	56(30)	27(29)	39(27)	69(23)	70(22)
Methyl ethyl ketone	43(100)	72(24)	29(19)	27(12)	57(7)	42(5)	26(4)	28(3)	44(2)	39(2)
N-Methylformamide	59(100)	30(54)	28(34)	29(13)	58(8)	15(7)	60(3)	41(3)	27(3)	31(2)
Methyl formate	31(100)	29(63)	32(34)	60(28)	30(7)	28(7)	44(2)	18(2)	61(1)	59(1)
Methyl iodide (Iodomethane)	142(100)	127(38)	141(14)	15(13)	139(5)	140(4)	128(3)	14(1)	13(1)	71(0)
Methyl isobutyl ketone	43(100)	58(84)	29(65)	41(56)	57(44)	27(42)	39(31)	85(19)	100(14)	42(14)
Methyl isopentyl ketone	43(100)	58(34)	27(14)	41(13)	15(13)	57(11)	39(9)	71(8)	59(8)	29(8)
2-Methylpentane	43(100)	42(53)	41(35)	27(31)	71(29)	39(20)	29(18)	57(11)	15(10)	70(7)
4-Methyl-2-pentanol	45(100)	43(47)	69(30)	41(27)	27(19)	39(13)	29(12)	87(11)	84(10)	57(10)
Methyl pentyl ketone	43(100)	58(60)	71(14)	41(11)	27(11)	59(9)	39(8)	29(8)	42(5)	114(4)
Methyl propyl ketone	43(100)	41(17)	86(12)	42(12)	27(11)	39(8)	71(7)	58(7)	45(7)	44(3)
N-Methyl-2-pyrrolidone	99(100)	44(89)	98(80)	42(60)	41(38)	43(17)	28(17)	71(13)	39(11)	70(10)
Morpholine	57(100)	29(100)	87(69)	28(69)	30(38)	56(33)	86(28)	31(28)	27(12)	15(7)
Nitrobenzene	77(100)	51(59)	123(42)	50(25)	30(15)	65(14)	39(10)	93(9)	74(7)	78(6)
Nitroethane	29(100)	30(12)	28(11)	26(9)	27(8)	43(5)	41(5)	14(5)	15(3)	46(2)
Nitromethane	30(100)	61(64)	46(39)	28(30)	45(8)	27(8)	44(7)	29(7)	60(5)	43(4)
1-Nitropropane	43(100)	27(93)	41(90)	39(34)	30(25)	44(20)	42(20)	26(20)	28(13)	54(12)
2-Nitropropane	43(100)	41(73)	27(71)	39(30)	30(18)	15(11)	42(9)	28(8)	26(8)	38(6)
Octane	43(100)	57(30)	85(25)	41(25)	71(19)	29(17)	56(14)	70(10)	42(10)	27(10)
1-Octanol	41(100)	56(85)	43(82)	55(81)	31(69)	27(69)	29(68)	42(62)	70(53)	69(48)
Pentachloroethane	167(100)	165(91)	117(90)	119(89)	83(58)	169(54)	130(43)	132(42)	60(40)	85(37)
Pentamethylene glycol (1,5-Pentanediol)	31(100)	56(85)	41(67)	57(59)	55(51)	44(45)	29(37)	43(31)	68(29)	27(26)
Pentane	43(100)	42(55)	41(45)	27(42)	29(26)	39(19)	57(13)	28(9)	15(9)	72(8)
1-Pentanol (Amyl alcohol)	42(100)	70(72)	55(65)	41(56)	31(47)	29(41)	27(26)	57(22)	28(22)	43(21)
Pentyl acetate (Amyl acetate)	43(100)	70(90)	42(52)	28(51)	61(50)	55(41)	73(21)	41(20)	29(14)	69(11)
2-Picoline (2-Methylpyridine)	93(100)	66(41)	39(31)	92(20)	78(19)	51(19)	65(16)	38(13)	50(12)	52(11)
α-Pinene	93(100)	92(30)	39(24)	41(23)	77(22)	91(21)	27(21)	79(18)	121(13)	53(10)
β-Pinene	93(100)	41(64)	69(47)	39(33)	27(31)	79(20)	77(18)	53(14)	94(13)	91(13)
Piperidine (Hexahydropyridine)	84(100)	85(53)	56(46)	57(43)	28(41)	29(37)	44(34)	42(30)	30(30)	43(25)
Propanenitrile	28(100)	54(63)	26(20)	27(17)	52(11)	55(10)	51(9)	15(9)	53(7)	25(7)
Propyl acetate	43(100)	61(19)	31(18)	27(15)	42(11)	73(9)	41(9)	29(9)	59(5)	39(5)
Propyl alcohol	31(100)	27(19)	29(18)	59(11)	42(9)	60(7)	41(7)	28(7)	43(3)	32(3)
Propylamine	30(100)	28(13)	59(8)	27(7)	41(5)	42(3)	39(3)	29(3)	26(3)	18(3)
Propylbenzene	91(100)	120(21)	92(10)	38(10)	65(9)	78(6)	51(6)	27(5)	63(4)	105(3)
1,2-Propylene glycol	45(100)	18(46)	29(21)	43(19)	31(18)	27(17)	28(11)	19(8)	44(6)	61(5)

MASS SPECTRAL PEAKS OF COMMON ORGANIC SOLVENTS (continued)

Compound	*e/m* (intensity)									
Pseudocumene (1,2,4-Trimethyl-benzene)	105(100)	120(56)	119(17)	77(15)	39(15)	51(11)	91(10)	27(10)	106(9)	79(7)
Pyridine	79(100)	52(62)	51(31)	50(19)	78(11)	53(7)	39(7)	80(6)	27(3)	77(2)
Pyrrole	67(100)	41(58)	39(58)	40(51)	28(42)	38(20)	37(12)	66(7)	68(5)	27(3)
Pyrrolidine	43(100)	28(52)	70(33)	71(26)	42(22)	41(20)	27(16)	39(15)	29(10)	30(9)
2-Pyrrolidone	85(100)	42(43)	41(36)	28(33)	30(29)	56(16)	84(14)	40(12)	27(12)	29(9)
Quinoline	129(100)	51(28)	76(25)	128(24)	44(24)	50(20)	32(19)	75(18)	74(12)	103(11)
Styrene	104(100)	103(41)	78(32)	51(28)	77(23)	105(12)	50(12)	52(11)	39(11)	102(10)
Sulfolane	41(100)	28(94)	56(82)	55(72)	120(37)	27(32)	39(19)	29(17)	26(11)	48(5)
α-Terpinene	121(100)	93(85)	136(43)	91(40)	77(34)	39(33)	27(33)	79(27)	41(26)	43(18)
1,1,1,2-Tetrachloro-2,2-difluoroethane	167(100)	169(96)	117(85)	119(82)	171(31)	85(29)	121(26)	82(14)	47(14)	101(13)
Tetrachloro-1,2-difluoroethane	101(100)	103(64)	167(54)	169(52)	117(19)	119(18)	171(17)	105(11)	31(11)	132(9)
1,1,1,2-Tetrachloroethane	131(100)	133(96)	117(76)	119(73)	95(34)	135(31)	121(23)	97(23)	61(19)	60(18)
1,1,2,2-Tetrachloroethane	83(100)	85(63)	95(11)	87(10)	168(8)	133(8)	131(8)	96(8)	61(8)	60(8)
Tetrachloroethylene	166(100)	164(82)	131(71)	129(71)	168(45)	94(38)	47(31)	96(24)	133(20)	59(17)
Tetraethylene glycol	45(100)	89(10)	44(8)	43(6)	31(6)	29(6)	27(6)	101(5)	75(5)	28(5)
Tetrahydrofuran	42(100)	41(52)	27(33)	72(29)	71(27)	39(24)	43(22)	29(22)	40(13)	15(10)
1,2,3,4-Tetrahydronaphthalene	104(100)	132(53)	91(43)	51(17)	39(17)	131(15)	117(15)	115(14)	78(13)	77(13)
Tetrahydropyran	41(100)	28(64)	56(57)	45(57)	29(51)	27(49)	85(47)	86(42)	39(28)	55(23)
Tetramethylsilane	73(100)	43(14)	45(12)	74(8)	29(7)	15(5)	75(4)	44(4)	42(4)	31(4)
Toluene	91(100)	92(73)	39(20)	65(14)	63(11)	51(11)	50(7)	27(6)	93(5)	90(5)
o-Toluidine	106(100)	107(83)	77(17)	79(13)	39(12)	53(10)	52(10)	54(9)	51(9)	28(9)
Triacetin	43(100)	103(44)	145(34)	116(17)	115(13)	44(10)	86(9)	28(8)	73(7)	42(7)
Tributylamine	142(100)	100(19)	143(11)	29(8)	185(7)	57(6)	44(6)	41(6)	30(5)	86(4)
1,1,1-Trichloroethane	97(100)	99(64)	61(58)	26(31)	27(24)	117(19)	63(19)	119(18)	35(17)	62(11)
1,1,2-Trichloroethane	97(100)	83(95)	99(62)	85(60)	61(58)	26(23)	96(21)	63(19)	27(17)	98(15)
Trichloroethylene	95(100)	130(90)	132(85)	60(65)	97(64)	35(40)	134(27)	47(26)	62(21)	59(13)
Trichlorofluoromethane	101(100)	103(66)	66(13)	105(11)	35(11)	47(9)	31(8)	82(4)	68(4)	37(4)
1,1,2-Trichlorotrifluoroethane	101(100)	151(68)	103(64)	85(45)	31(45)	153(44)	35(20)	66(19)	47(18)	87(14)
Triethanolamine	118(100)	56(69)	45(60)	42(56)	44(27)	43(25)	41(14)	116(8)	57(8)	86(7)
Triethylamine	86(100)	30(68)	58(37)	28(24)	29(23)	27(19)	44(18)	101(17)	42(16)	56(8)
Triethylene glycol	45(100)	58(11)	89(9)	31(8)	29(8)	75(7)	44(7)	43(7)	27(7)	28(5)
Triethyl phosphate	99(100)	81(71)	155(56)	82(45)	45(45)	109(44)	127(41)	43(24)	125(16)	111(14)
Trimethylamine	58(100)	59(47)	30(29)	42(26)	44(17)	15(14)	28(10)	18(10)	43(8)	57(7)
Trimethylene glycol (1,3-Propanediol)	28(100)	58(93)	31(76)	57(70)	29(40)	27(26)	45(24)	43(23)	19(18)	30(17)
Trimethyl phosphate	110(100)	109(35)	79(34)	95(25)	80(23)	15(20)	140(18)	47(10)	31(7)	139(5)
Veratrole	138(100)	95(65)	77(48)	123(44)	52(42)	41(33)	65(30)	51(29)	39(19)	63(17)
o-Xylene	91(100)	106(40)	39(21)	105(17)	51(17)	77(15)	27(12)	65(10)	92(8)	79(8)
m-Xylene	91(100)	106(65)	105(29)	39(18)	51(15)	77(14)	27(10)	92(8)	79(8)	78(8)
p-Xylene	91(100)	106(62)	105(30)	51(16)	39(16)	77(13)	27(11)	92(7)	78(7)	65(7)

SOLUBILITY OF COMMON SALTS AT AMBIENT TEMPERATURES

This table gives the aqueous solubility of selected salts at temperatures from 10°C to 40°C. Values are given in molality terms.

REFERENCES

1. Apelblat, A., *J. Chem. Thermodynamics*, 24, 619, 1992.
2. Apelblat, A., *J. Chem. Thermodynamics*, 25, 63, 1993.
3. Apelblat, A., *J. Chem. Thermodynamics*, 25, 1513, 1993.
4. Apelblat, A. and Korin, E., *J. Chem. Thermodynamics*, 30, 59, 1998.

Salt	10°C	15°C	20°C	25°C	30°C	35°C	40°C	Ref.
$BaCl_2$	1.603	1.659	1.716	1.774	1.834	1.895	1.958	1
$Ca(NO_3)_2$	6.896	7.398	7.986	8.675	9.480	10.421		1
$CuSO_4$	1.055	1.153	1.260	1.376	1.502	1.639		3
$FeSO_4$	1.352	1.533	1.729	1.940	2.165	2.405		3
KBr	5.002	5.237	5.471	5.703	5.932	6.157		3
KIO_3	0.291	0.333	0.378	0.426	0.478	0.534	0.593	4
K_2CO_3	7.756	7.846	7.948	8.063	8.191	8.331	8.483	1
LiCl	19.296	19.456	19.670	19.935				2
$Mg(NO_3)_2$	4.403	4.523	4.656	4.800	4.958	5.130	5.314	1
$MnCl_2$	5.421	5.644	5.884	6.143	6.422	6.721		3
NH_4Cl	6.199	6.566	6.943	7.331				2
NH_4NO_3	18.809	21.163	23.721	26.496				2
$(NH_4)_2SO_4$	5.494	5.589	5.688	5.790	5.896	6.005		3
NaBr	8.258	8.546	8.856	9.191	9.550	9.937	10.351	4
NaCl	6.110	6.121	6.136	6.153	6.174	6.197	6.222	4
$NaNO_2$	11.111	11.484	11.883	12.310	12.766	13.253	13.772	4
$NaNO_3$	9.395	9.819	10.261	10.723	11.204	11.706	12.230	4
RbCl	6.911	7.180	7.449	7.717	7.986	8.253	8.520	4
$ZnSO_4$	2.911	3.116	3.336	3.573	3.827	4.099	4.194	1

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BOND LENGTHS IN CRYSTALLINE ORGANIC COMPOUNDS

The following table gives average interatomic distances for bonds between the elements H, B, C, N, O, F, Si, P, S, Cl, As, Se, Br, Te, and I as determined from X-ray and neutron diffraction measurements on organic crystals. The table has been derived from an analysis of high-precision structure data on about 10,000 crystals contained in the 1985 version of the Cambridge Structural Database, which is maintained by the Cambridge Crystallographic Data Center. The explanation of the columns is:

Column 1: Specification of elements in the bond, with coordination number given in parentheses, and bond type (single, double, etc.). For carbon, the hybridization state is given.
Column 2: Substructure in which the bond is found. The target bond is set in boldface. Where X is not specified, it denotes any element type. C# indicates any sp^3 carbon atom, and C* denotes an sp^3 carbon whose bonds, in addition to those specified in the linear formulation, are to C and H atoms only.
Column 3: *d* is the unweighted mean in Å units of all the values for that bond length found in the sample.
Column 4: *m* is the median in Å units of all values.
Column 5: σ is the standard deviation in the sample.
Column 6: q_l is the lower quartile for the sample (i.e., 25% of values are less than q_l and 75% exceed it).
Column 7: q_u is the upper quartile for the sample.
Column 8: *n* is number of observations in the sample.
Column 9: Notes refer to the footnotes in Appendix 1.

References to special cases are given in a shorthand form and listed in Appendix 2. Further information on the method of analysis of the data may be found in the reference cited below.

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REFERENCE

Frank H. Allen, Olga Kennard, David G. Watson, Lee Brammer, A. Guy Orpen, and Robin Taylor, *J. Chem. Soc. Perkin Trans. II*, S1—S19, 1987.

Bond	Substructure	*d*	*m*	σ	q_l	q_u	*n*	Note
As(3)–As(3)	X_2–**As–As**–X_2	2.459	2.457	0.011	2.456	2.466	8	
As–B	see CUDLOC (2.065), CUDLUI (2.041)							
As–Br	see CODDEE, CODDII (2.346—3.203)							
As(4)–C	X_3–**As–C**H_3	1.903	1.907	0.016	1.893	1.916	12	
	$(X)_2$(C,O,S=)**As–C***sp*^{3}	1.927	1.929	0.017	1.921	1.937	16	
	As–C*ar* in Ph_4As^+	1.905	1.909	0.012	1.897	1.912	108	
	$(X)_2$(C,O,S=)**As–C***ar*	1.922	1.927	0.016	1.908	1.934	36	
As(3)–C	X_2–**As–C***sp*^{3}	1.963	1.965	0.017	1.948	1.978	6	
	X_2–**As–C***ar*	1.956	1.956	0.015	1.944	1.964	41	
As(3)–Cl	X_2–**As–Cl**	2.268	2.256	0.039	2.247	2.281	10	
As(6)–F	in AsF_6^-	1.678	1.676	0.020	1.659	1.695	36	
As(3)–I	see OPIMAS (2.579, 2.590)							
As(3)–N(3)	X_2–**As–N**–X_2	1.858	1.858	0.029	1.839	1.873	19	
As(4)=N(2)	see TPASSN (1.837)							
As(4)–O	$(X)_2$(O=)**As–O**H	1.710	1.712	0.017	1.695	1.726	6	
As(3)–O	see ASAZOC, PHASOC01 (1.787—1.845)							
As(4)=O	X_3–**As=O**	1.661	1.661	0.016	1.652	1.667	9	
As(3)=P(3)	see BELNIP (2.350, 2.362)							†
As(3)–P(3)	see BUTHAZ10 (2.124)							†
As(3)–S	X_2–**As–S**	2.275	2.266	0.032	2.247	2.298	14	
As(4)=S	X_3–**As=S**	2.083	2.082	0.004	2.080	2.086	9	
As(3)–Se(2)	see COSDIX, ESEARS (2.355—2.401)							†
As(3)–Si(4)	see BICGEZ, MESIAD (2.351—2.365)							†
As(3)–Te(2)	see ETEARS (2.571, 2.576)							†
B(n)–B(n)	*n* = 5—7 in boron cages	1.775	1.773	0.031	1.763	1.786	688	
B(4)–B(4)	see CETTAW (2.041)							
B(4)–B(3)	see COFVOI (1.698)							
B(3)–B(3)	X_2–**B–B**–X_2	1.701	1.700	0.014	1.691	1.712	8	
B(6)–Br		1.967	1.971	0.014	1.954	1.979	7	†
B(4)–Br		2.017	2.008	0.031	1.990	2.044	15	†
B(*n*)–C	*n* = 5—7: **B–C** in cages	1.716	1.717	0.020	1.707	1.728	96	
	n = 3—4: **B–C***sp*^{3} not cages	1.597	1.599	0.022	1.585	1.611	29	1
	n = 4: **B–C***ar*	1.606	1.607	0.012	1.596	1.615	41	
	n = 4: **B–C***ar* in Ph_4B^-	1.643	1.643	0.006	1.641	1.645	16	
B(*n*)–C	*n* = 3: **B–C***ar*	1.556	1.552	0.015	1.546	1.566	24	
B(*n*)–Cl	**B**(5)–**Cl** and **B**(3)–**Cl**	1.751	1.751	0.011	1.743	1.761	14	
	B(4)–**Cl**	1.833	1.833	0.013	1.821	1.843	22	
B(4)–F	**B–F** (B neutral)	1.366	1.368	0.017	1.356	1.375	25	
	B^-–**F** in BF_4^-	1.365	1.372	0.029	1.352	1.390	84	
B(4)–I	see TMPBTI (2.220, 2.253)							
B(4)–N(3)	X_3–**B–N**(=C)(X)	1.611	1.617	0.013	1.601	1.625	8	
	in pyrazaboles	1.549	1.552	0.015	1.536	1.560	10	

Bond	Substructure	d	m	σ	q_1	q_u	n	Note
B(3)–N(3)	X_2–**B**–N–C_2: all coplanar	1.404	1.404	0.014	1.389	1.408	40	2
	for τ(BN) > 30° see BOGSUL, BUSHAY, CILRUK (1.434—1.530)							
	S_2–**B**–N–X_2	1.447	1.443	0.013	1.435	1.470	14	
B(4)–O	B^-–**O** in BO_4	1.468	1.468	0.022	1.453	1.479	24	
	for neutral B–O see Note 3							3
B(3)–O(2)	X_2–**B**–**O**–X	1.367	1.367	0.024	1.349	1.382	35	
B(n)–P	n = 4: **B**–**P**	1.922	1.927	0.027	1.900	1.954	10	
	n = 3: see BUPSIB10 (1.892, 1.893)							
B(4)–S	**B**(4)–**S**(3)	1.930	1.927	0.009	1.925	1.934	10	
	B(4)–**S**(2)	1.896	1.896	0.004	1.893	1.899	6	
B(3)–S	N–**B**–**S**$_2$	1.806	1.806	0.010	1.799	1.816	28	
	(=X–)(N–)**B**–**S**	1.851	1.854	0.013	1.842	1.859	10	
Br–Br	see BEPZEB, TPASTB	2.542	2.548	0.015	2.526	2.551	4	
Br–C	**Br**–**C***	1.966	1.967	0.029	1.951	1.983	100	4
	Br–**C**sp^3 (cyclopropane)	1.910	1.910	0.010	1.900	1.914	8	
	Br–**C**sp^2	1.883	1.881	0.015	1.874	1.894	31	4
	Br–**C**ar (mono-Br + m,p-Br_2)	1.899	1.899	0.012	1.892	1.906	119	4
	Br–**C**ar (o-Br_2)	1.875	1.872	0.011	1.864	1.884	8	4
$^-$Br(2)–Cl	see TEACBR (2.362—2.402)							†
Br–I	see DTHIBR10 (2.646), TPHOSI (2.695)							
Br–N	see NBBZAM (1.843)							
Br–O	see CIYFOF	1.581	1.581	0.007	1.574	1.587	4	
Br–P	see CISTED (2.366)							
Br–S(2)	see BEMLIO (2.206)							†
Br–S(3)	see CIWYIQ (2.435, 2.453)							†
Br–S(3)$^+$	see THINBR (2.321)							†
Br–Se	see CIFZUM (2.508, 2.619)							
Br–Si	see BIZJAV (2.284)							
Br–Te	In Br_6Te^{2-} see CUGBAH (2.692—2.716)							
	Br–**Te**(4) see BETUTE10 (3.079, 3.015)							
	Br–**Te**(3) see BTUPTE (2.835)							
Csp^3–Csp^3	C#–**C**H_2–**C**H_3	1.513	1.514	0.014	1.507	1.523	192	
	(C#)$_2$–**C**H–**C**H_3	1.524	1.526	0.015	1.518	1.534	226	
	(C#)$_3$–**C**–**C**H_3	1.534	1.534	0.011	1.527	1.541	825	
	C#–**C**H_2–**C**H_2–C#	1.524	1.524	0.014	1.516	1.532	2 459	
	(C#)$_2$–**C**H–**C**H_2–C#	1.531	1.531	0.012	1.524	1.538	1 217	
	(C#)$_3$–**C**–**C**H_2–C#	1.538	1.539	0.010	1.533	1.544	330	
	(C#)$_2$–**C**H–**C**H–(C#)$_2$	1.542	1.542	0.011	1.536	1.549	321	
	(C#)$_3$–**C**–**C**H–(C#)$_2$	1.556	1.556	0.011	1.549	1.562	215	
	(C#)$_3$–**C**–**C**–(C#)$_3$	1.588	1.580	0.025	1.566	1.610	21	
	C*–**C*** (overall)	1.530	1.530	0.015	1.521	1.539	5 777	5,6
	in cyclopropane (any subst.)	1.510	1.509	0.026	1.497	1.523	888	7
	in cyclobutane (any subst.)	1.554	1.553	0.021	1.540	1.567	679	8
	in cyclopentane (C,H-subst.)	1.543	1.543	0.018	1.532	1.554	1 641	
	in cyclohexane (C,H-subst.)	1.535	1.535	0.016	1.525	1.545	2 814	
	cyclopropyl-C* (exocyclic)	1.518	1.518	0.019	1.505	1.531	366	7
	cyclobutyl-C* (exocyclic)	1.529	1.529	0.016	1.519	1.539	376	8
	cyclopentyl-C* (exocyclic)	1.540	1.541	0.017	1.527	1.549	956	
	cyclohexyl-C* (exocyclic)	1.539	1.538	0.016	1.529	1.549	2 682	
	in cyclobutene (any subst.)	1.573	1.574	0.017	1.566	1.586	25	8
	in cyclopentene (C,H-subst.)	1.541	1.539	0.015	1.532	1.549	208	
	in cyclohexene (C,H-subst.)	1.541	1.541	0.020	1.528	1.554	586	
	in oxirane (epoxide)	1.466	1.466	0.015	1.458	1.474	249	9
	in aziridine	1.480	1.481	0.021	1.465	1.496	67	9
	in oxetane	1.541	1.541	0.019	1.527	1.557	16	
	in azetidine	1.548	1.543	0.018	1.536	1.558	22	
	oxiranyl-C* (exocyclic)	1.509	1.507	0.018	1.497	1.519	333	9
	aziridinyl-C* (exocyclic)	1.512	1.512	0.018	1.496	1.526	13	9
Csp^3–Csp^2	**C**H_3–**C**=C	1.503	1.504	0.011	1.497	1.509	215	
	C#–**C**H_2–**C**=C	1.502	1.502	0.013	1.494	1.510	483	
	(C#)$_2$–**C**H–**C**=C	1.510	1.510	0.014	1.501	1.518	564	
	(C#)$_3$–**C**–**C**=C	1.522	1.522	0.016	1.511	1.533	193	
Csp^3–Csp^2	**C***–**C**=C (overall)	1.507	1.507	0.015	1.499	1.517	1 456	5
	C*–**C**=C (endocyclic)							
	in cyclopropene	1.509	1.508	0.016	1.500	1.516	20	10
	in cyclobutene	1.513	1.512	0.018	1.500	1.525	50	8
	in cyclopentene	1.512	1.512	0.014	1.502	1.521	208	
	in cyclohexene	1.506	1.505	0.016	1.495	1.516	391	
	in cyclopentadiene	1.502	1.503	0.019	1.490	1.515	18	
	in cyclohexa-1,3-diene	1.504	1.504	0.017	1.491	1.517	56	
	C*–**C**=C (exocyclic):							
	cyclopropenyl-C*	1.478	1.475	0.012	1.470	1.485	7	10
	cyclobutenyl-C*	1.489	1.483	0.015	1.479	1.496	11	8

Bond	Substructure	*d*	*m*	σ	q_1	q_u	*n*	Note
	cyclopentenyl-C*	1.504	1.506	0.012	1.495	1.512	115	
	cyclohexenyl-C*	1.511	1.511	0.013	1.502	1.519	292	
	C*–CH=O in aldehydes	1.510	1.510	0.008	1.501	1.518	7	
	$(C^*)_2$–C=O							
	in ketones	1.511	1.511	0.015	1.501	1.521	952	11
	in cyclobutanone	1.529	1.530	0.016	1.514	1.545	18	
	in cyclopentanone	1.514	1.514	0.016	1.505	1.523	312	
	acyclic and 6+ rings	1.509	1.509	0.016	1.499	1.519	626	
	C*–COOH in carboxylic acids	1.502	1.502	0.014	1.495	1.510	176	
	C*–COO^- in carboxylate anions	1.520	1.521	0.011	1.516	1.528	57	
	C*–C(=O)(–OC*)							
	in acyclic esters	1.497	1.496	0.018	1.484	1.509	553	12
	in β-lactones	1.519	1.519	0.020	1.500	1.538	4	13
	in γ-lactones	1.512	1.512	0.015	1.501	1.521	110	12
	in δ-lactones	1.504	1.502	0.013	1.495	1.517	27	12
	cyclopropyl (C)–C=O in ketones, acids and esters	1.486	1.485	0.018	1.474	1.497	105	7
	C*–C(=O)(–NH_2) in acyclic amides	1.514	1.512	0.016	1.506	1.526	32	14
	C*–C(=O)(–NHC*) in acyclic amides	1.506	1.505	0.012	1.498	1.515	78	14
	C*–C(=O)[–N$(C^*)_2$] in acyclic amides	1.505	1.505	0.011	1.496	1.517	15	14
Csp^3–Car	CH_3–Car	1.506	1.507	0.011	1.501	1.513	454	
	C#–CH_2–Car	1.510	1.510	0.009	1.505	1.516	674	
	$(C\#)_2$–CH–Car	1.515	1.515	0.011	1.508	1.522	363	
	$(C\#)_3$–C–Car	1.527	1.530	0.016	1.517	1.539	308	
	C*–Car (overall)	1.513	1.513	0.014	1.505	1.521	1 813	
	cyclopropyl (C)–Car	1.490	1.490	0.015	1.479	1.503	90	7
Csp^3–Csp^1	C*–C≡C	1.466	1.465	0.010	1.460	1.469	21	15
	C#–C≡C	1.472	1.472	0.012	1.464	1.481	88	15
	C*–C≡N	1.470	1.469	0.013	1.463	1.479	106	7b
	cyclopropyl (C)–C≡N	1.444	1.447	0.010	1.436	1.451	38	7
Csp^2–Csp^2	C=C–C=C							
	(conjugated)	1.455	1.455	0.011	1.447	1.463	30	16,18
	(unconjugated)	1.478	1.476	0.012	1.470	1.479	8	17,18
	(overall)	1.460	1.460	0.015	1.450	1.470	38	
	C=C–C=C–C=C	1.443	1.445	0.013	1.431	1.454	29	18
	C=C–C=C (endocyclic in TCNQ)	1.432	1.433	0.012	1.424	1.441	280	19
	C=C–C(=O)(–C*)							
	(conjugated)	1.464	1.462	0.018	1.453	1.476	211	16,18
	(unconjugated)	1.484	1.486	0.017	1.475	1.497	14	17,18
	(overall)	1.465	1.462	0.018	1.453	1.478	226	
	C=C–C(=O)–C=C							
	in benzoquinone (C,H-subst. only)	1.478	1.476	0.011	1.469	1.488	28	
	in benzoquinone (any subst.)	1.478	1.478	0.031	1.464	1.498	172	
	non-quinonoid	1.456	1.455	0.012	1.447	1.464	28	
	C=C–COOH	1.475	1.476	0.015	1.461	1.488	22	
	C=C–COOC*	1.488	1.489	0.014	1.478	1.497	113	
	C=C–COO^-	1.502	1.499	0.017	1.488	1.510	11	
	HOOC–COOH	1.538	1.537	0.007	1.535	1.541	9	
	HOOC–COO^-	1.549	1.552	0.009	1.546	1.553	13	
	^-OOC–COO^-	1.564	1.559	0.022	1.554	1.568	9	
	formal Csp^2–Csp^2 single bond in selected non-fused heterocycles:							
	in 1*H*-pyrrole (C3–C4)	1.412	1.410	0.016	1.401	1.427	29	
	in furan (C3–C4)	1.423	1.423	0.016	1.412	1.433	62	
	in thiophene (C3–C4)	1.424	1.425	0.015	1.415	1.433	40	
	in pyrazole (C3–C4)	1.410	1.412	0.016	1.400	1.418	20	
	in isoxazole (C3–C4)	1.425	1.425	0.016	1.413	1.438	9	
	in furazan (C3–C4)	1.428	1.427	0.007	1.422	1.435	6	
	in furoxan (C3–C4)	1.417	1.417	0.006	1.412	1.422	14	
Csp^2–Car	C=C–Car							
	(conjugated)	1.470	1.470	0.015	1.463	1.480	37	16,18
Csp^2–Car		1.488	1.490	0.012	1.480	1.496	87	17,18
	(overall)	1.483	1.483	0.015	1.472	1.494	124	
	cyclopropenyl (C=C)–Car	1.447	1.448	0.006	1.441	1.452	8	10
	Car–C(=O)–C*	1.488	1.489	0.016	1.478	1.500	84	
	Car–C(=O)–Car	1.480	1.481	0.017	1.468	1.494	58	
	Car–COOH	1.484	1.485	0.014	1.474	1.491	75	
	Car–C(=O)(–OC*)	1.487	1.487	0.012	1.480	1.494	218	
	Car–COO^-	1.504	1.509	0.014	1.495	1.512	26	
	Car–C(=O)–NH_2	1.500	1.503	0.020	1.498	1.510	19	
	Car–C=N–C#							
	(conjugated)	1.476	1.478	0.014	1.466	1.486	27	16
	(unconjugated)	1.491	1.490	0.008	1.485	1.496	48	17
	(overall)	1.485	1.487	0.013	1.481	1.493	75	

Bond	Substructure	*d*	*m*	σ	q_1	q_u	*n*	Note
	in indole (C3–C3a)	1.434	1.434	0.011	1.428	1.439	40	
Csp^2–Csp^1	C=C–C≡C	1.431	1.427	0.014	1.425	1.441	11	7b
	C=C–C≡N in TCNQ	1.427	1.427	0.010	1.420	1.433	280	19
Car–Car	in biphenyls (*ortho* subst. all H)	1.487	1.488	0.007	1.484	1.493	30	
	(≥1 non-H *ortho*-subst.)	1.490	1.491	0.010	1.486	1.495	212	
Car–Csp^1	*Car*–C≡C	1.434	1.436	0.006	1.430	1.437	37	
	Car–C≡N	1.443	1.444	0.008	1.436	1.448	31	
Csp^1–Csp^1	C≡C–C≡C	1.377	1.378	0.012	1.374	1.384	21	
Csp^2=Csp^2	C*–CH=CH$_2$	1.299	1.300	0.027	1.280	1.311	42	
	(C*)$_2$–C=CH$_2$	1.321	1.321	0.013	1.313	1.328	77	
	C*–CH=CH–C*							
	(*cis*)	1.317	1.318	0.013	1.310	1.323	106	
	(*trans*)	1.312	1.311	0.011	1.304	1.320	19	
	(overall)	1.316	1.317	0.015	1.309	1.323	127	
	(C*)$_2$–C=CH–C*	1.326	1.328	0.011	1.319	1.334	168	
	(C*)$_2$–C=C–(C*)$_2$	1.331	1.330	0.009	1.326	1.334	89	
	(C*,H)$_2$–C=C–(C*,H)$_2$ (overall)	1.322	1.323	0.014	1.315	1.331	493	5
	in cyclopropene (any subst.)	1.294	1.288	0.017	1.284	1.302	10	10
	in cyclobutene (any subst.)	1.335	1.335	0.019	1.324	1.347	25	8
	in cyclopentene (C,H-subst.)	1.323	1.324	0.013	1.314	1.331	104	
	in cyclohexene (C,H-subst.)	1.326	1.325	0.012	1.318	1.334	196	
	C=C=C (allenes, any subst.)	1.307	1.307	0.005	1.303	1.310	18	
	C=C–C=C (C,H subst., conjugated)	1.330	1.330	0.014	1.322	1.338	76	16
	C=C–C=C–C=C (C,H subst., conjugated)	1.345	1.345	0.012	1.337	1.350	58	16
	C=C-*Car* (C,H subst., conjugated)	1.339	1.340	0.011	1.334	1.346	124	16
	C=C in cyclopenta-1,3-diene (any subst.)	1.341	1.341	0.017	1.328	1.356	18	
	C=C in cyclohexa-1,3-diene (any subst.)	1.332	1.332	0.013	1.323	1.341	56	
	in C=C–C=O							
	(C,H subst., conjugated)	1.340	1.340	0.013	1.332	1.348	211	16,18
	(C,H subst., unconjugated)	1.331	1.330	0.008	1.326	1.339	14	17,18
	(C,H subst., overall)	1.340	1.339	0.013	1.332	1.348	226	
	in cyclohexa-2,5-dien-1-ones	1.329	1.327	0.011	1.321	1.335	28	
	in *p*-benzoquinones							
	(C*;H subst.)	1.333	1.337	0.011	1.325	1.338	14	
	(any subst.)	1.349	1.339	0.030	1.330	1.364	86	
	in TCNQ							
	(endocyclic)	1.352	1.353	0.010	1.345	1.358	142	19
	(exocyclic)	1.392	1.391	0.017	1.379	1.405	139	19
	C=C–OH in enol tautomers	1.362	1.360	0.020	1.349	1.370	54	
	in heterocycles (any subst.):							
	1*H*-pyrrole (C2–C3, C4–C5)	1.375	1.377	0.018	1.361	1.388	58	
	furan (C2–C3, C4–C5)	1.341	1.342	0.021	1.329	1.351	125	
	thiophene (C2–C3, C4–C5)	1.362	1.359	0.025	1.346	1.377	60	
	pyrazole (C4–C5)	1.369	1.372	0.019	1.362	1.383	20	
	imidazole (C4–C5)	1.360	1.361	0.014	1.352	1.367	44	
	isoxazole (C4–C5)	1.341	1.336	0.012	1.331	1.355	9	
	indole (C2–C3)	1.364	1.363	0.012	1.355	1.371	40	
Car≃*Car*	in phenyl rings with C*,H subst. only							
	H–C≃C–H	1.380	1.381	0.013	1.372	1.388	2 191	
	C*–C≃C–H	1.387	1.388	0.010	1.382	1.393	891	
	C*–C≃C–C*	1.397	1.397	0.009	1.392	1.403	182	
	C≃C (overall)	1.384	1.384	0.013	1.375	1.391	3 264	
	F–C≃C–F	1.372	1.374	0.011	1.366	1.380	84	4
	Cl–C≃C–Cl	1.388	1.389	0.014	1.380	1.398	152	4
	in naphthalene (D_{2h}, any subst.)							
	C1–C2	1.364	1.364	0.014	1.356	1.373	440	
	C2–C3	1.406	1.406	0.014	1.397	1.415	218	
	C1–C8a	1.420	1.419	0.012	1.412	1.426	440	
	C4a–C8a	1.422	1.424	0.011	1.417	1.429	109	
Car≃*Car*	in anthracene (D_{2h}, any subst.)							
	C1–C2	1.356	1.356	0.009	1.350	1.360	56	
	C2–C3	1.410	1.410	0.010	1.401	1.416	34	
	C1–C9a	1.430	1.430	0.006	1.426	1.434	56	
	C4a–C9a	1.435	1.436	0.007	1.429	1.440	34	
	C9–C9a	1.400	1.402	0.009	1.395	1.406	68	
	in pyridine (C,H subst.)	1.379	1.381	0.012	1.371	1.387	276	20
	(any subst.)	1.380	1.380	0.015	1.371	1.389	537	20
	in pyridinium cation							
	(N$^+$–H; C,H subst. on C)							
	C2–C3	1.373	1.375	0.012	1.368	1.380	30	
	C3–C4	1.379	1.380	0.011	1.371	1.388	30	
	(N$^+$–X; C,H subst. on C)							
	C2–C3	1.373	1.372	0.019	1.362	1.382	151	
	C3–C4	1.383	1.385	0.019	1.372	1.394	151	

BOND LENGTHS IN CRYSTALLINE ORGANIC COMPOUNDS (continued)

Bond	Substructure	*d*	*m*	σ	q_1	q_u	*n*	Note
	in pyrazine (H subst. on C)	1.379	1.377	0.010	1.370	1.388	10	
	(any subst. on C)	1.405	1.405	0.024	1.388	1.420	60	
	in pyrimidine (C,H subst. on C)	1.387	1.389	0.018	1.379	1.400	28	
$Csp^1{\equiv}Csp^1$	X–C≡C–X	1.183	1.183	0.014	1.174	1.193	119	15
	C,H–C≡C–C,H	1.181	1.181	0.014	1.173	1.192	104	15
	in C≡C–C(sp^2,*ar*)	1.189	1.193	0.010	1.181	1.195	38	15
	in C≡C–C≡C	1.192	1.192	0.010	1.187	1.197	42	15
	in CH≡C–C#	1.174	1.174	0.011	1.167	1.180	42	15
Csp^3–Cl	Omitting 1,2-dichlorides:							
	C–CH_2–Cl	1.790	1.790	0.007	1.783	1.795	13	4
	C_2–CH–Cl	1.803	1.802	0.003	1.800	1.807	8	4
	C_3–C–Cl	1.849	1.856	0.011	1.837	1.858	5	4
	X–CH_2–Cl (X = C,H,N,O)	1.790	1.791	0.011	1.783	1.797	37	4
	X_2–CH–Cl (X = C,H,N,O)	1.805	1.803	0.014	1.800	1.812	26	4
	X_3–C–Cl (X = C,H,N,O)	1.843	1.838	0.014	1.835	1.858	7	4
	X_2–C–Cl_2 (X = C,H,N,O)	1.779	1.776	0.015	1.769	1.790	18	4
	X–C–Cl_3 (X = C,H,N,O)	1.768	1.765	0.011	1.761	1.776	33	4
	Cl–CH(–C)–CH(–C)–Cl	1.793	1.793	0.013	1.786	1.800	66	4
	Cl–C(–C_2)–C(–C_2)–Cl	1.762	1.760	0.010	1.757	1.765	54	4
	cyclopropyl–Cl	1.755	1.756	0.011	1.749	1.763	64	
Csp^2–Cl	C=C–Cl (C,H,N,O subst. on C)	1.734	1.729	0.019	1.719	1.748	63	4
	C=C–Cl_2 (C,H,N,O subst. on C)	1.720	1.716	0.013	1.708	1.729	20	4
	Cl–C=C–Cl	1.713	1.711	0.011	1.705	1.720	80	4
Car–Cl	*Car*–Cl (mono-Cl + *m,p*-Cl_2)	1.739	1.741	0.010	1.734	1.745	340	4
	Car–Cl (*o*-Cl_2)	1.720	1.720	0.010	1.713	1.717	364	4
Csp^1–Cl	see HCLENE10 (1.634, 1.646)							
Csp^3–F	Omitting 1,2-difluorides							
	C-CH_2–F and C_2-CH–F	1.399	1.399	0.017	1.389	1.408	25	4
	C_3–C–F	1.428	1.431	0.009	1.421	1.435	11	4
	$(C^*,H)_2$-C–F_2	1.349	1.347	0.012	1.342	1.356	58	4
	C*–C–F_3	1.336	1.334	0.007	1.330	1.344	12	4
	F–C*–C*–F	1.371	1.374	0.007	1.362	1.375	26	4
	X_3–C–F (X = C,H,N,O)	1.386	1.389	0.033	1.373	1.408	70	4
	X_2–C–F_2 (X = C,H,N,O)	1.351	1.349	0.013	1.342	1.356	58	4
	X–C–F_3 (X = C,H,N,O)	1.322	1.323	0.015	1.314	1.332	309	4
	F–C$(-X)_2$–C$(-X)_2$–F (X = C,H,N,O)	1.373	1.374	0.009	1.362	1.377	30	4
	F–C$(-X)_2$–NO_2 (X = any subst.)	1.320	1.319	0.009	1.312	1.327	18	
Csp^2–F	C=C–F (C,H,N,O subst. on C)	1.340	1.340	0.013	1.334	1.346	34	4
Car–F	*Car*–F (mono-F + *m,p*-F_2)	1.363	1.362	0.008	1.357	1.368	38	4
	Car–F (*o*-F_2)	1.340	1.340	0.009	1.336	1.344	167	4
Csp^3–H	C–C–H_3 (methyl)	1.059	1.061	0.030	1.039	1.083	83	21
	C_2–C–H_2 (primary)	1.092	1.095	0.013	1.088	1.099	100	21
	C_3–C–H (secondary)	1.099	1.097	0.004	1.095	1.103	14	21
	$C_{2,3}$–C–H (primary and secondary)	1.093	1.095	0.012	1.089	1.100	118	21
	X–C–H_3 (methyl)	1.066	1.074	0.028	1.049	1.087	160	21
	X_2–C–H_2 (primary)	1.092	1.095	0.012	1.088	1.099	230	21
	X_3–C–H (secondary)	1.099	1.099	0.007	1.095	1.103	117	21
	$X_{2,3}$–C–H (primary and secondary)	1.094	1.096	0.011	1.091	1.100	348	21
Csp^2–H	C–C=C–H	1.077	1.079	0.012	1.074	1.085	14	21
Car–H	*Car*–H	1.083	1.083	0.011	1.080	1.087	218	21
Csp^3–I	C*–I	2.162	2.159	0.015	2.149	2.179	15	4
Car–I	*Car*–I	2.095	2.095	0.015	2.089	2.104	51	4
Csp^3–N(4)	C*–NH_3^+	1.488	1.488	0.013	1.482	1.495	298	
	$(C^*)_2$–NH_2^+	1.494	1.493	0.016	1.484	1.503	249	
	$(C^*)_3$–NH^+	1.502	1.502	0.015	1.491	1.512	509	
	$(C^*)_4$–N^+	1.510	1.509	0.020	1.496	1.523	319	
	C*–N^+ (overall)	1.499	1.498	0.018	1.488	1.510	1 370	
Csp^3–N(3)	C*–N^+ in N-subst. pyridinium	1.485	1.484	0.009	1.477	1.490	32	
	C*–NH_2 (Nsp^3: pyramidal)	1.469	1.470	0.010	1.462	1.474	19	22
	$(C^*)_2$–NH (Nsp^3: pyramidal)	1.469	1.467	0.012	1.461	1.477	152	5,22
	$(C^*)_3$–N (Nsp^3: pyramidal)	1.469	1.468	0.014	1.460	1.476	1 042	5,22
	C*–Nsp^3 (overall)	1.469	1.468	0.014	1.460	1.476	1 201	
	Csp^3–Nsp^3							
	in aziridine	1.472	1.471	0.016	1.464	1.482	134	
	in azetidine	1.484	1.481	0.018	1.472	1.495	21	
	in tetrahydropyrrole	1.475	1.473	0.016	1.464	1.483	66	
	in piperidine	1.473	1.473	0.013	1.460	1.479	240	
	Csp^3–Nsp^2 (N planar) in:							23
	acyclic amides C*–NH–C=O	1.454	1.451	0.011	1.446	1.461	78	14
	β-lactams C*–N(–X)–C=O (endo)	1.464	1.465	0.012	1.458	1.475	23	13
	γ-lactams							
	C*–NH–C=O (endo)	1.457	1.458	0.011	1.449	1.465	20	13
	C*–N(–C*)–C=O (endo)	1.462	1.461	0.010	1.453	1.466	15	13
	C*–N(–C*)–C=O (exo)	1.458	1.456	0.014	1.448	1.465	15	13

BOND LENGTHS IN CRYSTALLINE ORGANIC COMPOUNDS (continued)

Bond	Substructure	d	m	σ	q_1	q_u	n	Note
	δ-lactams							
	C*–NH–C=O (endo)	1.478	1.472	0.016	1.467	1.491	6	14
	C*–N(–C*)–C=O (endo)	1.479	1.476	0.007	1.475	1.482	15	14
	C*–N(–C*)–C=O (exo)	1.468	1.471	0.009	1.462	1.477	15	14
	nitro compounds (1,2-dinitro omitted):							
	C–CH$_2$–NO$_2$	1.485	1.483	0.020	1.478	1.502	8	
	C$_2$–CH–NO$_2$	1.509	1.509	0.011	1.502	1.511	12	
	C$_3$–C–NO$_2$	1.533	1.533	0.013	1.530	1.539	17	
	C$_2$–C–(NO$_2$)$_2$	1.537	1.536	0.016	1.525	1.550	19	
	1,2-dinitro: NO$_2$–C*–C*–NO$_2$	1.552	1.550	0.023	1.536	1.572	32	
Csp^3–N(2)	C#–N=N	1.493	1.493	0.020	1.477	1.506	54	
	C*–N=C–C*ar*	1.465	1.468	0.011	1.461	1.472	75	
Csp^2–N(3)	C=C–NH$_2$ Nsp^2 planar	1.336	1.344	0.017	1.317	1.348	10	23
	C=C–NH–C# Nsp^2 planar	1.339	1.340	0.016	1.327	1.351	17	23
	C=C–N–(C#)$_2$							
	Nsp^2 planar	1.355	1.358	0.014	1.341	1.363	22	23
	Nsp^3 pyramidal	1.416	1.418	0.018	1.397	1.432	18	22
	Csp^2–Nsp^2 (N planar) in:							23
	acyclic amides							
	NH$_2$–C=O	1.325	1.323	0.009	1.318	1.331	32	14
	C*–NH–C=O	1.334	1.333	0.011	1.326	1.343	78	14
	(C*)$_2$–N–C=O	1.346	1.342	0.011	1.339	1.356	5	14
	β-lactams C*–NH–C=O	1,385	1.388	0.019	1.374	1.396	23	13
	γ-lactams							
	C*–NH–C=O	1.331	1.331	0.011	1.326	1.337	20	13
	C*–N(–C*)–C=O	1.347	1.344	0.014	1.335	1.359	15	13
	δ-lactams							
	C*–NH–C=O	1.334	1.334	0.006	1.330	1.339	6	14
	C*–N(–C*)–C=O	1.352	1.353	0.010	1.344	1.356	15	14
	peptides C#–N(–X)–C(–C#)(=O)	1.333	1.334	0.013	1.326	1.340	380	24
	ureas							
	(NH$_2$)$_2$–C=O	1.334	1.334	0.008	1.329	1.339	48	25,26
	(C#–NH)$_2$–C=O	1.347	1.345	0.010	1.341	1.354	26	25
	[(C#)$_n$–N]$_2$–C=O	1.363	1.359	0.014	1.354	1.370	40	25,27
	thioureas	1.346	1.343	0.023	1.328	1.361	192	
	(X$_2$N)$_2$–C=S							
	imides							
	[C#–C(=O)]$_2$–NH	1.376	1.377	0.012	1.369	1.383	64	
	[C#–C(=O)]$_2$–N–C#	1.389	1.383	0.017	1.376	1.404	38	
	[Csp^2–C(=O)]$_2$–N–C#	1.396	1.396	0.010	1.389	1.403	46	
	[Csp^2–C(=O)]$_2$–N–Csp^2	1.409	1.406	0.020	1.391	1.419	28	
	guanidinium [C–(NH$_2$)$_3$]$^+$ (unsubst.)	1.321	1.320	0.008	1.314	1.327	39	
	(any subst.)	1.328	1.325	0.015	1.317	1.333	140	
	in heterocyclic systems (any subst.)							
	1*H*-pyrrole (N1–C2, N1–C5)	1.372	1.374	0.016	1.363	1.384	58	
	indole (N1–C2)	1.370	1.370	0.012	1.364	1.377	40	
	pyrazole (N1–C5)	1.357	1.359	0.012	1.347	1.365	20	
	imidazole (N1–C2)	1.349	1.349	0.018	1.338	1.358	44	
	imidazole (N1–C5)	1.370	1.370	0.010	1.365	1.377	44	
Csp^2–N(2)	in imidazole (N3–C4)	1.376	1.377	0.011	1.369	1.384	44	
C*ar*–N(4)	C*ar*–N$^+$–(C,H)$_3$	1.465	1.466	0.007	1.461	1.470	23	
C*ar*–N(3)	C*ar*–NH$_2$							
	(Nsp^2: planar)	1.355	1.360	0.020	1.340	1.372	33	23
	(Nsp^3: pyramidal)	1.394	1.396	0.011	1.385	1.403	25	22
	(overall)	1.375	1.377	0.025	1.363	1.394	98	28
C*ar*–N(3)	C*ar*–NH–C#							
	(Nsp^2: planar)	1.353	1.353	0.007	1.347	1.359	16	23
	(Nsp^3: pyramidal)	1.419	1.423	0.017	1.412	1.432	8	22
	(overall)	1.380	1.364	0.032	1.353	1.412	31	28
	C*ar*–N–(C#)$_2$							
	(Nsp^2: planar)	1.371	1.370	0.016	1.363	1.382	41	23
	(Nsp^3: pyramidal)	1.426	1.425	0.011	1.421	1.431	22	22
	(overall)	1.390	1.385	0.030	1.366	1.420	69	28
	in indole (N1–C7a)	1.372	1.372	0.007	1.367	1.376	40	
	C*ar*–NO$_2$	1.468	1.469	0.014	1.460	1.476	556	
C*ar*–N(2)	C*ar*–N=N	1.431	1.435	0.020	1.422	1.442	26	
Csp^2=N(3)	in furoxan ($^+$N2=C3)	1.316	1.316	0.009	1.311	1.324	14	
Csp^2=N(2)	C*ar*–C=N–C#	1.279	1.279	0.008	1.275	1.285	75	
	(C,H)$_2$–C=N–OH in oximes	1.281	1.280	0.013	1.273	1.288	67	
	S–C=N–X	1.302	1.302	0.021	1.285	1.319	36	
	in pyrazole (N2=C3)	1.329	1.331	0.014	1.315	1.339	20	
	in imidazole (C2=N3)	1.313	1.314	0.011	1.307	1.319	44	
	in isoxazole (N2=C3)	1.314	1.315	0.009	1.305	1.320	9	

Bond	Substructure	d	m	σ	q_l	q_u	n	Note
	in furazan (N2=C3, C4=N5)	1.298	1.299	0.006	1.294	1.303	12	
	in furoxan (C4=N5)	1.304	1.306	0.008	1.300	1.308	14	
Car≃N(3)	C≃N$^+$–H (pyrimidinium)	1.335	1.334	0.015	1.325	1.342	30	
	C≃N$^+$–C* (pyrimidinium)	1.346	1.346	0.010	1.340	1.352	64	
	C≃N$^+$–O$^-$ (pyrimidinium)	1.362	1.359	0.013	1.353	1.369	56	
Car≃N(2)	C≃N (pyridine)	1.337	1.338	0.012	1.330	1.344	269	
	C≃N (pyrazine)	1.336	1.335	0.022	1.319	1.347	120	
	C≃N≃C (pyrimidine)	1.339	1.338	0.015	1.333	1.342	28	
	N≃C≃N (pyrimidine)	1.333	1.335	0.013	1.326	1.337	28	
	C≃N (pyrimidine) (overall)	1.336	1.337	0.014	1.331	1.339	56	
	in any 6-membered N-containing aromatic ring:							
	H–C≃N≃C–H	1.334	1.334	0.014	1.327	1.341	146	
	H–C≃N≃C–C*	1.339	1.341	0.013	1.336	1.345	38	
	C*–C≃N≃C–C*	1.345	1.345	0.008	1.342	1.348	24	
	C≃N≃C (overall)	1.336	1.337	0.014	1.329	1.344	204	
C*sp*^{1}≡N(2)	X–S–N≡C$^-$ (isothiocyanide)	1.144	1.147	0.006	1.140	1.148	6	
C*sp*^{1}≡N(1)	C*–C≡N	1.136	1.137	0.010	1.131	1.142	140	
	C=C–C≡N in TCNQ	1.144	1.144	0.008	1.139	1.149	284	19
	Car–C≡N	1.138	1.138	0.007	1.133	1.143	31	
	X–C≡N	1.144	1.141	0.012	1.138	1.151	10	
	(S–C≡N)$^-$	1.155	1.156	0.012	1.147	1.165	14	
C*sp*^{3}–O(2)	in alcohols							
	CH$_3$–OH	1.413	1.414	0.018	1.395	1.425	17	
	C–CH$_2$–OH	1.426	1.426	0.011	1.420	1.431	75	
	C$_2$–CH–OH	1.432	1.431	0.011	1.425	1.439	266	
	C$_3$–C–OH	1.440	1.440	0.012	1.432	1.449	106	
	C*–OH (overall)	1.432	1.431	0.013	1.424	1.441	464	
	in dialkyl ethers							29
	CH$_3$–O–C*	1.416	1.418	0.016	1.405	1.426	110	
	C–CH$_2$–O–C*	1.426	1.424	0.011	1.418	1.435	34	
	C$_2$–CH–O–C*	1.429	1.430	0.010	1.420	1.437	53	
	C$_3$–C–O–C*	1.452	1.450	0.011	1.445	1.458	39	
	C*–O–C* (overall)	1.426	1.425	0.019	1.414	1.437	236	5
	in aryl alkyl ethers							29
	CH$_3$–O–*Car*	1.424	1.424	0.012	1.417	1.431	616	
	C–CH$_2$–O–*Car*	1.431	1.430	0.013	1.422	1.438	188	
	C$_2$–CH–O–*Car*	1.447	1.446	0.020	1.435	1.466	58	
	C$_3$–C–O–*Car*	1.470	1.469	0.018	1.456	1.483	55	
	C*–O–*Car* (overall)	1.429	1.427	0.018	1.419	1.436	917	
	in alkyl esters of carboxylic acids							12,29
	CH$_3$–O–C(=O)–C*	1.448	1.449	0.010	1.442	1.455	200	
	C–CH$_2$–O–C(=O)–C*	1.452	1.453	0.009	1.445	1.458	32	
	C$_2$–CH–O–C(=O)–C*	1.460	1.460	0.010	1.454	1.465	78	
	C$_3$–C–O–C(=O)–C*	1.477	1.475	0.008	1.472	1.484	6	
	C*–O–C(=O)–C* (overall)	1.450	1.451	0.014	1.442	1.459	314	
	in alkyl esters of α,β-unsaturated acids:							
	C*–O–C(=O)–C=C (overall)	1.453	1.452	0.013	1.444	1.459	112	
	in alkyl esters of benzoic acid							
	C*–O–C(=O)–C(phenyl) (overall)	1.454	1.454	0.012	1.446	1.463	219	
	in ring systems							
	oxirane (epoxides) (any subst.)	1.446	1.446	0.014	1.438	1.456	498	9
	oxetane (any subst.)	1.463	1.460	0.015	1.451	1.474	16	
	tetrahydrofuran (C,H subst.)	1.442	1.441	0.017	1.430	1.451	154	
C*sp*^{3}–O(2)	tetrahydropyran (C,H subst.)	1.441	1.442	0.015	1.431	1.451	22	
	β-lactones: C*–O–C(=O)	1.492	1.494	0.010	1.481	1.501	4	16
	γ-lactones: C*–O–C(=O)	1.464	1.464	0.012	1.455	1.473	110	12
	δ-lactones: C*–O–C(=O)	1.461	1.464	0.017	1.452	1.473	27	12
	O–C–O system in *gem*-diols, and pyranose and furanose sugars:							30,31
	HO–C*–OH	1.397	1.401	0.012	1.388	1.405	18	
	C$_5$–O$_5$–C$_1$–O$_1$H in pyranoses							
	O$_1$ axial (α):							
	C$_5$–O$_5$	1.439	1.440	0.008	1.432	1.445	29	
	O$_5$–C$_1$	1.427	1.426	0.012	1.421	1.432	29	
	C$_1$–O$_1$	1.403	1.400	0.012	1.391	1.412	29	
	O$_1$ equatorial (β):							
	C$_5$–O$_5$	1.435	1.436	0.008	1.429	1.440	17	
	O$_5$–C$_1$	1.430	1.431	0.010	1.424	1.436	17	
	C$_1$–O$_1$	1.393	1.393	0.007	1.386	1.399	17	
	α + β (overall):							
	C$_5$–O$_5$	1.439	1.440	0.008	1.432	1.446	60	
	O$_5$–C$_1$	1.430	1.429	0.012	1.421	1.436	60	
	C$_1$–O$_1$	1.401	1.399	0.011	1.392	1.407	60	

Bond	Substructure	d	m	σ	q_1	q_u	n	Note
	C_4–O_4–C_1–O_1H in furanoses							
	(overall values)							
	C_4–O_4	1.442	1.446	0.012	1.436	1.449	18	
	O_4–C_1	1.432	1.432	0.012	1.421	1.443	18	
	C_1–O_1	1.404	1.405	0.013	1.397	1.409	18	
	C_5–O_5–C_1–O_1–C* in pyranoses							
	O_1 axial (α):							
	C_5–O_5	1.439	1.438	0.010	1.433	1.446	67	
	O_5–C_1	1.417	1.417	0.009	1.410	1.424	67	
	C_1–O_1	1.409	1.409	0.014	1.401	1.417	67	
	O_1–C*	1.435	1.435	0.013	1.427	1.443	67	
	O_1 equatorial (β):							
	C_5–O_5	1.434	1.435	0.006	1.429	1.439	39	
	O_5–C_1	1.424	1.424	0.008	1.418	1.431	39	
	C_1–O_1	1.390	1.390	0.011	1.381	1.400	39	
	O_1–C*	1.437	1.438	0.013	1.428	1.445	39	
	α + β (overall):							
	C_5–O_5	1.436	1.436	0.009	1.431	1.442	126	
	O_5–C_1	1.419	1.419	0.011	1.412	1.426	126	
	C_1–O_1	1.402	1.403	0.016	1.391	1.413	126	
	O_1–C*	1.436	1.436	0.013	1.428	1.445	126	
	C_4–O_4–C_1–O_1–C* in furanoses							
	(overall values)							
	C_4–O_4	1.443	1.445	0.013	1.429	1.453	23	
	O_4–C_1	1.421	1.418	0.012	1.413	1.431	23	
	C_1–O_1	1.410	1.409	0.014	1.401	1.420	23	
	O_1–C*	1.439	1.437	0.014	1.429	1.449	23	
	Miscellaneous:							
	C#–O–SiX_3	1.416	1.416	0.017	1.405	1.428	29	
	C*–O–SO_2–C	1.465	1.461	0.014	1.454	1.475	33	
Csp^2–O(2)	in enols: C=C–OH	1.333	1.331	0.017	1.324	1.342	53	
	in enol esters: C=C–O–C*	1.354	1.353	0.016	1.341	1.363	40	
	in acids:							
	C*–C(=O)–OH	1.308	1.311	0.019	1.298	1.320	174	
	C=C–C(=O)–OH	1.293	1.295	0.019	1.279	1.307	22	
	Car–C(=O)–OH	1.305	1.311	0.020	1.291	1.317	75	
	in esters:							
	C*–C(=O)–O–C*	1.336	1.337	0.014	1.328	1.346	551	12,29
	C=C–C(=O)–O–C*	1.332	1.331	0.011	1.324	1.339	112	
	Car–C(=O)–O–C*	1.337	1.335	0.013	1.329	1.344	219	12
	C*–C(=O)–O–C=C	1.362	1.359	0.018	1.351	1.374	26	
	C*–C(=O)–O–C=C	1.407	1.405	0.017	1.394	1.420	26	
	C*–C(=O)–O–*Car*	1.360	1.359	0.011	1.355	1.367	40	12
	in anhydrides: O=C–O–C=O	1.386	1.386	0.011	1.379	1.393	70	
	in ring systems:							
	furan (O1–C2, O1–C5)	1.368	1.369	0.015	1.359	1.377	125	
	isoxazole (O1–C5)	1.354	1.354	0.010	1.345	1.360	9	
	β-lactones: C*–C(=O)–O–C*	1.359	1.359	0.013	1.348	1.371	4	13
	γ-lactones: C*–C(=O)–O–C*	1.350	1.349	0.012	1.342	1.359	110	12
	δ-lactones: C*–C(=O)–O–C*	1.339	1.339	0.016	1.332	1.347	27	12
Car–O(2)	in phenols: *Car*–OH	1.362	1.364	0.015	1.353	1.373	551	
	in aryl alkyl ethers: *Car*–O–C*	1.370	1.370	0.011	1.363	1.377	920	29,32
Car–O(2)	in diaryl ethers: *Car*–O–*Car*	1.384	1.381	0.014	1.375	1.391	132	
	in esters: *Car*–O–C(=O)–C*	1.401	1.401	0.010	1.394	1.408	40	12
Csp^2=O(1)	in aldehydes and ketones:							
	C*–CH=O	1.192	1.192	0.005	1.188	1.197	7	
	$(C^*)_2$–C=O	1.210	1.210	0.008	1.206	1.215	474	5
	$(C\#)_2$–C=O							
	in cyclobutanones	1.198	1.198	0.007	1.194	1.204	12	
	in cyclopentanones	1.208	1.208	0.007	1.203	1.212	155	
	in cyclohexanones	1.211	1.211	0.009	1.207	1.216	312	
	C=C–C=O	1.222	1.222	0.010	1.216	1.229	225	
	$(C{=}C)_2$–C=O	1.233	1.229	0.010	1.226	1.242	28	
	Car–C=O	1.221	1.218	0.014	1.212	1.229	85	
	$(Car)_2$–C=O	1.230	1.226	0.015	1.220	1.238	66	
	C=O in benzoquinones	1.222	1.220	0.013	1.211	1.231	86	
	delocalized double bonds in carboxylate anions:							
	H–C$\simeq O_2^-$ (formate)	1.242	1.243	0.012	1.234	1.252	24	
	C*–C$\simeq O_2^-$	1.254	1.253	0.010	1.247	1.261	114	
	C=C–C$\simeq O_2^-$	1.250	1.248	0.017	1.238	1.261	52	
	Car–C$\simeq O_2^-$	1.255	1.253	0.010	1.249	1.262	22	
	HOOC–C$\simeq O_2^-$ (hydrogen oxalate)	1.243	1.247	0.015	1.232	1.256	26	
	$^-O_2\simeq$C–C$\simeq O_2$– (oxalate)	1.251	1.251	0.007	1.248	1.254	18	

Bond	Substructure	d	m	σ	q_l	q_u	n	Note
	in carboxylic acids (X–COOH)							
	C*–C(=O)–OH	1.214	1.214	0.019	1.203	1.224	175	
	C=C–C(=O)–OH	1.229	1.226	0.017	1.218	1.237	22	
	Car–C(=O)–OH	1.226	1.223	0.020	1.211	1.241	75	
	in esters:							
	C*–C(=O)–O–C*	1.196	1.196	0.010	1.190	1.202	551	12
	C=C–C(=O)–O–C*	1.199	1.198	0.009	1.193	1.203	113	
	Car–C(=O)–O–C*	1.202	1.201	0.009	1.196	1.207	218	12
	C*–C(=O)–O–C=C	1.190	1.190	0.014	1.184	1.198	26	
	C*–C(=O)–O–*Car*	1.187	1.188	0.011	1.181	1.195	40	12
	in anhydrides: O=C–O–C=O	1.187	1.187	0.010	1.184	1.193	70	
	in β-lactones: C*–C(=O)–O–C*	1.193	1.193	0.006	1.187	1.198	4	13
	γ-lactones: C*–C(=O)–O–C*	1.201	1.202	0.009	1.196	1.206	109	12
	δ-lactones: C*–C(=O)–O–C*	1.205	1.207	0.008	1.201	1.209	27	12
	in amides:							
	NH_2-C(–C*)=O	1.234	1.233	0.012	1.225	1.243	32	14
	(C*–)(C*,H–)N–C(–C*)=O	1.231	1.231	0.012	1.224	1.238	378	14
	β-lactams: C*–NH–C=O	1.198	1.200	0.012	1.193	1.204	23	13
	γ-lactams:							
	C*–NH–C=O	1.235	1.235	0.008	1.232	1.240	20	13
	C*–N(–C*)–C=O	1.225	1.226	0.011	1.217	1.233	15	13
	δ-lactams:							
	C*–NH–C=O	1.240	1.241	0.003	1.237	1.243	6	14
	C*–N(–C*)–C=O	1.233	1.233	0.007	1.229	1.239	15	14
	in ureas:							
	$(NH)_2)_2$–C=O	1.256	1.256	0.007	1.249	1.261	24	25,26
	$(C\#–NH)_2$–C=O	1.241	1.237	0.011	1.235	1.245	13	25
	$[(C\#)_n–N]_2$–C=O	1.230	1.230	0.007	1.224	1.234	20	25,27
Csp^3–P(4)	$C_3–P^+–C^*$	1.800	1.802	0.015	1.790	1.812	35	33
	C_2–P(=O)–CH_3	1.791	1.790	0.006	1.786	1.795	10	
	C_2–P(=O)–CH_2–C	1.806	1.806	0.009	1.801	1.813	45	
	C_2–P(=O)–CH–C_2	1.821	1.821	0.009	1.815	1.828	15	
	C_2–P(=O)–C–C_3	1.841	1.842	0.008	1.835	1.847	14	
	C_2–P(=O)–C* (overall)	1.813	1.811	0.017	1.800	1.822	84	
Csp^3–P(3)	C_2–P–C*	1.855	1.857	0.019	1.840	1.870	23	
Car–P(4)	$C_3–P^+$–*Car*	1.793	1.792	0.011	1.786	1.800	276	
	C_2–P(=O)–*Car*	1.801	1.802	0.011	1.796	1.807	98	
	$Ph_3–P{=}N^+{=}P–Ph_3$	1.795	1.795	0.008	1.789	1.800	197	
Car–P(3)	C_2–P–*Car*	1.836	1.837	0.010	1.830	1.844	102	
	$(N\simeq)_2$P-*Car* (P≃N aromatic)	1.795	1.793	0.011	1.788	1.803	43	
Csp^3–S(4)	C*–SO_2–C (C* = CH_3 excluded)	1.786	1.782	0.018	1.774	1.797	75	
	C*–SO_2–C (overall)	1.779	1.778	0.020	1.764	1.790	94	
	C*–SO_2–O–X	1.745	1.744	0.009	1.738	1.754	7	34
	C*–SO_2–N–X_2	1.758	1.756	0.018	1.746	1.773	17	34
Csp^3–S(3)	C*–S(=O)–C (C* = CH_3 excluded)	1.818	1.814	0.024	1.802	1.829	69	
	C*–S(=O)–C (overall)	1.809	1.806	0.025	1.793	1.820	88	
	$CH_3–S^+–X_2$	1.786	1.787	0.007	1.779	1.792	21	
	$C^*–S^+–X_2$ (C* = CH_3 excluded)	1.823	1.820	0.016	1.812	1.834	18	
	$C^*–S^+–X_2$ (overall)	1.804	1.794	0.025	1.788	1.820	41	
Csp^3–S(2)	C*–SH	1.808	1.805	0.010	1.800	1.819	6	
	CH_3–S–C*	1.789	1.787	0.008	1.784	1.794	9	
Csp^3–S(2)	C-CH_2–S–C*	1.817	1.816	0.013	1.808	1.824	92	
	C_2–CH–S–C*	1.819	1.819	0.011	1.811	1.825	32	
	C_3–C–S–C*	1.856	1.860	0.011	1.854	1.863	26	
	C*–S–C* (overall)	1.819	1.817	0.019	1.809	1.827	242	
	in thiirane	1.834	1.835	0.025	1.810	1.858	4	9
	in thietane: see ZCMXSP (1.817, 1.844)							
	in tetrahydrothiophene	1.827	1.826	0.018	1.811	1.837	20	
	in tetrahydrothiopyran	1.823	1.821	0.014	1.812	1.832	24	
	C–CH_2–S–S–X	1.823	1.820	0.014	1.813	1.832	41	
	C_3–C–S–S–X	1.863	1.865	0.015	1.848	1.878	11	
	C*–S–S–X (overall)	1.833	1.828	0.022	1.818	1.848	59	
Csp^2–S(2)	C=C–S–C*	1.751	1.755	0.017	1.740	1.764	61	
	C=C–S–C=C (in tetrathiafulvalene)	1.741	1.741	0.011	1.733	1.750	88	
	C=C–S–C=C (in thiophene)	1.712	1.712	0.013	1.703	1.722	60	
	O=C–S–C#	1.762	1.759	0.018	1.747	1.778	20	
Car–S(4)	*Car*–SO_2–C	1.763	1.764	0.009	1.756	1.769	96	
	Car–SO_2–O–X	1.752	1.750	0.008	1.749	1.756	27	
	Car–SO_2–N–X_2	1.758	1.759	0.013	1.749	1.765	106	35
Car–S(3)	*Car*–S(=O)–C	1.790	1.790	0.010	1.783	1.798	41	
	Car–$S^+–X_2$	1.778	1.779	0.010	1.771	1.787	10	
Car–S(2)	*Car*–S–C*	1.773	1.774	0.009	1.765	1.779	44	
	Car–S–*Car*	1.768	1.767	0.010	1.762	1.774	158	
	Car–S–*Car* (in phenothiazine)	1.764	1.764	0.008	1.760	1.769	48	

Bond	Substructure	*d*	*m*	σ	q_l	q_u	*n*	Note
	*C*ar–S–S–X	1.777	1.777	0.012	1.767	1.785	47	
Csp^1–S(2)	N≡C–S–X	1.679	1.683	0.026	1.645	1.698	10	
Csp^1–S(1)	$(N≡C–S)^-$	1.630	1.630	0.014	1.619	1.641	14	
Csp^2=S(1)	$(C^*)_2$–C=S: see IPMUDS (1.599)							
	$(Car)_2$–C=S: see CELDOM (1.611)							
	$(X)_2$–C=S (X = C,N,O,S)	1.671	1.675	0.024	1.656	1.689	245	
	X_2N–C(=S)–S–X	1.660	1.660	0.016	1.648	1.674	38	
	$(X_2N)_2$–C=S (thioureas)	1.681	1.684	0.020	1.669	1.693	96	
	N–C(≃S)$_2$	1.720	1.721	0.012	1.709	1.731	20	
Csp^3–Se	C#–Se	1.970	1.967	0.032	1.948	1.998	21	
Csp^2–Se(2)	C=C–Se–C=C (in tetraselenafulvalene)	1.893	1.895	0.013	1.882	1.902	32	
*C*ar–Se(3)	Ph_3–Se^+	1.930	1.929	0.006	1.924	1.936	13	
Csp^3–Si(5)	C#–Si^-–X_4	1.874	1.876	0.015	1.859	1.884	9	
Csp^3–Si(4)	CH_3–Si–X_3	1.857	1.857	0.018	1.848	1.869	552	
	C*–Si–X_3 (C* = CH_3 excluded)	1.888	1.887	0.023	1.872	1.905	124	
	C*–Si–X_3 (overall)	1.863	1.861	0.024	1.850	1.875	681	
*C*ar–Si(4)	*C*ar–Si–X_3	1.868	1.868	0.014	1.857	1.878	178	
Csp^1–Si(4)	C≡C–Si–X_3	1.837	1.840	0.012	1.824	1.849	8	
Csp^3–Te	C#–Te	2.158	2.159	0.030	2.128	2.177	13	
*C*ar–Te	*C*ar–Te	2.116	2.115	0.020	2.104	2.130	72	
Csp^2=Te	see CEDCUJ (2.044)							
Cl–Cl	see PHASCL (2.306, 2.227)							
Cl–I	see CMBIDZ (2.563), HXPASC (2.541, 2.513), METAMM (2.552), BQUINI (2.416, 2.718)							
Cl–N	see BECTAE (1.743—1.757), BOGPOC (1.705)							
Cl–O(1)	in ClO_4^-	1.414	1.419	0.026	1.403	1.431	252	
Cl–P	(N≃)$_2$P–Cl (N≃P aromatic)	1.997	1.994	0.015	1.989	2.004	46	
	Cl–P (overall)	2.008	2.001	0.035	1.986	2.028	111	
Cl–S	Cl–S (overall)	2.072	2.079	0.023	2.047	2.091	6	
	see also longer bonds in CILSAR (2.283), BIHXIZ (2.357), CANLUY (2.749)							
Cl–Se	see BIRGUE10, BIRHAL10, CTCNSE (2.234—2.851)							
Cl–Si(4)	Cl–Si–X_3 (monochloro)	2.072	2.075	0.009	2.066	2.078	5	
	Cl_2–Si–X_2 and Cl_3–Si–X	2.020	2.012	0.015	2.007	2.036	5	
Cl–Te	Cl–Te in range 2.34—2.60	2.520	2.515	0.034	2.493	2.537	22	36
	see also longer bonds in BARRIV, BOJPUL, CETUTE, EPHTEA, OPNTEC10 (2.73—2.94)							
F–N(3)	F–N–C_2 and F_2–N–C	1.406	1.404	0.016	1.395	1.416	9	
F–P(6)	in hexafluorophosphate, PF_6^-	1.579	1.587	0.025	1.563	1.598	72	
F–P(3)	(N≃)$_2$P–F (N≃P aromatic)	1.495	1.497	0.016	1.481	1.510	10	
F–S	43 observations in range 1.409—1.770 in a wide variety of environments; F–S(6) in F_2–SO_2–C_2 (see FPSULF10, BETJOZ)	1.640	1.646	0.011	1.626	1.649	6	
	F–S(4) in F_2–S(=O)–N (see BUDTEZ)	1.527	1.528	0.004	1.524	1.530	24	37
F–Si(6)	in SiF_6^{2-}	1.694	1.701	0.013	1.677	1.703	6	
F–Si(5)	F–Si^-–X_4	1.636	1.639	0.035	1.602	1.657	10	
F–Si(4)	F–Si–X_3	1.588	1.587	0.014	1.581	1.599	24	
F–Te	see CUCPIZ (F–Te(6) = 1.942, 1.937), FPHTEL (F–Te(4) = 2.006)							
H–N(4)	X_3–N^+–H	1.033	1.036	0.022	1.026	1.045	87	21
H–N(3)	X_2–N–H	1.009	1.010	0.019	0.997	1.023	95	21
H–O(2)	in alcohols C*–O–H	0.967	0.969	0.010	0.959	0.974	63	21
	C#–O–H	0.967	0.970	0.010	0.959	0.974	73	21
	in acids O=C–O–H	1.015	1.017	0.017	1.001	1.031	16	21,38
I–I	in I_3^-	2.917	2.918	0.011	2.907	2.927	6	
I–N	see BZPRIB, CMBIDZ, HMTITI, HMTNTI, IFORAM, IODMAM (2.042—2.475)							
I–O	X–I–O (see BZPRIB, CAJMAB, IBZDAC11)	2.144	2.144	0.028	2.127	2.164	6	
	for IO_6^- see BOVMEE (1.829—1.912)							
I–P(3)	see CEHKAB (2.490—2.493)							†
I–S	see DTHIBR10 (2.687), ISUREA10 (2.629), BZTPPI (3.251)							
I–Te(4)	I–Te–X_3	2.926	2.928	0.026	2.902	2.944	8	
N(4)–N(3)	X_3–N^+–N^0–X_2 (N^0 planar)	1.414	1.414	0.005	1.412	1.418	13	
N(3)–N(3)	(C)(C,H)–N_a–N_b–(C)(C,H)							5,39
	N_a, N_b pyramidal	1.454	1.452	0.021	1.444	1.457	44	40
	N_a pyramidal, N_b planar	1.420	1.420	0.015	1.407	1.433	68	40
	N_a, N_b planar	1.401	1.401	0.018	1.384	1.418	40	40
	overall	1.425	1.425	0.027	1.407	1.443	139	
N(3)–N(2)	in pyrazole (N1–N2)	1.366	1.366	0.019	1.350	1.375	20	
	in pyridazinium ($N1^+$≃N2)	1.350	1.349	0.010	1.345	1.361	7	

Bond	Substructure	d	m	σ	q_1	q_u	n	Note
N(2)≃N(2)	N≃N (aromatic) in pyridazine							
	with C,H as *ortho* substituents	1.304	1.300	0.019	1.287	1.326	6	
	with N,Cl as *ortho* substituents	1.368	1.373	0.011	1.362	1.375	9	
N(2)=N(2)	C#–N=N–C#							
	cis	1.245	1.244	0.009	1.239	1.252	21	
	trans	1.222	1.222	0.006	1.218	1.227	6	
	(overall)	1.240	1.241	0.012	1.230	1.251	27	
	Car–N=N–*Car*	1.255	1.253	0.016	1.247	1.262	13	
	X–N=N=N (azides)	1.216	1.226	0.028	1.202	1.237	19	
N(2)=N(1)	X–N=N=N (azides)	1.124	1.128	0.015	1.114	1.137	19	
N(3)–O(2)	$(C,H)_2$–N–OH (Nsp^2: planar)	1.396	1.394	0.012	1.390	1.401	28	
	C_2–N–O–C							
	(Nsp^3: pyramidal)	1.463	1.465	0.012	1.457	1.468	22	
	(Nsp^2: planar)	1.397	1.394	0.011	1.388	1.409	12	
	in furoxan (N2–O1)	1.438	1.436	0.009	1.430	1.447	14	
N(3)–O(1)	$(C\simeq)_2N^+$–O^- in pyridine *N*-oxides	1.304	1.299	0.015	1.291	1.316	11	
	in furoxan ($^+$N2–O6$^-$)	1.234	1.234	0.008	1.228	1.240	14	
N(2)–O(2)	in oximes							
	$(C\#)_2$–C=N–OH	1.416	1.418	0.006	1.416	1.420	7	
	(H)(Csp^2)–C=N–OH	1.390	1.390	0.011	1.380	1.401	20	
	(C#)(Csp^2)–C=N–OH	1.402	1.403	0.010	1.393	1.410	18	
	$(Csp^2)_2$–C=N–OH	1.378	1.377	0.017	1.365	1.393	16	
	$(C,H)_2$–C=N–OH (overall)	1.394	1.395	0.018	1.379	1.408	67	
	in furazan (O1–N2, O1–N5)	1.385	1.383	0.013	1.378	1.392	12	
	in furoxan (O1–N5)	1.380	1.380	0.011	1.370	1.388	14	
	in isoxazole (O1–N2)	1.425	1.425	0.010	1.417	1.434	9	
N(3)=O(1)	in nitrate ions NO_3^-	1.239	1.240	0.020	1.227	1.251	105	
	in nitro groups							
	C*–NO_2	1.212	1.214	0.012	1.206	1.221	84	
	C#–NO_2	1.210	1.210	0.011	1.203	1.218	251	
	Car– NO_2	1.217	1.218	0.011	1.211	1.215	1 116	
	C–NO_2 (overall)	1.218	1.219	0.013	1.210	1.226	1 733	
N(3)–P(4)	X_2–P(=X)–NX_2							
	Nsp^2: planar	1.652	1.651	0.024	1.634	1.670	205	
	Nsp^3: pyramidal	1.683	1.683	0.005	1.680	1.686	6	
	(overall)	1.662	1.662	0.029	1.639	1.682	358	
	subsets of this group are:							
	O_2–P(=S)–NX_2	1.628	1.624	0.015	1.615	1.634	9	
	C–P(=S)–$(NX_2)_2$	1.691	1.694	0.018	1.678	1.703	28	
	O–P(=S)–$(NX_2)_2$	1.652	1.654	0.014	1.642	1.664	28	
	P(=O)–$(NX_2)_3$	1.663	1.668	0.026	1.640	1.679	78	
N(3)–P(3)	–NX–P(–X)–NX–P(–X)– (P_2N_2 ring)	1.730	1.721	0.017	1.716	1.748	20	
	–NX–P(=S)–NX–P(=S)– (P_2N_2 ring)	1.697	1.697	0.015	1.690	1.703	44	
	in *P*-substituted phosphazenes:							
	$(N\simeq)_2$P–N (amino)	1.637	1.638	0.014	1.625	1.651	16	
	(aziridinyl)	1.672	1.674	0.010	1.665	1.676	15	
N(2)=P(4)	Ph_3–P=N^+=P–Ph_3	1.571	1.573	0.013	1.563	1.580	66	
N(2)=P(3)	Ph_3–P=N–C,S	1.599	1.597	0.018	1.580	1.615	7	
N(2)≃P(3)	N≃P aromatic							
	in phosphazenes	1.582	1.582	0.019	1.571	1.594	126	
	in P≃N≃S	1.604	1.606	0.009	1.594	1.612	36	
N(3)–S(4)	C–SO_2–NH_2	1.600	1.601	0.012	1.591	1.610	14	35
	C–SO_2–NH–C#	1.633	1.633	0.019	1.615	1.652	47	35
	C–SO_2–N–$C(\#)_2$	1.642	1.641	0.024	1.623	1.659	38	35
N(3)–S(2)	C–S–NX_2 Nsp^2: planar	1.710	1.707	0.019	1.698	1.722	22	23
	(for Nsp^3 pyramidal see MODIAZ: 1.765)							
	X–S–NX_2 Nsp^2: planar	1.707	1.705	0.012	1.699	1.715	30	23
N(2)–S(2)	C=N–S–X	1.656	1.663	0.027	1.632	1.677	36	
N(2)≃S(2)	N≃S aromatic in P≃N≃S	1.560	1.558	0.011	1.554	1.563	37	
N(2)=S(2)	N=S in N=S=N and N=S=S	1.541	1.546	0.022	1.521	1.558	37	
N(3)–Se	see COJCUZ (1.830), DSEMOR10 (1.846, 1.852), MORTRS10 (1.841)							
N(2)–Se	see SEBZQI (1.805), NAPSEZ10 (1.809, 1.820)							
N(2)=Se	see CISMUM (1.790, 1.791)							
N(3)–Si(5)	see DMESIP01, BOJLER, CASSAQ, CASYOK, CECXEN, CINTEY, CIPBUY, FMESIB, MNPSIL, PNPOSI (1.973—2.344)							
N(3)–Si(4)	X_3–Si–NX_2 (overall)	1.748	1.746	0.022	1.735	1.757	170	
	subsets of this group are:							
	X_3–Si–NHX	1.714	1.719	0.014	1.702	1.727	16	
	X_3–Si–NX–Si–X_3 acyclic	1.743	1.744	0.016	1.731	1.755	45	
	N–Si–N in 4-membered rings	1.742	1.742	0.009	1.735	1.748	53	
	N–Si–N in 5-membered rings	1.741	1.742	0.019	1.726	1.749	33	
N(2)–Si(4)	X_3–Si–N^-–Si–X_3	1.711	1.712	0.019	1.693	1.729	15	

Bond	Substructure	d	m	σ	q_l	q_u	n	Note
N–Te	see ACLTEP (2.402), BIBLAZ (1.980), CESSAU (2.023)							
O(2)–O(2)	C*–O–O–C*,H							
	τ(OO) = 70—85°	1.464	1.464	0.009	1.458	1.472	12	
	τ(OO) *ca.* 180°	1.482	1.480	0.005	1.478	1.486	5	
	overall	1.469	1.471	0.012	1.461	1.478	17	
	O=C–O–O–C=O see ACBZPO01 (1.446), CEYLUN (1.452), CIMHIP (1.454)							
	Si–O–O–Si	1.496	1.499	0.005	1.490	1.499	10	
O(2)–P(5)	X–P–$(OX)_4$							41
	trigonal bipyramidal:							
	axial	1.689	1.685	0.024	1.675	1.712	20	
	equatorial	1.619	1.622	0.024	1.604	1.628	20	
	square pyramidal	1.662	1.661	0.020	1.649	1.673	28	
O(2)–P(4)	C–O–P$(\simeq O)_3^{2-}$	1.621	1.622	0.007	1.615	1.628	12	
	$(H–O)_2$–P$(\simeq O)_2^-$	1.560	1.561	0.009	1.555	1.566	16	
	$(C–O)_2$–P$(\simeq O)_2^-$	1.608	1.607	0.013	1.599	1.615	16	
	$(C\#–O)_3$–P=O	1.558	1.554	0.011	1.550	1.564	30	
	$(Car–O)_3$–P=O	1.587	1.588	0.014	1.572	1.599	19	
	X–O–P(=O)–$(C,N)_2$	1.590	1.585	0.016	1.577	1.601	33	
	$(X–O)_2$–P(=O)–(C,N)	1.571	1.572	0.013	1.563	1.579	70	
O(2)–P(3)	$(N\simeq)_2$P–O–C (N≃P aromatic)	1.573	1.573	0.011	1.563	1.584	16	
O(1)=P(4)	C–O–P$(\simeq O)_3^{2-}$ (declocalized)	1.513	1.512	0.008	1.508	1.518	42	
	$(H–O)_2$–P$(\simeq O)_2^-$ (delocalized)	1.503	1.503	0.005	1.499	1.508	16	
	$(C–O)_2$–P$(\simeq O)_2^-$ (delocalized)	1.483	1.485	0.008	1.474	1.490	16	
	$(C–O)_3$–P=O	1.449	1.448	0.007	1.446	1.452	18	
	C_3–P=O	1.489	1.486	0.010	1.481	1.496	72	
	N_3–P=O	1.461	1.462	0.014	1.449	1.470	26	
	$(C)_2$(N)–P=O	1.487	1.489	0.007	1.479	1.493	5	
	$(C,N)_2$(O)–P=O	1.467	1.465	0.007	1.462	1.472	33	
	(C,N)$(O)_2$–P=O	1.457	1.458	0.009	1.454	1.462	35	
O(2)–S(4)	C–O–SO_2–C	1.577	1.576	0.015	1.566	1.584	41	
	C–O–SO_2–CH_3	1.569	1.569	0.013	1.556	1.582	7	
	C–O–SO_2–*Car*	1.580	1.578	0.015	1.571	1.588	27	
O(1)=S(4)	C–SO_2–C	1.436	1.437	0.010	1.431	1.442	316	42
	X–SO_2–NX_2	1.428	1.428	0.010	1.422	1.434	326	
	C–SO_2–N–$(C,H)_2$	1.430	1.430	0.009	1.425	1.435	206	
	C–SO_2–O–C	1.423	1.423	0.008	1.418	1.428	82	
	in SO_4^{2-}	1.472	1.473	0.013	1.463	1.481	104	
O(1)=S(3)	C–S(=O)–C	1.497	1.498	0.013	1.489	1.505	90	5
O–Se	see BAPPAJ, BIRGUE10, BIRHAL10, CXMSEO, DGLYSE, SPSEBU (1.597 for O=Se to 1.974 for O–Se)							
O(2)–Si(5)	$(X–O)_3$–Si–(N)(C)	1.663	1.658	0.023	1.650	1.665	21	
O(2)–Si(4)	X_3–Si–O–X (overall)	1.631	1.630	0.022	1.617	1.646	191	
O(2)–Si(4)	subsets of this group are:							
	X_3–Si–O–C#	1.645	1.647	0.012	1.634	1.652	29	
	X_3–Si–O–Si–X_3	1.622	1.625	0.014	1.614	1.631	70	
	X_3–Si–O–O–Si–X_3	1.680	1.676	0.008	1.673	1.688	10	
O(2)–Te(6)	$(X–O)_6$–Te	1.927	1.927	0.020	1.908	1.942	16	
O(2)–Te(4)	$(X–O)_2$–Te–X_2	2.133	2.136	0.054	2.078	2.177	12	
P(4)–P(4)	X_3–P–P–X_3	2.256	2.259	0.025	2.243	2.277	6	
P(4)–P(3)	see CECHEX (2.197), COZPIQ (2.249)							
P(3)–P(3)	X_2–P–P–X_2	2.214	2.210	0.022	2.200	2.224	41	
P(4)=P(4)	see BUTSUE (2.054)							
P(3)=P(3)	see BALXOB (2.034)							
P(4)=S(1)	C_3–P=S	1.954	1.952	0.005	1.950	1.957	13	
	$(N,O)_2$(C)–P=S	1.922	1.924	0.014	1.913	1.927	26	
	$(N,O)_3$–P=S	1.913	1.914	0.014	1.906	1.921	50	
P(4)=Se(1)	X_3–P=Se	2.093	2.099	0.019	2.075	2.108	12	
P(3)–Si(4)	X_2–P–Si–X_3: 3- and 4-rings excluded (see BOPFER, BOPFIV, CASTOF10, COZVIW: 2.201—2.317)	2.264	2.260	0.019	2.249	2.283	22	
P(4)=Te(1)	see MOPHTE (2.356), TTEBPZ (2.327)							
S(2)–S(2)	C–S–S–C							
	τ(SS) = 75—105°	2.031	2.029	0.015	2.021	2.038	46	
	τ(SS) = 0—20°	2.070	2.068	0.022	2.057	2.077	28	
	(overall)	2.048	2.045	0.026	2.028	2.068	99	
	in polysulphide chain–S–S–S–	2.051	2.050	0.022	2.037	2.065	126	
S(2)–S(1)	X–N=S–S	1.897	1.896	0.012	1.887	1.908	5	
S–Se(4)	see BUWZUO (2.264, 2.269)							
S–Se(2)	X–Se–S (any)	2.193	2.195	0.015	2.174	2.207	9	
S(2)–Si(4)	X_3–Si–S–X	2.145	2.138	0.020	2.130	2.158	19	

Bond	Substructure	d	m	σ	q_l	q_u	n	Note
S(2)–Te	X–S–Te (any)	2.405	2.406	0.022	2.383	2.424	10	
	X=S–Te (any)	2.682	2.686	0.035	2.673	2.694	28	
Se(2)–Se(2)	X–Se–Se–X	2.340	2.340	0.024	2.315	2.361	15	
Se(2)–Te(2)	see BAWFUA, BAWGAH (2.524—2.561)							†
Si(4)–Si(4)	X_3–Si–Si–X_3 3-membered rings excluded: see CIHRAM (2.511)	2.359	2.359	0.012	2.349	2.366	42	
Te–Te	see CAHJOK (2.751, 2.704)							

Appendix 1. (Footnotes to Table)

1. Sample dominated by B–CH_3. For longer bonds in B^-–CH_3 see LITMEB10 [B(4)–CH_3 = 1.621—1.644Å].
2. $p(\pi)$–$p(\pi)$ Bonding with Bsp^2 and Nsp^2 coplanar (τBN = 0 ± 15°) predominates. See G. Schmidt, R. Boese, and D. Bläser, *Z. Naturforsch.*, 1982, **37b**, 1230.
3. 84 observations range from 1.38 to 1.61 Å and individual values depend on substituents on B and O. For a discussion of borinic acid adducts see S. J. Rettig and J. Trotter, *Can. J. Chem.*, 1982, **60**, 2957.
4. See M. Kaftory in 'The Chemistry of Functional Groups. Supplement D: The Chemistry of Halides, Pseudohalides, and Azides' eds. S. Patai and Z. Rappoport, Wiley: New York, 1983, Part 2, ch. 24.
5. Bonds which are endocyclic or exocyclic to any 3- or 4-membered rings have been omitted from all averages in this section.
6. The overall average given here is for Csp^3–Csp^3 bonds which carry only C or H substituents. The value cited reflects the relative abundance of each 'substitution' group. The 'mean of means' for the 9 subgroups is 1.538 (σ = 0.022) Å.
7. See F. H. Allen, (*a*) *Acta Crystallogr.*, 1980, **B36**, 81; (*b*) 1981, **B37**, 890.
8. See F. H. Allen, *Acta Crystallogr.*, 1984, **B40**, 64.
9. See F. H. Allen, *Tetrahedron*, 1982, **38**, 2843.
10. See F. H. Allen, *Tetrahedron*, 1982, **38**, 645.
11. Cyclopropanones and cyclobutanones excluded.
12. See W. B. Schweizer and J. D. Dunitz, *Helv. Chim. Acta*, 1982, **65**, 1547.
13. See L. Norskov-Lauritsen, H.-B. Bürgi, P. Hoffmann, and H. R. Schmidt, *Helv. Chim. Acta*, 1985, **68**, 76.
14. See P. Chakrabarti and J. D. Dunitz, *Helv. Chim. Acta*, 1982, **65**, 1555.
15. See J. L. Hencher in 'The Chemistry of the C≡C Triple Bond,' ed. S. Patai, Wiley, New York, 1978, ch. 2.
16. Conjugated: torsion angle about central C–C single bond is 0 ± 20° (*cis*) or 180 ± 20° (*trans*).
17. Unconjugated: torsion angle about central C–C single bond is 20—160°.
18. Other conjugative substituents excluded.
19. TCNQ is tetracyanoquinodimethane.
20. No difference detected between C2≃C3 and C3≃C4 bonds.
21. Derived from neutron diffraction results only.
22. Nsp^3: pyramidal; mean valence angle at N is in range 108—114°.
23. Nsp^2: planar; mean valence angle at N is ⩾117.5°.
24. Cyclic and acyclic peptides.
25. See R. H. Blessing, *J. Am. Chem. Soc.*, 1983, **105**, 2776.
26. See L. Lebioda, *Acta Crystallogr.*, 1980, **B36**, 271.
27. *n* = 3 or 4, *i.e.* tri- or tetra-substituted ureas.
28. Overall value also includes structures with mean valence angle at N in the range 115—118°.
29. See F. H. Allen and A. J. Kirby, *J. Am. Chem. Soc.*, 1984, **106**, 6197.
30. See A. J. Kirby, 'The Anomeric Effect and Related Stereoelectronic Effects at Oxygen,' Springer, Berlin, 1983.
31. See B. Fuchs, L. Schleifer, and E. Tartakovsky, *Nouv. J. Chim.*, 1984, **8**, 275.
32. See S. C. Nyburg and C. H. Faerman, *J. Mol. Struct.*, 1986, **140**, 347.
33. Sample dominated by P–CH_3 and P–CH_2–C.
34. Sample dominated by C* = methyl.
35. See A. Kalman, M. Czugler, and G. Argay, *Acta Crystallogr.*, 1981, **B37**, 868.
36. Bimodal distribution resolved into 22 'short' bonds and 5 longer outliers.
37. All 24 observations come from BUDTEZ.
38. 'Long' O–H bonds in centrosymmetric O - - - H - - - O H-bonded dimers are excluded.
39. N–N bond length also dependent on torsion angle about N–N bond and on nature of substituent C atoms; these effects are ignored here.
40. N pyramidal has average angle at N in range 100—113.5°; N planar has average angle of ⩾117.5°.
41. See R. R. Holmes and J. A. Deiters, *J. Amer. Chem. Soc.*, 1977, **99**, 3318.
42. No detectable variation in S=O bond length with type of C-substituent.

Appendix 2.

Short-form references to individual CSD entries cited by reference code in the Table. A full list of CSD bibliographic entries is given in SUP 56701.

ACBZPO01	*J. Am. Chem. Soc.*, 1975, **97**, 6729.
ACLTEP	*J. Organomet. Chem.*, 1980, **184**, 417.
ASAZOC	*Dokl. Akad. Nauk SSSR*, 1979, **249**, 120.
BALXOB	*J. Am. Chem. Soc.*, 1981, **103**, 4587.
BAPPAJ	*Inorg. Chem.*, 1981, **20**, 3071.
BARRIV	*Acta Chem. Scand., Ser. A*, 1981, **35**, 443.
BAWFUA	*Cryst. Struct. Commun.*, 1981, **10**, 1345.
BAWGAH	*Cryst. Struct. Commun.*, 1981, **10**, 1353.
BECTAE	*J. Org. Chem.*, 1981, **46**, 5048, 1981.
BELNIP	*Z. Naturforsch., Teil B*, 1982, **37**, 299.
BEMLIO	*Chem. Ber.*, 1982, **115**, 1126.
BEPZEB	*Cryst. Struct. Commun.*, 1982, **11**, 175.
BETJOZ	*J. Am. Chem. Soc.*, 1982, **104**, 1683.
BETUTE10	*Acta Chem. Scand., Ser. A*, 1976, **30**, 719.
BIBLAZ	*Zh. Strukt. Khim.*, 1981, **22**, 118.
BICGEZ	*Z. Anorg. Allg. Chem.*, 1982, **486**, 90.
BIHXIZ	*J. Chem. Soc., Chem. Commun.*, 1982, 982.
BIRGUE10	*Z. Naturforsch., Teil B*, 1983, **38**, 20.
BIRHAL10	*Z. Naturforsch., Teil B*, 1982, **37**, 1410.
BIZJAV	*J. Organomet. Chem.*, 1982, **238**, C1.
BOGPOC	*Z. Naturforsch., Teil B*, 1982, **37**, 1402.
BOGSUL	*Z. Naturforsch., Teil* B, 1982, **37**, 1230.
BOJLER	*Z. Anorg. Allg. Chem.*, 1982, **493**, 53.
BOJPUL	*Acta Chem. Scand., Ser. A*, 1982, **36**, 829.
BOPFER	*Chem. Ber.*, 1983, **116**, 146.
BOPFIV	*Chem. Ber.*, 1983, **116**, 146.
BOVMEE	*Acta Crystallogr., Sect. B*, 1982, **38**, 1048.
BQUINI	*Acta Crystallogr., Sect. B*, 1979, **35**, 1930.

BTUPTE	*Acta Chem. Scand., Ser. A*, 1975, **29**, 738.
BUDTEZ	*Z. Naturforsch., Teil B*, 1983, **38**, 454.
BUPSIB10	*Z. Anorg. Allg. Chem.*, 1981, **474**, 31.
BUSHAY	*Z. Naturforsch., Teil. B*, 1983, **38**, 692.
BUTHAZ10	*Inorg. Chem.*, 1984, **23**, 2582.
BUTSUE	*J. Chem. Soc., Chem. Commun.*, 1983, 862.
BUWZUO	*Acta Chem. Scand., Ser A*, 1983, **37**, 219.
BZPRIB	*Z. Naturforsch., Teil B*, 1981, **36**, 922.
BZTPPI	*Inorg. Chem.*, 1978, **17**, 894.
CAHJOK	*Inorg. Chem.*, 1983, **22**, 1809.
CAJMAB	*Chem. Z*, 1983, **107**, 169.
CANLUY	*Tetrahedron Lett.*, 1983, **24**, 4337.
CASSAQ	*J. Struct. Chem.*, 1983, **2**, 101.
CASTOF10	*Acta Crystallogr., Sect. C*, 1984, **40**, 1879.
CASYOK	*J. Struct. Chem.*, 1983, **2**, 107.
CECHEX	*Z. Anorg. Allg. Chem.*, 1984, **508**, 61.
CECXEN	*J. Struct. Chem.*, 1983, **2**, 207.
CEDCUJ	*J. Org. Chem.*, 1983, **48**, 5149.
CEHKAB	*Z. Naturforsch., Teil B*, 1984, **39**, 139.
CELDOM	*Acta Crystallogr., Sect. C*, 1984, **40**, 556.
CESSAU	*Acta Crystallogr., Sect. C*, 1984, **40**, 653.
CETTAW	*Chem. Ber.*, 1984, **117**, 1089.
CETUTE	*Acta Chem. Scand., Ser A*, 1975, **29**, 763.
CEYLUN	*Izv. Akad. Nauk SSSR, Ser. Khim.*, 1983, 2744.
CIFZUM	*Acta Chem. Scand., Ser A*, 1984, **38**, 289.
CIHRAM	*Angew. Chem., Int. Ed. Engl.*, 1984, **23**, 302.
CILRUK	*J. Chem. Soc., Chem. Commun.*, 1984, 1023.
CILSAR	*J. Chem. Soc., Chem. Commun.*, 1984, 1021.
CIMHIP	*Acta Crystallogr., C*, 1984, **40**, 1458.
CINTEY	*Dokl. Akad. Nauk SSSR*, 1984, **274**, 615.
CIPBUY	*J. Struct. Chem.*, 1983, **2**, 281.
CISMUM	*Z. Naturforsch., Teil B*, 1984, **39**, 485.
CISTED	*Z. Anorg. Allg. Chem.*, 1984, **511**, 95.
CIWYIQ	*Inorg. Chem.*, 1984, **23**, 1946.
CIYFOF	*Inorg. Chem.*, 1984, **23**, 1790.
CMBIDZ	*J. Org. Chem.*, 1979, **44**, 1447.
CODDEE	*Z. Naturforsch., Teil B*, 1984, **39**, 1257.
CODDII	*Z. Naturforsch., Teil B*, 1984, **39**, 1257.
COFVOI	*Z. Naturforsch., Teil B*, 1984, **39**, 1027.
COJCUZ	*Chem. Ber.*, 1984, **117**, 2686.
COSDIX	*Z. Naturforsch., Teil B*, 1984, **39**, 1344.
COZPIQ	*Chem. Ber.*, 1984, **117**, 2063.
COZVIW	*Z. Anorg. Allg. Chem.*, 1984, **515**, 7.
CTCNSE	*J. Am. Chem. Soc.*, 1980, **102**, 5430.
CUCPIZ	*J. Am. Chem. Soc.*, 1984, **106**, 7529.
CUDLOC	*J. Cryst. Spectrosc.*, 1985, **15**, 53.
CUDLUI	*J. Cryst. Spectrosc.*, 1985, **15**, 53.

CUGBAH	*Acta Crystallogr., Sect. C*, 1985, **41**, 476.
CXMSEO	*Acta Crystallogr., Sect. B*, 1973, **29**, 595.
DGLYSE	*Acta Crystallogr., Sect. B*, 1975, **31**, 1785.
DMESIP01	*Acta Crystallogr., Sect. C*, 1984, **40**, 895.
DSEMOR10	*J. Chem. Soc., Dalton Trans.*, 1980, 628.
DTHIBR10	*Inorg. Chem.*, 1971, **10**, 697.
EPHTEA	*Inorg. Chem.*, 1980, **19**, 2487.
ESEARS	*J. Chem. Soc. C*, 1971, 1511.
ETEARS	*J. Chem. Soc. C*, 1971, 1511.
FMESIB	*J. Organomet. Chem.*, 1980, **197**, 275.
FPHTEL	*J. Chem. Soc., Dalton Trans.*, 1980, 2306.
FPSULF10	*J. Am. Chem. Soc.*, 1982, **104**, 1683.
HCLENE10	*Acta Crystallogr., Sect. B*, 1982, **38**, 3139.
HMTITI	*Acta Crystallogr., Sect. B*, 1975, **31**, 1505.
HMTNTI	*Z. Anorg. Allg. Chem.*, 1974, **409**, 237.
HXPASC	*J. Chem. Soc., Dalton Trans.*, 1975, 1381.
IBZDAC11	*J. Chem. Soc., Dalton Trans.*, 1979, 854.
IFORAM	*Monatsh. Chem.*, 1974, **105**, 621.
IODMAM	*Acta Crystallogr., Sect. B*, 1977, **33**, 3209.
IPMUDS	*Acta Crystallogr., Sect. B*, 1973, **29**, 2128.
ISUREA10	*Acta Crystallogr., Sect. B*, 1972, **28**, 643.
LITMEB10	*J. Am. Chem. Soc.*, 1975, **97**, 6401.
MESIAD	*Z. Naturforsch., Teil B*, 1980, **35**, 789.
METAMM	*Acta Crystallogr.*, 1964, **17**, 1336.
MNPSIL	*J. Am. Chem. Soc.*, 1969, **91**, 4134.
MODIAZ	*J. Heterocycl. Chem.*, 1980, **17**, 1217.
MOPHTE	*Acta Chem. Scand., Ser. A*, 1980, **34**, 333.
MORTRS10	*J. Chem. Soc., Dalton Trans.*, 1980, 628.
NAPSEZ10	*J. Am. Chem. Soc.*, 1980, **102**, 5070.
NBBZAM	*Z. Naturforsch., Teil B*, 1977, **32**, 1416.
OPIMAS	*Aust. J. Chem.*, 1977, **30**, 2417.
OPNTEC10	*J. Chem. Soc., Dalton Trans.*, 1982, 251.
PHASCL	*Acta Crystallogr., Sect. B*, 1981, **37**, 1357.
PHASOC01	*Aust. J. Chem.*, 1975, **28**, 15.
PNPOSI	*J. Am. Chem. Soc.*, 1968, **90**, 5102.
SEBZQI	*J. Chem. Soc., Chem. Commun.*, 1977, 325.
SPSEBU	*Acta Chem. Scand., Ser. A*, 1979, **33**, 403.
TEACBR	*Cryst. Struct. Commun.*, 1974, **3**, 753.
THINBR	*J. Am. Chem. Soc.*, 1970, **92**, 4002.
TMPBTI	*Acta Crystallogr., Sect. B*, 1975, **31**, 1116.
TPASSN	*J. Chem. Soc., Dalton Trans.*, 1977, 514.
TPASTB	*Cryst. Struct. Commun.*, 1976, **5**, 39.
TPHOSI	*Z. Naturforsch., Teil B*, 1979, **34**, 1064.
TTEBPZ	*Z. Naturforsch., Teil B*, 1979, **34**, 256.
ZCMXSP	*Cryst. Struct. Commun.*, 1977, **6**, 93.

BOND LENGTHS AND ANGLES IN GAS-PHASE MOLECULES

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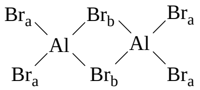
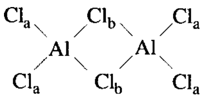
Internuclear distances and bond angles are represented in units of Å (1 Å = 10^{-10} m) and degrees, respectively. The same but inequivalent atoms are discriminated by subscripts a, b, etc. In some molecules ax for axial and eq for equatorial are also used. All measurements were made in the gas phase. The methods used are abbreviated as follows. UV: ultraviolet (including visible) spectroscopy; IR: infrared spectroscopy; R: Raman spectroscopy; MW: microwave spectroscopy; ED: electron diffraction; NMR: nuclear magnetic resonance; LMR: laser magnetic resonance; EPR: electron paramagnetic resonance; MBE: molecular beam electric resonance. If two methods were used jointly for structure determination, they are listed together, as (ED, MW). If the numerical values listed refer to the equilibrium values, they are specified by r_e and θ_e. In other cases the listed values represent various average values in vibrational states; it is frequently the case that they represent the r_s structure derived from several isotopic species for MW or the r_g structure (i.e., the average internuclear distances at thermal equilibrium) for ED. These internuclear distances for the same atom pair with different definitions may sometimes differ as much as 0.01 Å. Appropriate comments are made on the symmetry and conformation in the equilibrium structure.

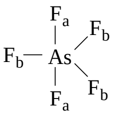
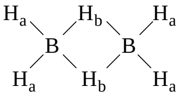
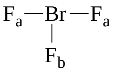
In general, the numerical values listed in the following tables contain uncertainties in the last digits. However, for certain molecules such as diatomic molecules, with experimental uncertainties of the order of 10^{-5} Å or smaller, numerical values are listed to four decimal places.

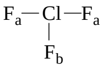
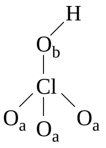
REFERENCES

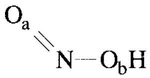
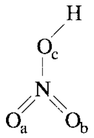
1. L. E. Sutton, ed., *Tables of Interatomic Distances and Configuration in Molecules and Ions*, The Chemical Society Special Publication, No. 11, 18, The Chemical Society (London) (1958, 1965).
2. K.-H. Hellwege, ed., *Landolt-Börnstein Numerical Data and Functional Relations in Science and Technology*, New Series, II/7, J. H. Callomon, E. Hirota, K. Kuchitsu, W. J. Lafferty, A. G. Maki, C. S. Pote, with assistance of I. Buck and B. Starck, *Structure Data of Free Polyatomic Molecules*, Springer-Verlag (1976).
3. K. P. Huber and G. Herzberg, *Molecular Spectra and Molecular Structure IV. Constants of Diatomic Molecules*, Van Nostrand Reinhold Co., London (1979).
4. B. Starck, *Microwave Catalogue and Supplements*.
5. B. Starck, *Electron Diffraction Catalogue and Supplements*.

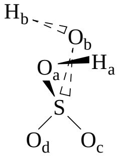
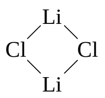
STRUCTURES OF ELEMENTS AND INORGANIC COMPOUNDS
Compounds are Arranged in Alphabetical Order by their Chemical Formulas
(Lengths in Å and Angles in Degrees)

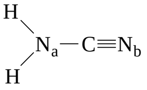
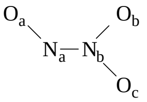
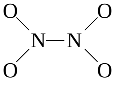
Compound	Structure				Method
AgBr	Ag—Br (r_e)	2.3931			MW
AgCl	Ag—Cl (r_e)	2.2808			MW
AgF	Ag—F (r_e)	1.9832			MW
AgH	Ag—H (r_e)	1.617			UV
AgI	Ag—I (r_e)	2.5446			MW
AgO	Ag—O (r_e)	2.0030			UV
AlBr	Al—Br (r_e)	2.295			UV
AlCl	Al—Cl (r_e)	2.1301			MW
AlF	Al—F (r_e)	1.6544			MW
AlH	Al—H (r_e)	1.6482			UV
AlI	Al—I (r_e)	2.5371			MW
AlO	Al—O (r_e)	1.6176			UV
Al_2Br_6			Al—Br_a Al—Br_b ∠Br_bAlBr_b ∠Br_aAlBr_a (D_{2h})	2.22 2.38 82 118	ED
Al_2Cl_6			Al—Cl_a Al—Cl_b ∠Cl_bAlCl_b ∠Cl_aAlCl_a (D_{2h})	2.04 2.24 87 122	ED
$AsBr_3$	As—Br	2.324	∠BrAsBr	99.6	ED
$AsCl_3$	As—Cl	2.165	∠ClAsCl	98.6	ED, MW
AsF_3	As—F	1.710	∠FAsF	95.9	ED, MW

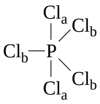
Compound	Structure						Method
AsF_5			As—F_a 1.711		As—F_b	1.656	
					(D_{3h})		
AsH_3	As—H (r_e)	1.511			∠HAsH (θ_e)	92.1	MW, IR
AsI_3	As—I	2.557			∠IAsI	100.2	ED
AuH	Au—H (r_e)	1.5237					UV
BBr_3	B—Br	1.893			(D_{3h})		ED
BCl_3	B—Cl	1.742			(D_{3h})		ED
BF	B—F (r_e)	1.2626					UV
BF_2H	B—H	1.189	B—F	1.311	∠FBF	118.3	MW
BF_2OH	B—F	1.32	B—O	1.34	O—H	0.941	MW
	∠FBF	118	∠FBO	123	∠BOH	114.1	
BF_3	B—F	1.313			(D_{3h})		ED, IR
BH	B—H (r_e)	1.2325					UV
BH_3PH_3	B—P	1.937	B—H	1.212	P—H	1.399	MW
	∠PBH	103.6	∠BPH	116.9	∠HBH	114.6	
	∠HPH	101.3	staggered form				
BI_3	B—I	2.118			(D_{3h})		ED
BN	B—N (r_e)	1.281					UV
BO	B—O (r_e)	1.2045					EPR
BO_2	B—O	1.265			linear		UV
BS	B—S	1.6091					UV
B_2H_6					B—H_a	1.19	IR, ED
					B—H_b	1.33	
					B···B	1.77	
					∠H_aBH_a	122	
					∠H_bBH_b	97	
$B_3H_3O_3$	B—O	1.376			∠BOB≅∠OBO	120	ED
$B_3H_6N_3$	B—N	1.435	B—H	1.26	N—H	1.05	ED
	∠NBN	118	∠BNB	121	(C_2)		
BaH	Ba—H (r_e)	2.2318					UV
BaO	Ba—O (r_e)	1.9397					MW
BaS	Ba—S (r_e)	2.5074					MBE
BeF	Be—F (r_e)	1.3609					UV
BeH	Be—H (r_e)	1.3431					UV
BeO	Be—O (r_e)	1.3308					UV
BiBr	Bi—Br (r_e)	2.6095					MW
$BiBr_3$	Bi—Br	2.63			∠BrBiBr	90 (C_{3v})	ED
BiCl	Bi—Cl (r_e)	2.4716					MW
$BiCl_3$	Bi—Cl	2.423			∠ClBiCl	100 (C_{3v})	ED
BiF	Bi—F (r_e)	2.0516					MW
BiH	Bi—H (r_e)	1.805					UV
BiI	Bi—I (r_e)	2.8005					MW
BiO	Bi—O (r_e)	1.934					UV
BrCN	C—N (r_e)	1.157			C—Br (r_e)	1.790	IR
BrCl	Br—Cl (r_e)	2.1361					MW
BrF	Br—F (r_e)	1.7590					MW
BrF_3			Br—F_a	1.810	Br—F_b	1.721	MW
			∠F_aBrF_b	86.2	(C_{2v})		
BrF_5	Br—F (average)	1.753					ED, MW
	(Br—F_{eq}) – (Br—F_{ax}) = 0.069						
	∠F_{ax}BrF_{eq}	85.1			(C_{4v})		
BrO	Br—O (r_e)	1.7172					MW
Br_2	Br—Br (r_e)	2.2811					R
CBr_4	C—Br	1.935			(T_d)		ED
CCl	C—Cl	1.6512					UV

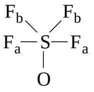
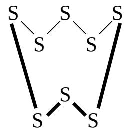
Compound	Structure						Method
$CClF_3$	C—Cl	1.752	C—F	1.325	∠FCF	108.6	ED, MW
CCl_3F	C—Cl	1.754	C—F	1.362	∠ClCCl	111	MW
					(C_{3v})		
CCl_4	C—Cl	1.767	(T_d)				ED
CF	C—F (r_e)	1.2718					EPR
CF_3I	C—I	2.138	C—F	1.330	∠FCF	108.1	ED, MW
CF_4	C—F	1.323	(T_d)				ED
CH	C—H (r_e)	1.1199					UV
CI_4	C—I	2.15	(T_d)				ED
CN	C—N (r_e)	1.1718					MW
CO	C—O (r_e)	1.1283					MW
$COBr_2$	C—O	1.178	C—Br	1.923			ED, MW
	∠BrCBr	112.3					
COClF	C—F	1.334	C—O	1.173	C—Cl	1.725	ED, MW
	∠FCCl	108.8	∠ClCO	127.5			
$COCl_2$	C—O	1.179	C—Cl	1.742			ED, MW
	∠ClCCl	111.8					
COF_2	C—F	1.3157	C—O	1.172			ED, MW
	∠FCF	107.71					
CO_2	C—O (r_e)	1.1600					IR
CP	C—P (r_e)	1.562					UV
CS	C—S (r_e)	1.5349					MW
CS_2	C—S (r_e)	1.5526					IR
C_2	C—C (r_e)	1.2425					UV
C_3O_2	C—O	1.163	C—C	1.289			ED
	linear (large-amplitude bending vibration)						
CaH	Ca—H (r_e)	2.002					UV
CaO	Ca—O (r_e)	1.8221					UV
CaS	Ca—S (r_e)	2.3178					UV
CdH	Cd—H (r_e)	1.781					EPR
$CdBr_2$	Cd—Br	2.35	linear				ED
$CdCl_2$	Cd—Cl	2.24	linear				ED
CdI_2	Cd—I	2.56	linear				ED
ClCN	C—Cl (r_e)	1.629	C—N (r_e)	1.160			MW
ClF	Cl—F (r_e)	1.6283					MW
ClF_3			$Cl—F_a$	1.698	$Cl—F_b$	1.598	MW
			$∠F_aClF_b$	87.5	(C_{2v})		
ClO	Cl—O (r_e)	1.5696					MW, UV
ClOH	O—Cl	1.690	O—H	0.975	∠HOCl	102.5	MW, IR
ClO_2	Cl—O	1.470	∠OClO	117.38			MW
$ClO_3(OH)$	$O_a—Cl$	1.407	$O_b—Cl$	1.639			ED
			$∠O_aClO_a$	114.3	$∠O_aClO_b$	104.1	
Cl_2	Cl—Cl (r_e)	1.9878					UV
Cl_2O	Cl—O	1.6959	∠ClOCl	110.89			MW
CoH	Co—H (r_e)	1.542					UV
$Cr(CO)_6$	C—O	1.16	Cr—C	1.92			ED
	∠CrCO	180					
CrO	Cr—O (r_e)	1.615					UV
CsBr	Cs—Br (r_e)	3.0723					MW
CsCl	Cs—Cl (r_e)	2.9063					MW
CsF	Cs—F (r_e)	2.3454					MW
CsH	Cs—H (r_e)	2.4938					UV
CsI	Cs—I (r_e)	3.3152					MW

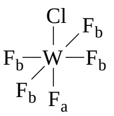
Compound	Structure						Method
CsOH	Cs—O (r_e)	2.395	O—H (r_e)	0.97			MW
CuBr	Cu—Br (r_e)	2.1734					MW
CuCl	Cu—Cl (r_e)	2.0512					MW
CuF	Cu—F (r_e)	1.7449					MW
CuH	Cu—H (r_e)	1.4626					UV
CuI	Cu—I (r_e)	2.3383					MW
FCN	C—F	1.262	C—N	1.159			MW
FOH	O—H	0.96	O—F	1.442	∠HOF	97.2	MW
F_2	F—F (r_e)	1.4119					R
$Fe(CO)_5$	Fe—C (average)	1.821					ED
	$(Fe—C)_{eq} – (Fe—C)_{ax}$	0.020					
	C—O (average)	1.153	(D_{3h})				
GaBr	Ga—Br (r_e)	2.3525					MW
GaCl	Ga—Cl (r_e)	2.2017					MW
GaF	Ga—F (r_e)	1.7744					MW
GaF_3	Ga—F	1.88	(D_{3h})				ED
GaI	Ga—I (r_e)	2.5747					MW
GaI_3	Ga—I	2.458	(D_{3h})				ED
GdI_3	Gd—I	2.841	∠IGdI	108	(C_{3v})		ED
$GeBrH_3$	Ge—H	1.526	Ge—Br	2.299			MW, IR
	∠HGeH	106.2					
$GeBr_4$	Ge—Br	2.272	(T_d)				ED
$GeClH_3$	Ge—H	1.537	Ge—Cl	2.150			IR, MW
	∠HGeH	111.0					
$GeCl_2$	Ge—Cl	2.183	∠ClGeCl	100.3			ED
$GeCl_4$	Ge—Cl	2.113	(T_d)				ED
$GeFH_3$	Ge—H	1.522	Ge—F	1.732			MW, IR
	∠HGeH	113.0					
GeF_2	Ge—F (r_e)	1.7321	∠FGeF (θ_e)	97.17			MW
GeH	Ge—H (r_e)	1.5880					UV
GeH_4	Ge—H	1.5251	(T_d)				IR, R
GeO	Ge—O (r_e)	1.6246					MW
GeS	Ge—S (r_e)	2.0121					MW
GeSe	Ge—Se (r_e)	2.1346					MW
GeTe	Ge—Te (r_e)	2.3402					MW
Ge_2H_6	Ge—H	1.541	Ge—Ge	2.403			ED
	∠HGeH	106.4	∠GeGeH	112.5			
HBr	H—Br (r_e)	1.4145					MW
HCN	C—H (r_e)	1.0655	C—N (r_e)	1.1532			MW, IR
			linear				
HCNO	H—C	1.027	C—N	1.161	N—O	1.207	MW
					linear		
HCl	H-Cl (r_e)	1.2746					MW
HF	H—F (r_e)	0.9169					MW
HI	H—I (r_e)	1.6090					MW
HNCO	N—H	0.986	N—C	1.209	C—O	1.166	MW
	∠HNC	128.0					
HNCS	N—H	0.989	N—C	1.216	C—S	1.561	MW
	∠HNC	135.0	∠NCS	180			
HNO	N—H	1.063	N—O	1.212	∠HNO	108.6	UV
HNO_2			*s-trans* conformer		*s-cis* conformer		MW
			O_b—H	0.958	0.98		
			N—O_b	1.432	1.39		
			N—O_a	1.170	1.19		
			∠O_aNO_b	110.7	114		
			∠NO_bH	102.1	104		
HNO_3			O_c—H	0.96	N—O_c	1.41	MW
			N—O_a	1.20	N—O_b	1.21	
			∠HO_cN	102.2	∠O_cNO_a	113.9	
			∠O_cNO_b	115.9	planar		

Compound	Structure						Method
HNSO	N—H	1.029	N—S	1.512	S—O	1.451	MW
	∠HNS	115.8	∠NSO	120.4			
			planar				
H_2	H—H (r_e)	0.7414					UV
H_2O	O—H (r_e)	0.9575	∠HOH (θ_e)	104.51			MW, IR
H_2O_2	O—O	1.475	∠OOH	94.8			IR
	dihedral angle of internal rotation		119.8	(C_2)			
H_2S	H—S (r_e)	1.3356	∠HSH (θ_e)	92.12			MW, IR
H_2SO_4			O—H	0.97	S—O_a	1.574	MW
			S—O_c	1.422	∠H_aO_aS	108.5	
			∠O_aSO_b	101.3	∠O_cSO_d	123.3	
			∠O_aSO_c	108.6	∠O_aSO_d	106.4	
			dihedral angle between the H_aO_aS and O_aSO_c planes		20.8		
			dihedral angle between the H_aO_aS and O_aSO_b planes		90.9		
			dihedral angle between the H_aSO_b and O_cSO_d planes		88.4	(C_2)	
H_2S_2	S—S	2.055	S—H	1.327	∠SSH	91.3	ED, MW
	dihedral angle of internal rotation		90.6	(C_2)			
$HfCl_4$	Hf—Cl	2.33	(T_d)				ED
$HgCl_2$	Hg—Cl	2.252	linear				ED
HgH	Hg—H (r_e)	1.7404					UV
HgI_2	Hg—I	2.553	linear				ED
IBr	I—Br (r_e)	2.4691					MW
ICN	C—I	1.995	C—N	1.159			MW
ICl	I—Cl (r_e)	2.3210					MW
IF_5	I—F (average)	1.860	$(I—F)_{eq} – (I—F)_{ax}$	0.03			ED, MW
	∠$F_{ax}IF_{eq}$	82.1	(C_{4v})				
IO	I—O (r_e)	1.8676					MW
I_2	I—I (r_e)	2.6663					R
InBr	In—Br (r_e)	2.5432					MW
InCl	In—Cl (r_e)	2.4012					MW
InF	In—F (r_e)	1.9854					MW
InH	In—H (r_e)	1.8376					UV
InI	In—I (r_e)	2.7537					MW
IrF_6	Ir—F	1.830	(O_h)				ED
KBr	K—Br (r_e)	2.8208					MW
KCl	K—Cl (r_e)	2.6667					MW
KF	K—F (r_e)	2.1716					MW
KH	K—H (r_e)	2.244					UV
KI	K—I (r_e)	3.0478					MW
KOH	O—H	0.91	K—O	2.212 linear			MW
K_2	K—K (r_e)	3.9051					UV
KrF_2	Kr—F	1.89	linear				ED
LiBr	Li—Br (r_e)	2.1704					MW
LiCl	Li—Cl (r_e)	2.0207					MW
LiF	Li—F (r_e)	1.5639					MW
LiH	Li—H (r_e)	1.5949					MW
LiI	Li—I (r_e)	2.3919					MW
Li_2	Li—Li (r_e)	2.6729					UV
Li_2Cl_2			Li—Cl	2.23			ED
			Cl—Cl	3.61			
			∠ClLiCl	108			
$LuCl_3$	Lu—Cl	2.417	∠ClLuCl	112	(C_{3v})		ED
MgF	Mg—F (r_e)	1.7500					UV
MgH	Mg—H (r_e)	1.7297					UV
MgO	Mg—O (r_e)	1.749					UV
MnH	Mn—H (r_e)	1.7308					UV
$Mo(CO)_6$	Mo—C	2.063	C—O	1.145	(O_h)		ED
$MoCl_4O$	Mo—Cl	2.279	Mo—O	1.658			ED
	∠ClMoCl	87.2	(C_{4v})				

Compound	Structure						Method
MoF_6	Mo—F	1.820	(O_h)				ED
$NClH_2$	N—H	1.017	N—Cl	1.748			MW, IR
	∠HNCl	103.7	∠HNH	107			
NCl_3	N—Cl	1.759	∠ClNCl	107.1			ED
NF_2	N—F	1.3528	∠FNF	103.18			MW
NH_2	N—H	1.024	∠HNH	103.3			UV
NH_2CN	N—H	1.00	N_a—C	1.35			MW
			$C—N_b$	1.160	∠HNH	114	
			angle between the NH_2 plane and the N—C bond			142	
NH_2NO_2	N—N	1.427	N—H	1.005			MW
	∠HNH	115.2	∠ONO	130.1			
	dihedral angle between the NH_2 and NNO_2 planes			128.2			
NH_3	N—H (r_e)	1.012	∠HNH (θ_e)	106.7			IR
NH_4Cl	N—H	1.22	N—Cl	2.54	(C_{3v})		ED
NF_2CN	$F_2N_b—C≡N_a$		$C—N_a$	1.158	$C—N_b$	1.386	MW
	$N_b—F$	1.399	$∠N_aCN_b$	174			
	$∠CN_bF$	105.4	$∠FN_bF$	102.8			
NH	N—H (r_e)	1.0362					LMR
NH_2OH	N—H	1.02	N—O	1.453	O—H	0.962	MW
	∠HNH	107	∠HNO	103.3	∠NOH	101.4	
	The bisector of H—N—H angle is *trans* to the O—H bond						
NO	N—O (r_e)	1.1506					IR
NOCl	N—Cl	1.975	N—O	1.14	∠ONCl	113	MW
NOF	O—N	1.136	N—F	1.512	∠FNO	110.1	MW
NO_2	N—O	1.193	∠ONO	134.1			MW
NO_2Cl	N—Cl	1.840	N—O	1.202			MW
	∠ONO	130.6	(C_{2v})				
NO_2F	N—O	1.1798	N—F	1.467			MW
	∠ONO	136	(C_{2v})				
NS	N—S (r_e)	1.4940					IR
N_2	N—N (r_e)	1.0977					UV
N_2H_4	N—H	1.021	N—N	1.449			ED, MW
	∠HNH	106.6 (assumed)	$∠NNH_a$	112			
	$∠NNH_b$ 106		dihedral angle of internal rotation	91			
	H_a: the H atom closer to the C_2 axis, H_b: the H atom farther from the C_2 axis						
N_2O	N—N (r_e)	1.1284	N—O (r_e)	1.1841			MW, IR
N_2O_3			$N_a—N_b$	1.864	$N_a—O_a$	1.142	MW
			$N_b—O_b$	1.202	$N_b—O_c$	1.217	
			$∠O_aN_aN_b$	105.05			
			$∠N_aN_bO_b$	112.72			
			$∠N_aN_bO_c$	117.47			
N_2O_4			N—N	1.782	N—O	1.190	ED
			∠ONO	135.4	(D_{2h})		
NaBr	Na—Br (r_e)	2.5020					MW
NaCl	Na—Cl (r_e)	2.3609					MW
NaF	Na—F (r_e)	1.9260					MW
NaH	Na—H (r_e)	1.8873					UV
NaI	Na—I (r_e)	2.7115					MW
Na_2	Na—Na (r_e)	3.0789					UV
$NbCl_5$	$Nb—Cl_{eq}$	2.241	$Nb—Cl_{ax}$	2.338 (D_{3h})	ED		
NbO	Nb—O (r_e)	1.691					UV
$Ni(CO)_4$	Ni—C	1.838	C—O	1.141	(T_d)		ED
NiH	Ni—H (r_e)	1.476					UV
NpF_6	Np—F	1.981	(O_h)				ED
OCS	C—O (r_e)	1.1578	C—S (r_e)	1.5601			MW

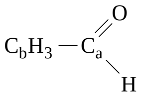
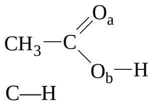
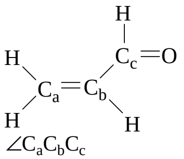
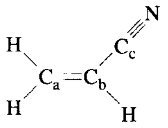
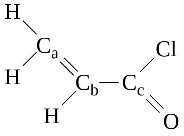
Compound	Structure					Method
OCSe	C—O	1.159	C—Se	1.709		MW
OF	O—F (r_e)	1.3579				LMR
OF_2	O—F (r_e)	1.4053	∠FOF (θ_e)	103.07	(C_{2v})	MW
$O(SiH_3)_2$	Si—H	1.486	Si—O	1.634		ED
	∠SiOSi	144.1				
O_2	O—O (r_e)	1.2074				MW
O_2F_2	O—O	1.217	F—O	1.575		MW
	∠OOF	109.5	dihedral angle of internal rotation	87.5	(C_2)	
O_3	O—O (r_e)	1.2716	∠OOO (θ_e)	117.47	(C_{2v})	MW
OsF_6	Os—F	1.831	(O_h)			ED
OsO_4	Os—O	1.712	(T_d)			ED
PBr_3	P—Br	2.220	∠BrPBr	101.0		ED
PCl_3	P—Cl	2.039	∠ClPCl	100.27		ED
PCl_5		P—Cl_a 2.124	P—Cl_b	2.020	(D_{3h})	ED
PF	P—F (r_e)	1.5896				UV
PF_3	P—F	1.570	∠FPF	97.8		ED, MW
PF_5	P—F_{ax}	1.577	P—F_{eq}	1.534	(D_{3h})	ED
PH	P—H (r_e)	1.4223				LMR
PH_2	P—H	1.418	∠HPH	91.70		UV
PH_3	P—H	1.4200	∠HPH	93.345		MW
PN	N—P (r_e)	1.4909				MW
PO	O—P (r_e)	1.4759				UV
$POCl_3$	P—O	1.449	P—Cl	1.993		ED
	∠ClPCl	103.3				
POF_3	P—O 1.436		P—F 1.524	∠FPF	101.3	ED, MW
P_2	P—P (r_e)	1.8931				UV
P_2F_4	P—F	1.587	P—P	2.281		ED
	∠PPF	95.4	∠FPF	99.1		
	The two PF_2 planes are *trans* to each other (the *gauche* conformer is less than 10%)					
P_4	P—P	2.21	(T_d)			ED
P_4O_6	P—O 1.638		∠POP 126.4		(T_d)	ED
PbH	Pb—H (r_e)	1.839				UV
PbO	Pb—O (r_e)	1.9218				MW
PbS	Pb—S (r_e)	2.2869				MW
PbSe	Pb—Se (r_e)	2.4022				MW
PbTe	Pb—Te (r_e)	2.5950				MW
PrI_3	Pr—I 2.904		∠IPrI 113		(C_{3v})	ED
PtO	Pt—O (r_e)	1.7273				UV
PuF_6	Pu—F	1.971	(O_h)			ED
RbBr	Rb—Br (r_e)	2.9447				MW
RbCl	Rb—Cl (r_e)	2.7869				MW
RbF	Rb—F (r_e)	2.2703				MW
RbH	Rb—H (r_e)	2.367				UV
RbI	Rb—I (r_e)	3.1768				MW
RbOH	Rb—O 2.301		O—H 0.957		linear	MW
$ReClO_3$	Re—O	1.702	Re—Cl	2.229		MW
	∠ClReO	109.4	(C_{3v})			
ReF_6	Re—F	1.832	(O_h)			ED
RuO_4	Ru—O	1.706	(T_d)			ED
SCSe	C—Se	1.693	C—S	1.553		MW
SCTe	C—S	1.557	C—Te	1.904		MW
SCl_2	S—Cl 2.006		∠ClSCl 103.0		(C_{2v})	ED
SF	S—F (r_e)	1.6006				MW
SF_2	S—F	1.5921	∠FSF	98.20		MW
SF_6	S—F	1.561	(O_h)			ED

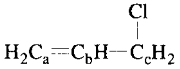
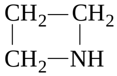
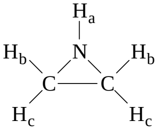
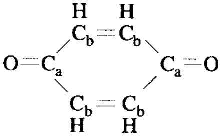
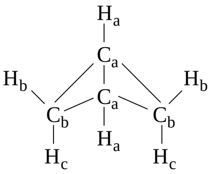
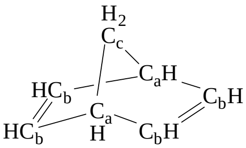
Compound	Structure						Method
SO	S—O (r_e)	1.4811					MW
$SOCl_2$	S—O	1.44	S—Cl	2.072			MW
	∠ClSCl	97.2	∠OSCl	108.0			
SOF_2	S—O	1.420	S—F	1.583			ED
	∠OSF	106.2	∠FSF	92.2			
SOF_4			S—O	1.403	S—F_a	1.575	ED
			S—F_b	1.552	∠OSF_a	90.7	
			∠OSF_b	124.9	∠F_aSF_b	89.6	
			∠F_bSF_b	110.2	(C_{2v})		
SO_2	S—O (r_e)	1.4308	∠OSO (θ_e)	119.329			MW
SO_2Cl_2	S—O	1.404	S—Cl	2.011	∠OSO	123.5	ED
	∠ClSCl	100.0	(C_{2v})				
SO_2F_2	S—O	1.397	S—F	1.530	∠OSO	123	ED
	∠FSF	97	(C_{2v})				
SO_3	S—O	1.4198	(D_{3h})				IR
$S(SiH_3)_2$	Si—H	1.494	Si—S	2.136	∠SiSSi	97.4	ED
S_2	S—S (r_e)	1.8892					R
S_2Br_2	S—Br	2.24	S—S	1.98			ED
	∠SSBr	105	dihedral angle of internal rotation	83.5			
S_2Cl_2	S—Cl	2.057	S—S	1.931			ED
	∠SSCl	108.2	dihedral angle of internal rotation	84.1	(C_2)		
S_2O_2	S—O	1.458	S—S	2.025	∠OSS	112.8	MW
					planar *cis* form		
S_8			S—S	2.07			ED
			∠SSS	105			
			(D_{4d})				
$SbCl_3$	Sb—Cl	2.333	∠ClSbCl	97.2			ED
SbH_3	Sb—H	1.704	∠HSbH	91.6			MW
SeF	Se—F	1.742					MW
SeF_6	Se—F	1.69	(O_h)				ED
SeO	Se—O (r_e)	1.6393					MW
$SeOF_2$	Se—O	1.576	Se—F	1.730			MW
	∠OSeF	104.82	∠FSeF	92.22			
SeO_2	Se—O (r_e)	1.6076	∠OSeO (θ_e)	113.83			MW
SeO_3	Se—O	1.69	(D_{3h})				ED
Se_2	Se—Se (r_e)	2.1660					UV
Se_6	Se—Se	2.34	∠SeSeSe	102			ED
		six-membered ring with chair conformation					
$SiBrF_3$	Si—F	1.560	Si—Br	2.153			MW
	∠FSiBr	108.5	(C_{3v})				
$SiBrH_3$	Si—H	1.485	Si—Br	2.210			MW
	∠HSiBr	107.8	(C_{3v})				
$SiClH_3$	Si—H	1.482	Si—Cl	2.048			MW
	∠HSiCl	107.9	(C_{3v})				
$SiCl_4$	Si—Cl	2.019	(T_4)				ED
SiF	Si—F	1.6008					UV
$SiFH_3$	Si—H	1.484	Si—F	1.593			MW, IR
	∠HSiH	110.63	(C_{3v})				
SiF_2	Si—F (r_e)	1.590	∠FSiF (θ_e)	100.8			MW
SiF_3H	Si—H (r_e)	1.4468	Si—F (r_e)	1.5624			MW
	∠HSiF (θ_e)	110.64					
SiF_4	Si—F	1.553	(T_d)				ED
SiH	Si—H (r_e)	1.5201					UV
SiH_3I	Si—H	1.485	Si—I	2.437			MW
	∠HSH	107.8					
SiH_4	Si—H	1.4798	(T_d)				IR
SiN	N—Si (r_e)	1.572					UV
SiO	Si—O (r_e)	1.5097					MW

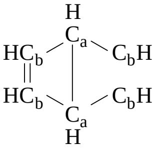
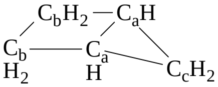
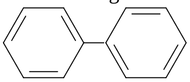
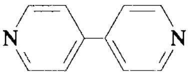
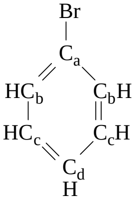
Compound	Structure					Method
SiS	Si—S (r_e)	1.9293				MW
SiSe	Se—Si (r_e)	2.0583				MW
Si_2	Si—Si (r_e)	2.246				UV
Si_2Cl_6	Si—Si	2.32	Si—Cl	2.009		ED
	∠ClSiCl	109.7				
Si_2F_6	Si—Si	2.317	Si—F	1.564		ED
	∠FSiF	108.6				
Si_2H_6	Si—H	1.492	Si—Si	2.331		ED
	∠SiSiH	110.3	∠HSiH	108.6		
			staggered form (assumed)			
$SnCl_4$	Sn—Cl	2.280	(T_d)			ED
SnH	Sn—H (r_e)	1.7815				UV
SnH_4	Sn—H	1.711	(T_d)			R, IR
SnO	Sn—O	1.8325				MW
SnS	S—Sn (r_e)	2.2090				MW
SnSe	Se—Sn (r_e)	2.3256				MW
SnTe	Sn—Te (r_e)	2.5228				MW
SrH	Sr—H (r_e)	2.1455				UV
SrO	Sr—O (r_e)	1.9198				MW
SrS	S—Sr (r_e)	2.4405				UV
$TaCl_5$	Ta—Cl_{eq}	2.227	Ta—Cl_{ax}	2.369	(D_{3h})	ED
TaO	Ta—O (r_e)	1.6875				UV
TeF_6	Te—F	1.815	(O_h)			ED
Te_2	Te—Te (r_e)	2.5574				UV
$ThCl_4$	Th—Cl	2.58	(T_d)			ED
ThF_4	Th—F	2.14	(T_d)			ED
TlBr	Tl—Br (r_e)	2.6182				MW
TlCl	Tl—Cl (r_e)	2.4848				MW
TlF	Tl—F (r_e)	2.0844				MW
TlH	Tl—H (r_e)	1.870				UV
TlI	Tl—I (r_e)	2.8137				MW
$TiBr_4$	Ti—Br	2.339	(T_d)			ED
$TiCl_4$	Ti—Cl	2.170	(T_d)			ED
TiO	Ti—O (r_e)	1.620				UV
TiS	Ti—S (r_e)	2.0825				UV
UF_6	U—F	1.996	(O_h)			ED
$V(CO)_6$	V—C	2.015	C—O	1.138		ED
		(O_h, involving dynamic Jahn-Teller effect)				
VCl_3O	V—O	1.570	V—Cl	2.142		ED, MW
	∠ClVCl	111.3				
VCl_4	V—Cl	2.138	(T_d, involving dynamic Jahn-Teller effect)			ED
VF_5	V—F (average)	1.71				ED
VO	V—O (r_e)	1.5893				UV
$W(CO)_6$	W—C	2.059	C—O	1.149	(O_h)	ED
$WClF_5$			W—Cl	2.251		MW
			W—F (average)	1.836		
			∠F_aWF_b	88.7		
WF_4O	W—O	1.666	W—F	1.847		ED
	∠FWF	86.2	(C_{4v})			
WF_6	W—F	1.832	(O_h)			ED
XeF_2	Xe—F	1.977	linear			IR
XeF_4	Xe—F	1.94	(D_{4h})			ED
XeF_6	Xe—F	1.890	(large-amplitude bending vibration around the O_h structure)			ED
XeO_4	Xe—O	1.736	(T_d)			ED
ZnH	Zn—H (r_e)	1.5949				UV
$ZrCl_4$	Zr—Cl	2.32	(T_d)			ED
ZrF_4	Zr—F	1.902	(T_d)			ED
ZrO	Zr—O (r_e)	1.7116				UV

STRUCTURES OF ORGANIC MOLECULES

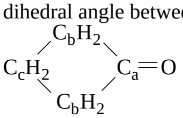
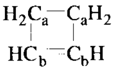
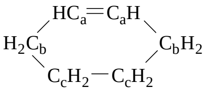
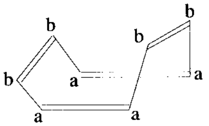
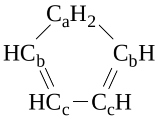
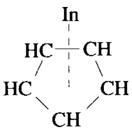
Compounds are Arranged in Alphabetical Order by Chemical Name; Cross References are Given for Common Synonyms (Lengths in Å and Angles in Degrees)

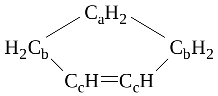
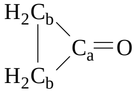
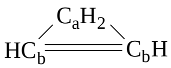
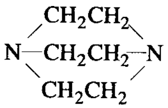
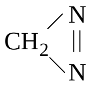
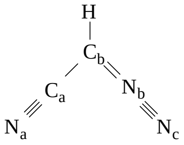
Compound	Structure				Method
Acetaldehyde			C_a—O	1.210	ED, MW
			C_b—H	1.107	
			C_a—H	1.128	
	C_a—C_b	1.515	∠C_bC_aO	124.1	
	∠HC_bH	109.8	∠C_bC_aH	115.3	
Acetamide	C—O	1.220	C—N	1.380	ED
CH_3CONH_2	C—C	1.519	N—H	1.022	
	C—H	1.124	∠NCO	122.0	
	∠CCN	115.1			
Acetic acid			C—C	1.520	ED
			C—O_a	1.214	
			C—O_b	1.364	
	C—H	1.10	∠CCO_a	126.6	
	∠CCO_b	110.6			
Acetone	C—C	1.520	C—O	1.213	ED, MW
$(CH_3)_2CO$	C—H	1.103	∠CCC	116.0	
	∠HCH	108.5	symmetry axis of each methyl group is tilted 2° from the C—C bond		
Acetonitrile	C—H	1.107	C—C	1.468	ED, MW
CH_3CN	C—N	1.159	∠CCH	109.7	
Acetonitrile oxide	C—C	1.442	C—N	1.169	MW
CH_3CNO	N—O	1.217	(C_{3v})		
Acetyl chloride	C—H	1.105	C—O	1.187	ED, MW
CH_3COCl	C—C	1.506	C—Cl	1.798	
	∠HCH	108.6	∠OCCl	121.2	
	∠CCCl	111.6			
Acetyl cyanide → Pyruvonitrile					
Acetylene	C—H (r_e)	1.060	C—C (r_e)	1.203	IR
HC≡CH					
Acrolein → Acrylaldehyde					
Acrylaldehyde			C_b—C_c	1.484	ED, MW
			C_a—C_b	1.345	
			C_c—O	1.217	
			C_a—H	1.10	
			C_c—H	1.13	
	∠$C_aC_bC_c$	120.3	∠C_bC_cO	123.3	
	∠HC_cC_b	114	other CCH angles (average)	122	
	planar *s-trans* form				
Acrylonitrile			C_a—C_b	1.343	ED, MW
			C_b—C_c	1.438	
			C_c—N	1.167	
			C_a—H	1.114	
			∠$C_aC_bC_c$	121.7	
	∠C_bC_cN	178	∠HCC	120	
Acryloyl chloride	C—H	1.086 (assumed)	C_b—C_c	1.48	MW
	C_c—Cl	1.82	C_a—C_b	1.35	
			C_c—O	1.19	
			∠C_aC_bH	120 (assumed)	
			∠C_bC_aH	121.5 (assumed)	
			∠$C_aC_bC_c$	123	
			∠C_bC_cCl	116	
			∠C_bC_cO	127	

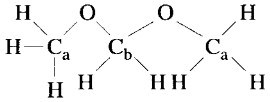
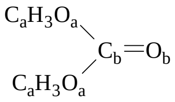
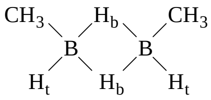
Compound	Structure				Method
Allene	C—C	1.3084	C—H	1.087	IR
CH_2=C=CH_2	∠HCH	118.2			
Allyl chloride			*cis* conformer C—Cl 1.811 ∠CCCl 115.2 *skew* conformer C—Cl 1.809		MW
	∠CCCl	109.6	CCCCl	dihedral angle of internal rotation 122.4	
Aniline	C—C	1.392	C—N	1.431	MW
$C_6H_5NH_2$	N—H	0.998	∠HNH	113.9	
	dihedral angle between the NH_2 plane and the N—C bond			140.6	
Azetidine			C—N	1.482	ED
			C—C	1.553	
			C—H	1.107	
	N—H	1.03	∠CNC	92.2	
	∠CCC	86.9	∠CCN	85.8	
	dihedral angle between the CCC and CNC planes			147	
Aziridine			N—H	1.016	MW
			N—C	1.475	
			C—C	1.481	
			C—H	1.084	
			∠CNC	60.3	
			∠H_aNC	109.3	
	∠H_bCH_c	115.7	∠H_bCC	117.8	
	∠H_bCN	118.3	∠H_cCC	119.3	
	∠H_cCN	114.3			
Azomethane	C—N	1.482	N—N	1.247	ED
CH_3N=NCH_3	∠CNN	112.3	*trans* conformer		
Benzene	C—C	1.399	C—H	1.101	ED, IR
C_6H_6					
p-Benzoquinone			C_a—O	1.225	ED
			C_b—C_b	1.344	
			C_a—C_b	1.481	
			∠$C_bC_aC_b$	118.1	
Biacetyl	C—O	1.215	C—C (average)	1.524	ED
$CH_3COCOCH_3$	C—H	1.108	∠CCO	119.5	
	∠CCC	116.2	*trans* conformer		
Bicyclo[1.1.0]butane			C_a—C_a	1.497	MW
			C_a—C_b	1.498	
			C_a—H_a	1.071	
			C_b—H_b, C_b—H_c	1.093	
			∠$H_bC_bH_c$	115.6	
	∠$C_bC_aH_a$	130.4	∠$C_aC_bC_a$	60.0	
	∠$C_aC_aH_a$	128.4	dihedral angle between the two $C_aC_aC_b$ planes	121.7	
Bicyclo[2.2.1]hepta-2,5-diene			C_a—C_b	1.535	ED
			C_b—C_b	1.343	
			C_a—C_c	1.573	
			C—H	1.12	
			∠$C_aC_cC_a$	94	
		dihedral angle between the two $C_aC_bC_bC_a$ planes		115.6 (C_{2v})	
Bicyclo[2.2.1]heptane	See the preceding molecule for the labels of the C atoms				ED
C_7H_{12}	C_a—C_b	1.54	C_b—C_b	1.56	
	C_a—C_c	1.56	C—C (average)	1.549	
	–$C_aC_cC_a$	93.1	dihedral angle between the two $C_aC_bC_bC_a$ planes	113.1	

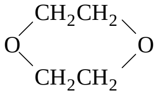
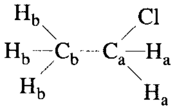
Compound	Structure				Method
Bicyclo[2.2.0]hexa-2,5-diene			$C_b—C_b$	1.345	ED
			$C_a—C_a$	1.574	
			$C_a—C_b$	1.524	
		dihedral angle between the two $C_aC_bC_bC_a$ planes		117.3	
Bicyclo[2.2.2]octane	$HC_a(C_bH_2C_bH_2)_3C_aH$		$C_a—C_b$	1.54	ED
	$C_b—C_b$	1.55	$\angle C_aC_bC_b$	109.7	
	C—C (average)	1.542			
	large-amplitude torsional motion about the D_{3h} symmetry axis				
Bicyclo[1.1.1]pentane C_5H_8	C—C	1.557	∠CCC	74.2	ED
Bicyclo[2.1.0]pentane			$C_a—C_a$	1.536	MW
			$C_b—C_b$	1.565	
			$C_a—C_b$	1.528	
			$C_a—C_c$	1.507	
	Dihedral angle between the $C_aC_aC_bC_b$ and $C_aC_aC_c$ planes			112.7	
Biphenyl			C—C (intra-ring)	1.396	ED
			(inter-ring)	1.49	
			torsional dihedral angle between the two rings	~40	
4,4′-Bipyridyl	C—C, C—N (intra-ring)		1.375		ED
			C—C (inter-ring)	1.465	
			torsional dihedral angle between the two rings	~37	
Bis (cyclopentadienyl) beryllium $(C_5H_5)_2Be$	Be—(cyclopentadienyl plane)		1.470, 1.92		ED
	C—C 1.423 (C_{5v}) (The Be atom has two equilibrium positions)				
Bis (cyclopentadienyl) iron → Ferrocene					
Bis (cyclopentadienyl) lead $(C_5H_5)_2Pb$	C—C	1.430	Pb—C	2.79	ED
	dihedral angle between the two C_5H_5 planes 40~50 (The two rings are not parallel.)				
Bis (cyclopentadienyl) manganese $(C_5H_5)_2Mn$	Mn—C 2.383	C—C 1.429	(D_{5h})		ED
Bis (cyclopentadienyl) nickel $(C_5H_5)_2Ni$	Ni—C	2.196	C—C	1.430 (D_{5h})	ED
Bis (cyclopentadienyl) ruthenium $(C_5H_5)_2Ru$	C—C	1.439	Ru—C	2.196	ED
Bis (cyclopentadienyl) tin $(C_5H_5)_2Sn$	C—C	1.431	Sn—C	2.71	ED
	C—H	1.14	(D_{5h})		
Bis (trifluoromethyl) peroxide CF_3OOCF_3	O—O	1.42	C—O	1.399	ED
	C—F	1.320	∠COO	107	
	∠FCF	109.0	COOC dihedral angle of internal rotation	123	
Borine carbonyl BH_3CO	B—H	1.194	B—C	1.540	MW
	C—O	1.131	∠HBH	113.9	
	∠BCO	180	(C_{3v})		
Bromobenzene			C—H	1.072	MW
			$C_c—C_d$	1.401	
			$C_b—C_c$	1.375	
			C—Br	1.85	
			$C_a—C_b$	1.42	
			$\angle C_bC_aC_b$	117.4	
Bromoform $CHBr_3$	C—Br	1.924	C—H	1.11	ED, MW
	∠BrCBr	111.7	(C_{3v})		
Bromoiodoacetylene IC≡CBr	C—I	1.972	C—C	1.206	ED
	C—Br	1.795			

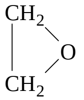
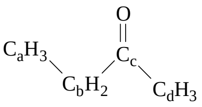
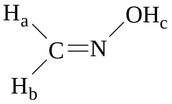
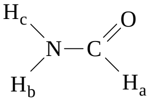
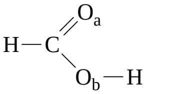
Compound	Structure				Method
1,3-Butadiene	C_aH_2=C_bH—C_bH=C_aH_2		C_b—C_b	1.467	ED
			C_a—C_b	1.349	
			C—H (average)	1.108	
			∠CCC	124.4	
	∠C_bC_aH	120.9	*anti* conformer	(C_{2h})	
1,3-Butadiyne	HC_a≡C_b—C_b≡C_aH		C—H	1.09	ED
	C_a—C_b	1.218	C_b—C_b	1.384	
			linear		
Butane	C—C	1.531	C—H	1.117	ED
$CH_3CH_2CH_2CH_3$	∠CCC	113.8	∠CCH	111.0	
	trans conformer 54%		dihedral angle for the *gauche* conformer	65	
2-Butanone → Ethyl methyl ketone					
Butatriene	H_2C_a=C_b=C_b=C_aH_2		C—H	1.08	ED
	C_a—C_b	1.32	C_b—C_b	1.28 (D_{2h})	
2-Butene	C_aH_3—C_bH=C_bH—C_aH_3		ED		
	C_a—C_b	*cis* conformer	1.506	*trans* conformer 1.508	
	C_b—C_b	1.346	1.347		
	∠$C_aC_bC_b$	125.4	123.8		
3-Buten-1-yne → Vinylacetylene					
tert-Butyl chloride	C—H	1.102	C—C	1.528	ED, MW
$(CH_3)_3CCl$	C—Cl	1.828	∠CCCl	107.3	
	∠CCH	110.8	∠CCC	111.6	
tert-Butyl cyanide → Pivalonitrile					
2-Butyne	C_aH_3—C_b≡C_b—C_aH_3	C—H	1.116	ED	
	C_b—C_b	1.214	C_a—C_b	1.468	
	∠C_bC_aH	110.7			
Carbon C_2	C—C (r_e)	1.3119			UV
Carbon C_3	C—C	1.277	linear		UV
Carbon suboxide → Tricarbon dioxide					
Carbon tetrabromide	C—Br	1.935	(T_d)		ED
CBr_4					
Carbon tetrachloride	C—Cl	1.767	(T_d)		ED
CCl_4					
Carbon tetrafluoride	C—F	1.323	(T_d)		ED
CF_4					
Carbon tetraiodide	C—I	2.15	(T_d)		ED
CI_4					
Carbonyl cyanide	C—O	1.209	C—C	1.466	ED, MW
$CO(CN)_2$	C—N	1.153	∠CCC	115	
	∠CCN	180			
Chloroacetylene	C—H	1.0550	C—C	1.2033	MW
HC≡CCl	C—Cl	1.6368			
Chlorobenzene	C—C	1.400	C—Cl	1.737	ED
C_6H_5Cl	C—H	1.083	∠CC(Cl)C	121.7	
	∠CC(H)C	120			
Chlorobromoacetylene	Cl—C	1.636	C—C	1.206	ED
ClC≡CBr	C—Br	1.784			
Chlorocyanoacetylene	C—Cl	1.624	C—C	1.205	ED
ClC≡CCN	C—CN	1.362	C—N	1.160	
Chloroethane → Ethyl chloride					
2-Chloroethanol	C—O	1.413	C—C	1.519	ED
$ClCH_2CH_2OH$	C—Cl	1.801	C—H	1.093	
	O—H 1.033	∠CCCl 110.7	∠CCO 113.8		
	fraction of the *gauche* conformer at 37°C is 92 ~ 94%,				
	dihedral angle of internal rotation		62.4		
Chloroethylene → Vinyl chloride					
Chloroform	C—H	1.100	C—Cl	1.758	MW
$CHCl_3$	∠ClCCl	111.3	(C_{3v})		

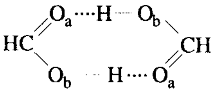
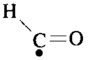
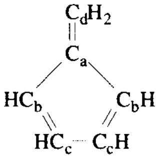
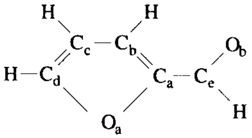
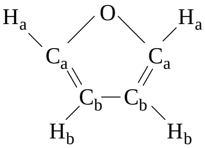
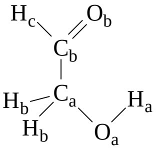
Compound	Structure				Method
Chloroiodoacetylene	C—Cl	1.63	C—I	1.99	MW
ClC≡CI	C—C	1.209 (assumed)			
Chloromethane → Methyl chloride					
3-Chloropropene → Allyl chloride					
Cyanamide	N_a—C	1.346	C—N_b	1.160	MW
$H_2N_aCN_b$	N—H	1.00	∠HNH	114	
	dihedral angle between the NH_2 plane and the N—C bond			142	
Cyanoacetylene	C_b—H	1.058	C_a—C_b	1.205	MW
H—C_b≡C_a—C_c≡N	C_a—C_c	1.378	C_c—N	1.159	
Cyanocyclopropane	C—C (ring)	1.513	C—C_a	1.472	MW
$C_3H_5C_aN$	C—H	1.107	C_a—N	1.157	
	∠HCH	114.6	∠C_aCH	119.6	
Cyanogen	C—N	1.163	C—C	1.393	ED
$(CN)_2$				linear	
Cyclobutane	C—H	1.113	C—C	1.555	ED
$(CH_2)_4$	dihedral angle between the two CCC planes		145		
Cyclobutanone			C_a—C_b	1.527	MW
			C_b—C_c	1.556	
			∠$C_bC_aC_b$	93.1	
			∠$C_aC_bC_c$	88.0	
Cyclobutene			C_b—C_b 1.342	C_a—C_a 1.566	MW
			C_a—C_b 1.517	C_a—H 1.094	
			C_b—H 1.083		
	∠$C_aC_bC_b$	94.2	∠C_bC_bH	133.5	
	∠C_aC_aH	114.5	∠$C_aC_aC_b$	85.8	
	∠HC_aH	109.2	dihedral angle between the CH_2 plane and the C_a—C_a bond	135.8	
Cyclohexane	C—C	1.536	C—H	1.119	ED
C_6H_{12}	∠CCC	111.3	chair form		
Cyclohexene			C_a—C_a	1.334	ED
			C_a—C_b	1.50	
			C_b—C_c	1.52	
			C_c—C_c	1.54	
	∠$C_aC_aC_b$	123.4	∠$C_aC_bC_c$	112.0	
	∠$C_bC_cC_c$	110.9	(C_2)	half-chair form	
Cyclooctatetraene			C_a—C_b	1.476	ED
			C—H	1.100	
			C_a—C_a,C_b—C_b	1.340	
			∠$C_bC_aC_a$, ∠$C_aC_bC_b$	126.1	
	dihedral angle between the $C_aC_aC_aC_a$ and $C_aC_bC_bC_a$ planes			136.9	
	tub form	(D_{2d})			
1,3-Cyclopentadiene			C_a—C_b	1.509	MW
			C_b—C_c	1.342	
			C_c—C_c	1.469	
			∠$C_aC_bC_c$	109.3	
	∠$C_bC_cC_c$	109.4	∠$C_bC_aC_b$	102.8	
Cyclopentadienylindium			In—C	2.621	ED
			C—C	1.426	
			(C_{5v})		
Cyclopentane	C—H	1.114	C—C	1.546	ED
$(CH_2)_5$	∠CCH	111.7			
	(The out-of-plane vibration of the C atoms is essentially free pseudorotation; average value of the displacements of the C atoms from the molecular plane 0.43)				

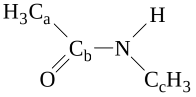
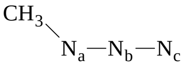
Compound	Structure				Method
Cyclopentene			$C_a—C_b$	1.546	ED
			$C_b—C_c$	1.519	
			$C_c—C_c$	1.342	
			$∠C_bC_aC_b$	104.0	
	$∠C_bC_cC_c$	110.0	$∠C_aC_bC_c$	103.0	
	dihedral angle between the $C_bC_aC_b$ and $C_bC_cC_cC_b$ planes			151.2	
Cyclopropane $(CH_2)_3$	C—C	1.512	C—H	1.083	R
	∠HCH	114.0			
Cyclopropanone		C—H 1.086; $C_b—C_b$ 1.575; $∠C_aC_bC_b$ 57.7	$C_a—C_b$ 1.475; $C_a—O$ 1.191		MW
	$∠HC_bH$	114	dihedral angle between the CH_2 plane and the $C_b—C_b$ bond	151	
Cyclopropene			$C_b—C_b$	1.304	ED
			$C_a—C_b$	1.519	
			$C_b—H$	1.077	
	$C_a—H$	1.112	$∠C_bC_bH$	133	
	$∠HC_aH$	118			
Decalin $C_{10}H_{18}$	C—C (average)	1.530	C—H (average)	1.113	ED
	∠CCC (average)	111.4			
Dewer benzene → Bicyclo[2.2.0] hexa-2,5-diene					
Diacetylene → 1,3-Butadiyne					
1,4-Diazabicyclo[2.2.2]octane			C—N	1.472	ED
			C—C	1.562	
			∠NCC	110.2	
			∠CNC	108.7	
	large-amplitude torsional motion about the D_{3h} symmetry axis				
2,3-Diaza-1,3-butadiene → Formaldehyde azine					
Diazirine			C—H	1.09	MW
			C—N	1.482	
			N—N	1.228	
			∠HCH	117	
Diazoacetonitrile			$C_b—N_b$	1.280	MW
			$N_b—N_c$	1.132	
			$C_a—N_a$	1.165	
			C—H	1.082	
			$C_a—C_b$	1.424	
	$∠C_aC_bH$	117	$∠C_aC_bN_b$	119.5	
Diazomethane CH_2N_2	C—H	1.075	C—N	1.32	MW, IR
	N—N	1.12	∠HCH	126.0 linear	
1,2-Dibromoethane CH_2BrCH_2Br	C—C	1.506	C—Br	1.950	ED
	C—H	1.108	∠CCBr	109.5	
	∠CCH 110	fraction of the *trans* conformer at 25°C		95%	
Dibromomethane CH_2Br_2	C—H	1.08	C—Br	1.924	ED
	∠HCBr	109	∠BrCBr	113.2	
2,2′-Dichlorobiphenyl $C_6H_4Cl—C_6H_4Cl$	C—C	1.398	C—C inter-ring	1.495	ED
	C—Cl	1.732	C—H	1.10	
	∠CCCl	121.4	∠CCH	126	
	dihedral angle between the two aromatic rings 74 (defined to be 0 for that of the *cis* conformer)				
trans-1,4-Dichlorocyclohexane $C_6H_{10}Cl_2$	C—H	1.102	C—Cl	1.810	ED
	C—C	1.530	∠CCC	111.5	
	∠CCCl (*ee*)	108.6	∠CCCl (*aa*)	110.6	
	∠HCCl (*ee*)	111.5	∠HCCl (*aa*)	107.6	
	ee 49%	*aa* 51%	e: equatorial, a: axial		

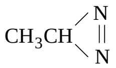
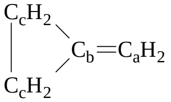
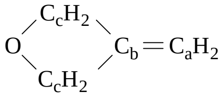
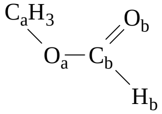
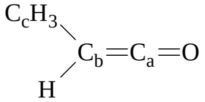
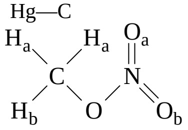
Compound	Structure				Method
1,1-Dichloroethane	C—Cl	1.766	C—C	1.540	MW
$CHCl_2CH_3$	∠ClCCl	112.0	∠CCCl	111.0	
1,2-Dichloroethane	C—C	1.531	C—Cl	1.790	ED
CH_2ClCH_2Cl	C—H	1.11	∠CCCl	109.0	
	∠CCH	113			
	fraction of the *trans* conformer at room temperature 73%, that of the *gauche* conformer 27%				
1,1-Dichloroethylene	C—C	1.32 (assumed)	C—Cl	1.73	MW
$CH_2{=}CCl_2$	∠ClCC	123	(C_{2v})		
cis-1,2-Dichloroethylene	C—Cl	1.718	C—C	1.354	ED
CHCl=CHCl	∠ClCC	123.8			
Dichloromethane	C—H (r_e)	1.087	C—Cl (r_e)	1.765	MW, IR
CH_2Cl_2	∠HCH (θ_e)	111.5	∠ClCCl (θ_e)	112.0	
1,1-Difluoroethane	C—C	1.498	C—H (average)	1.081	ED
CH_3CHF_2	C—F	1.364	∠CCH (average)	111.0	
	∠CCF 110.7	dihedral angle between the two CCF planes 118.9			
1,2-Difluoroethane	C—F	1.389	C—C	1.503	ED
CH_2FCH_2F	C—H	1.103	∠CCF	110.3	
	∠CCH 111	dihedral angle of internal rotation 109			
	fraction of the *gauche* conformer at 22°C 94%				
1,1-Difluoroethane	C—C	1.340	C—F	1.315	ED, MW
$CH_2{=}CF_2$	C—H	1.091	∠CCF	124.7	
	∠CCH	119.0			
cis-1,2-Difluoroethylene	C—C	1.33	C—F	1.342	ED, MW
CHF=CHF	C—H	1.099	∠CCF	122.0	
	∠CCH	124.1			
Difluoromethane	C—H	1.093	C—F	1.357	MW
CH_2F_2	∠HCH	113.7	∠FCF	108.3	
Dimethoxymethane			C_a—O	1.432	ED
			C_b—O	1.382	
			C—H (average)	1.108	
	∠COC	114.6	∠OCO	114.3	
	∠OCH	110.3			
Dimethylacetylene → 2-Butyne					
Dimethylamine	C—H	1.106	N—H	1.00	ED
$(CH)_2NH$	C—N	1.455	∠CNC	111.8	
	∠CNH	107	∠NCH	112	
	∠HCH	107			
Dimethylberyllium	Be—C	1.698	C—H	1.127	ED
$(CH_3)_2Be$	∠BeCH	113.9	CBeC linear		
Dimethylcadmium	C—Cd	2.112	∠HCH	108.4	R
$(CH_3)_2Cd$					
Dimethyl carbonate			C_b—O_b	1.209	ED
			C_b—O_a	1.34	
			C_a—O_a	1.42	
	∠$O_aC_bO_a$	107	∠$C_bO_aC_a$	114.5	
Dimethylcyanamide	C_b—N_b	1.161	C_b—N_a	1.338	ED
$(C_aH_3)_2N_a$—$C_b{\equiv}N_b$	C_a—N_a	1.463	∠C_aNC_a	115.5	
	∠C_aNC_b	116.0			
1,2-Dimethyldiborane			B—B	1.799	ED
			B—C	1.580	
			B—H_b	1.358 (*cis*), 1.365 (*trans*)	
	B—H_t	1.24			
	∠BBC	122.6 (*cis*), 121.8 (*trans*)			
Dimethyl diselenide	C—H	1.13	C—Se	1.95	ED
$(CH_3)_2Se_2$	Se—Se	2.326	∠CSeSe	98.9	
	∠HCSe 108	dihedral angle between the CSeSe and SeSeC planes 88			

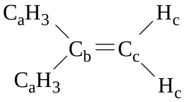
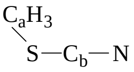
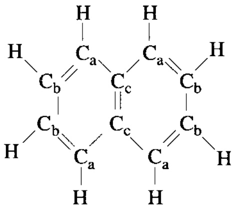
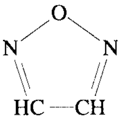
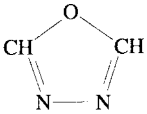
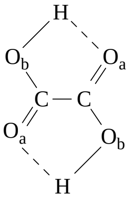
Compound	Structure				Method
Dimethyl disulfide	C—S	1.816	S—S	2.029	ED
$(CH_3)_2S_2$	C—H	1.105	∠SSC	103.2	
	∠SCH 111.3	CSSC dihedral angle of internal rotation		85	
S,S′-Dimethyl dithiocarbonate	$C_aH_3SC_bSC_aH_3$ (with O double-bonded to C_b)		C_b—O	1.206	ED
			C_b—S	1.777	
			C_a—S	1.802	
	∠OCS	124.9	∠CSC	99.3	
			syn-syn conformer		
Dimethyl ether	C—O	1.416	C—H	1.121	ED
$(CH_3)_2O$	∠COC	112	∠HCH	108	
Dimethylglyoxal → Biacetyl					
N,N′-Dimethylhydrazine	N—N	1.42	C—N	1.46	ED
$CH_3NH—NHCH_3$	N—H	1.03	C—H	1.12	
	∠NNC 112	CNNC dihedral angle of internal rotation		90	
Dimethylmercury	C—Hg	2.083	C—H	1.160 (assumed)	ED
$(CH_3)_2Hg$	Hg···H	2.71			
Dimethylphosphine	C—P	1.848	P—H	1.419	MW
$(CH_3)_2PH$	∠CPC	99.7	∠CPH	97.0	
Dimethyl selenide	C—H	1.093	Se—C	1.943	MW
$(CH_3)_2Se$	∠CSeC	96.2	∠SeCH	108.7	
	∠HCH	110.3			
Dimethyl sulfide	C—S	1.807	C—H	1.116	ED, MW
$(CH_3)_2S$	∠CSC	99.05	∠HCH	109.3	
Dimethyl sulfone	C—H	1.114	S—O	1.435	ED
$(CH_3)_2SO_2$	S—C	1.771	∠CSC	102	
	∠OSO	121			
Dimethyl sulfoxide	C—H	1.081	C—S	1.799	MW
$(CH_3)_2SO$	S—O	1.485	∠CSC	96.6	
	∠CSO	106.7	∠HCH	110.3	
	dihedral angle between the SCC plane and the S—O bond			115.5	
Dimethylzinc	Zn—C	1.929	∠HCH	107.7	R
$(CH_3)_2Zn$					
1,4-Dioxane	C—C	1.523	C—O	1.423	ED
	C—H	1.112	∠COC	112.45	
	∠CCO	109.2	chair form		
Ethanal → Acetaldehyde					
Ethane	C—C	1.5351	C—H	1.0940	MW
C_2H_6	∠CCH	111.17	staggered conformation		
Ethanethiol	$C_bH_3—C_aH_2—SH$		C_a—H	1.090	MW
	C_b—H	1.093	C_a—C_b	1.530	
	C_a—S	1.829	S—H	1.350	
	∠C_bC_aH	109.6	∠C_aC_bH	109.7	
	∠C_bC_aS	108.3	∠C_aSH	96.4	
Ethanol	$C_bH_3C_aH_2OH$		C—C	1.512	MW
	C—O	1.431	O—H	0.971	
	C_a—H	1.10	C_b—H	1.09	
	∠CCO	107.8	∠COH	105	
	∠C_bC_aH	111	∠C_aC_bH	110	
	staggered conformation				
Ethyl chloride			C—C	1.528	ED, MW
			C—Cl	1.802	
			C—H	1.103	
			C_a—H_a=C_b—H_b (assumed)		
			∠CCCl	110.7	
	∠$H_bC_bH_b$	109.8	∠$H_aC_aH_a$	109.2	
	∠$C_bC_aH_a$	110.6			
Ethylene	C—H	1.087	C—C	1.339	MW
CH_2=CH_2	∠CCH	121.3			

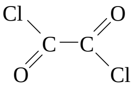
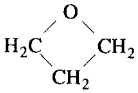
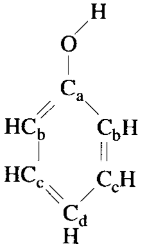
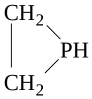
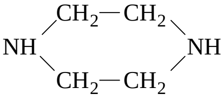
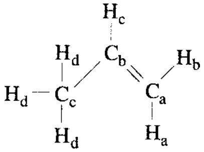
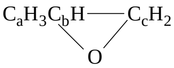
Compound	Structure				Method
Ethylenediamine	C—N	1.469	C—C	1.545	ED
$H_2NCH_2CH_2NH_2$	C—H	1.11	∠CCN	110.2	
	gauche conformer	dihedral angle between the NCC and CCN planes		64	
Ethylene dibromide → 1,2-Dibromoethane					
Ethylene dichloride → 1,2-Dichloroethane					
Ethyleneimine → Aziridine					
Ethylene oxide	C—C	1.466	C—H	1.085	MW
	C—O	1.431	∠HCH	116.6	
	dihedral angle between the NH_2 plane and the N—C bond			158.0	
Ethylene sulfide → Thiirane					
Ethyl methyl ether	C—O (average)	1.418	C—C	1.520	ED
$C_2H_5OCH_3$	C—H (average)	1.118	∠COC	111.9	
	∠OCC	109.4	∠HCH	109.0	
	fraction of the *trans* conformer at 20°C		80%		
Ethyl methyl ketone			C—C (average)	1.518	ED
			C_c—O	1.219	
			C—H (average)	1.102	
			$\angle C_aC_bC_c$	113.5	
	$\angle C_bC_cO$, $\angle C_dC_cO$	121.9	*trans* conformer	95%	
Ethyl methyl sulfide	C—S (average)	1.813	C—C	1.536	ED
$C_2H_5SCH_3$	C—H	1.111	∠CSC	97	
	∠SCC	114.0	∠HCH	110	
	fraction of the *gauche* conformer at 20°C		75%		
Ferrocene	C—C	1.440	C—H	1.104	ED
$(C_5H_5)_2Fe$	Fe—C	2.064	(D_{5h})		
Fluoroform	C—H	1.098	C—F	1.332	MW
CHF_3	∠FCF	108.8	(C_{3v})		
Formaldehyde	C—H	1.116	C—O	1.208	MW
H_2CO	∠HCH	116.5			
Formaldehyde azine	H_2C=N—N=CH_2	N—N	1.418		ED
	C—N	1.277	C—H	1.094	
	∠CNN	111.4	∠HCN	120.7	
	fraction of the *trans* conformer at –30°C		91%		
Formaldehyde dimethylacetal → Dimethoxy-methane					
Formaldoxime			$C—H_a$	1.085	MW
			$C—H_b$	1.086	
			C—N	1.276	
	N—O	1.408	$O—H_c$	0.956	
	$\angle H_bCN$	115.6	∠CNO	110.2	
	$\angle H_aCN$	121.8	$\angle NOH_c$	102.7	
Formamide			$C—H_a$	1.125	ED, MW
			N—H	1.027	
			C—N	1.368	
	C—O	1.212	∠NCO	125.0	
	∠CNH (average)	119.2			
Formic acid			$C—O_a$	1.202	MW
			$C—O_b$	1.343	
	$O_b—H$	0.972	C—H	1.097	
	$\angle HCO_a$	124.1	$\angle O_aCO_b$	124.9	
	$\angle CO_bH$	106.3	planar		

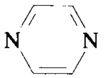
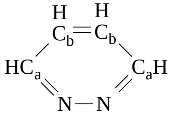
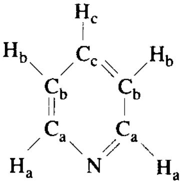
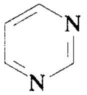
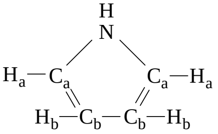
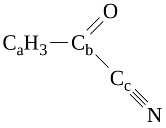
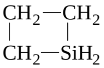
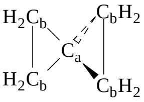
Compound	Structure				Method
Formic acid dimer			$O_a \cdots O_b$	2.703	ED
			C—O_a	1.220	
			C—O_b	1.323	
			∠O_aCO_b	126.2	
			∠CO_aO_b	108.5	
Formyl radical	 C—H	1.110	C—O	1.1712	MW
	∠HCO	127.43			
Fulvene			C_a—C_d	1.349	MW
			C_a—C_b	1.470	
			C_b—C_c	1.355	
			C_c—C_c	1.476	
			C_b—H	1.078	
			C_c—H	1.080	
	C_d—H	1.13	∠$C_bC_aC_b$	106.6	
	∠$C_aC_bC_c$	107.7	∠$C_bC_cC_c$	109	
	∠C_aC_bH	124.7	∠C_bC_cH	126.4	
	∠HC_dH	117			
2-Furaldehyde			C_a—C_e	1.458	MW
			C_e—O_b	1.250	
			C_e—H	1.088	
			∠$C_eC_aC_b$	133.9	
	∠C_aC_eH	116.9	∠C_aC_eO	121.6	
	trans conformer (with respect to the O_a and O_b atoms)				
Furan			C_b—C_b	1.431	MW
			C_a—C_b	1.361	
			C_a—O	1.362	
			C_a—H_a	1.075	
			C_b—H_b	1.077	
	∠$C_aC_bC_b$	106.1	∠C_aOC_a	106.6	
	∠C_bC_aO	110.7	∠OC_aH_a	115.9	
	∠$C_bC_bH_b$	128.0			
Furfural → 2-Furaldehyde					
Glycolaldehyde			C_b—O_b	1.209	MW
			C_a—O_a	1.437	
			C_a—C_b	1.499	
			O_a—H_a	1.051	
			C_b—H_c	1.102	
			C_a—H_b	1.093	
	∠$C_aC_bO_b$	122.7	∠$C_aC_bH_c$	115.3	
	∠$C_bC_aO_a$	111.5	∠$C_aO_aH_a$	101.6	
	∠$C_bC_aH_b$	109.2	∠$H_bC_aH_b$	107.6	
	∠$H_bC_aO_a$	109.7			
Glyoxal	C—C	1.526	C—O	1.212	ED, UV
CHOCHO	C—H	1.132	∠CCO	121.2	
	∠HCO	112	*trans* conformer	(C_{2h} (assumed))	
Hexachloroethane	C—C	1.56	C—Cl	1.769	ED
Cl_3CCCl_3	∠CCCl	110.0			
2,4-Hexadiyne	C_aH_3—C_b≡C_c—C_c≡C_b—C_aH_3				ED
	C_a—C_b	1.450	C_b—C_c	1.208	
	C_c—C_c	1.377	C_a—H	1.09	
Hexafluoroethane	C—C	1.545	C—F	1.326	ED
F_3CCF_3	∠CCF	109.8	staggered conformation		
Hexafluoropropene	average value of the C=C and C—F distances			1.329	ED
CF_2=$CFCF_3$	C—C	1.513	∠CCC	127.8	
	∠FCC (CF_2)	124	∠FCC (CF)	120	
	∠FCC (CF_3)	110			

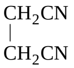
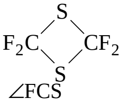
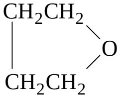
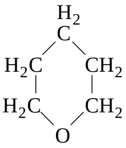
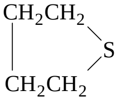
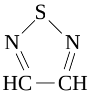
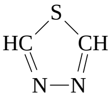
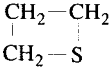
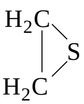
Compound	Structure				Method
1,3,5-Hexatriene	H_2C_a=C_bH—C_cH=C_cH—C_bH=C_aH_2				ED
	C_a—C_b	1.337	C_b—C_c	1.458	
	C_c—C_c	1.368	∠$C_aC_bC_c$	121.7	
	∠$C_bC_cC_c$	124.4			
Iminocyanide radical	N—H	1.034	N···N	2.470	UV
HṄCN	∠HNC	116.5	∠NCN	~180	
Iodocyanoacetylene	I—C_a	1.985	C_a—C_b	1.207	MW
I—C_a≡C_b—C_c≡N	C_b—C_c	1.370	C_c—N	1.160	
Isobutane	C_a—H	1.122	C_b—H	1.113	ED, MW
$(C_bH_3)_3C_aH$	C_a—C_b	1.535	∠$C_bC_aC_b$	110.8	
	∠C_aC_bH	111.4			
Isobutylene → 2-Methylpropene					
Ketene	C—C	1.317	C—O	1.161	MW
CH_2=C=O	C—H	1.080	∠HCH	123.0	
Malononitrile	C—H	1.091	C—C	1.480	MW
$C_aH_2(C_bN)_2$	C—N	1.147	∠CCC	110.4	
	∠HCH	108.4	∠CCN	176.6	
	(The two N atoms are bent away from each other in the plane of C_b—C_a—C_b)				
Methane	C—H (r_e)	1.0870	(T_d)		MW
CH_4					
Methanethiol	C—H	1.09	C—S	1.819	MW
CH_3SH	S—H	1.34	∠HSC	96.5	
	∠HCH	109.8			
	angle between the CH_3 symmetry axis and the C—S bond 2.2. (The axis of the CH_3 group is tilted away from the H atom with respect to the C—S bond.)				
Methanol	C—H	1.0936	C—O	1.4246	MW
CH_3OH	O—H	0.9451	∠HCH	108.63	
	∠COH	108.53			
	angle between the CH_3 symmetry axis and the C—O bond (The axis of the CH_3 group is tilted away from the H atom with respect to the C—O bond.)			3.27	
Methyl radical	C—H	1.08	planar		UV
$\cdot CH_3$					
N-Methylacetamide			C_a—C_b	1.520	ED
			N—C_c	1.469	
			C—H	1.107	
	C_b—N	1.386	C_b—O	1.225	
	∠C_bNC_c	119.7			
	∠NC_bO	121.8			
	∠C_aC_bN	114.1			
Methylacetylene → Propyne					
Methylal → Dimethoxymethane					
Methylamine	N—H	1.010	C—N	1.471	MW
CH_3NH_2	C—H	1.099	∠NHN	107.1	
	∠HNC	110.3	∠HCH	108.0	
	dihedral angle between the CH_3 symmetry axis and the C—N bond (The axis of the CH_3 group is tilted away from the NH_2 group with respect to the C—N bond.)			2.9	
Methyl azide			C—H	1.09	ED
			C—N_a	1.468	
			N_a—N_b	1.216	
	N_b—N_c	1.113	∠CN_aN_b	116.8	
	NNN linear				
Methyl bromide	C—H (r_e)	1.086	C—Br (r_e)	1.933	MW, IR
CH_3Br	∠HCH (θ_e)	111.2	(C_{3v})		
Methyl chloride	C—H	1.090	C—Cl	1.785	MW, IR
CH_3Cl	∠HCH	110.8			

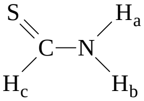
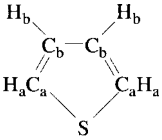
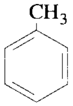
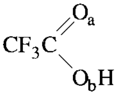
Compound	Structure				Method
Methyldiazirine	 C—N 1.481; N—N 1.235		C—C 1.501; ∠NCN 49.3		MW
	dihedral angle between the CNN plane and the C—C bond			122.3	
Methylene :CH_2	C—H	1.078	∠HCH	130	LMR
Methylenecyclopropane			C_a—C_b	1.332	MW
			C_b—C_c	1.457	
			C_c—C_c	1.542	
	C_c—H	1.09	$\angle C_cC_bC_c$	63.9	
	$\angle HC_aH$	114.3	$\angle HC_cH$	113.5	
	dihedral angle between the C_cH_2 plane and the C_c—C_c bond			150.8	
3-Methyleneoxetane			C_b—C_c	1.52	MW
			C_c—O	1.45	
			C_a—C_b	1.33	
	C—H	1.09 (assumed)	$\angle C_cC_bC_c$	87	
	$\angle HC_cH$	114 (assumed)	$\angle HC_aH$	120 (assumed)	
Methyl fluoride	C—H (r_e)	1.095			MW, IR
CH_3F	C—F (r_e)	1.382	∠HCH (θ_e)	110.45 (C_{3v})	
Methyl formate			C_a—H	1.08	ED
			C_b—O_b	1.206	
			C—O (average)	1.393	
			C_b—H	1.101 (assumed)	
	$\angle O_aC_bO_b$	127	∠COC	114	
	$\angle O_aC_aH$	110			
Methylgermane	C—H	1.083	Ge—H	1.529	MW
CH_3GeH_3	C—Ge	1.945	∠HCH	108.4	
	∠HGeH	109.3			
Methyl hypochlorite	C—H	1.103	O—Cl	1.674	MW
CH_3OCl	O—C	1.389	∠HCH	109.6	
	∠COCl	112.8			
Methylidyne radical :ĊH	C—H (r_e)	1.1198			UV
Methylidyne phosphide HCP	H—C (r_e)	1.0692	C—P (r_e)	1.5398	MW
Methyl iodide	C—H (r_e)	1.084	C—I (r_e)	2.132	MW, IR
CH_3I	∠HCH (θ_e)	111.2	(C_{3v})		
Methyl isocyanide	C_aH_3—N≡C_b	C_a—H 1.102	C_a—N	1.424	MW
	N—C_b	1.166	$\angle NC_aH$	109.12	
Methylketene			O—C_a	1.171	MW
			C_b—C_c	1.518	
			C_c—H	1.10	
	C_a—C_b	1.306	C_b—H	1.083	
	$\angle OC_aC_b$	180.5	$\angle C_aC_bC_c$	122.6	
	$\angle C_aC_bH$	113.7	$\angle C_cC_bH$	123.7	
	∠HCH	109.2			
Methylmercury chloride	Hg—Cl	2.282	C—H	1.15	MW,
CH_3HgCl	Hg—C	1.99	(C_{3v})		NMR
Methyl nitrate			C—H_a	1.10	MW
			C—H_b	1.09	
			C—O	1.437	
			O—N	1.402	
	N—O_a	1.205	N—O_b	1.208	
	$\angle OCH_a$	110	$\angle OCH_b$	103	
	∠CON	112.7	$\angle ONO_a$	118.1	
	$\angle ONO_b$	112.4			

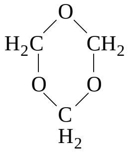
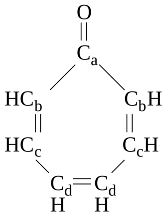
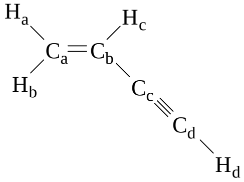
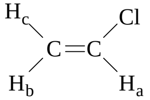
Compound	Structure						Method
Methylphosphine CH_3PH_2	C—P	1.858	C—H	1.094			ED
2-Methylpropane → Isobutane							
2-Methylpropene			C_a—H	1.119			ED, MW
			C_c—H_c	1.10			
			C_a—C_b	1.508			
			C_b—C_c	1.342			
	∠HC_aC_b (average)	111.4	∠$H_cC_cH_c$	118.5			
	∠$C_aC_bC_a$	115.6	∠$C_aC_bC_c$	122.2			
	∠HC_aH	107.9	∠C_bC_cH	121			
Methylsilane CH_3SiH_3	C—H	1.093	C—Si	1.867			MW
	Si—H	1.485	∠HCH	107.7			
	∠HSiH	108.3	(C_{3v})				
Methylstannane CH_3SnH_3	C—Sn	2.143	Sn—H	1.700			MW
			(C_{3v})				
Methyl thiocyanate			S—C_b	1.684	S—C_a	1.824	MW
			C_b—N	1.170	C—H	1.081	
	∠C_aSC_b	99.0	∠HCH	110.6	∠HCS	108.3	
Naphthalene			C_a—C_b	1.37			ED
			C_b—C_b	1.41			
			C_a—C_c	1.42			
			C_c—C_c	1.42			
			C—C (average)	1.40			
			∠$C_aC_cC_c$	119.4			
Neopentane $C(CH_3)_4$	C—C	1.537	C—H	1.114			ED
	∠CCH	112					
Nickelocene → Bis (cyclopentadienyl) nickel							
Nitromethane CH_3NO_2	C—H	1.088 (assumed)	C—N	1.489			MW
	N—O	1.224	∠NCH	107			
	∠ONO	125.3					
N-Nitrosodimethylamine $(CH_3)_2NNO$	N—O	1.235	N—N	1.344			ED
	C—N	1.461	∠ONN	113.6			
	∠CNC	123.2	∠CNN	116.4			
Nitrosomethane CH_3NO	C—N	1.49	N—O	1.22			MW
	C—H	1.084	∠CNO	112.6			
	∠NCH	109.0					
Norbornane → Bicyclo[2.2.1]heptane							
Norbornadiene → Bicyclo[2.2.1]hepta-2,5-diene							
1,2,5-Oxadiazole			O—N	1.380	∠NON	110.4	MW
			C—N	1.300	∠ONC	105.8	
			C—C	1.421	∠CCN	109.0	
			C—H	1.076	∠CCH	130.2	
			∠NCH	120.9	planar		
1,3,4-Oxadiazole			O—C	1.348	∠COC	102.0	MW
			C—N	1.297	∠OCN	113.4	
			N—N	1.399	∠CNN	105.6	
			C—H	1.075	∠OCH	118.1	
			∠NCH	128.5	planar		
Oxalic acid			C—C	1.544			ED
			C—O_a	1.205			
			C—O_b	1.336			
			O_b—H	1.05			
			∠CCO_a	123.1			
			∠O_aCO_b	125.0			
			∠CO_bH	104			

Compound	Structure				Method
Oxalyl dichloride			C—O	1.182	ED
			C—C	1.534	
			C—Cl	1.744	
	∠CCO	124.2	∠CCCl	111.7	
	fraction of the *trans* conformer at 0°C 68%, that of the *gauche* conformer 32%				
Oxetane			C—O	1.448	MW
			C—C	1.546	
			C—H (average)	1.090	
			∠COC	92	
	∠CCC	85	∠OCC	92	
	∠HCH (average)	109.9			
Oxirane → Ethylene oxide					
Phenol			C—C (average)	1.397	MW
			C_b—H	1.084	
			C_c—H	1.076	
			C_d—H	1.082	
			C_a—O	1.364	
			O—H	0.956	
			∠COH	109.0	
Phosphirane	 C—P 1.867; C—C 1.502; ∠CPC 47.4		P—H	1.43	MW
			C—H	1.09	
			∠HCH	114.4	
	∠HPC	95.2	∠CCH	118	
	dihedral angle between the PCC plane and the PH bond		95.7		
Piperazine			C—C	1.540	ED
			C—N	1.467	
			C—H	1.110	
	∠CNC	109.0	∠CCN	110.4	
			(C_{2h})		
Pivalonitrile	C_a—C_b	1.495	C_a—N	1.159	MW
($(C_cH_3)_3C_b$—C_a≡N)	C_b—C_c	1.536	∠$C_cC_bC_c$	110.5	
Propadiene → Allene					
Propane	C—C	1.532	C—H	1.107	ED
C_3H_8	∠CCC	112	∠HCH	107	
Propenal → Acrylaldehyde					
Propene			C_a—H_a	1.104	ED, MW
			C_a—C_b	1.341	
			C_c—H_d	1.117	
			C_b—C_c	1.506	
			∠$C_bC_aH_{a,b,c}$	121.3	
	∠$C_bC_cH_d$	110.7	∠$C_aC_bC_c$	124.3	
l-Propenyl chloride	CH_3—C_bH=C_aH—Cl	C_a—Cl	1.728	MW	
	∠C_bC_aCl	121.9	*trans* conformer		
Propiolaldehyde	H_aC_a≡C_b—C_cH_cO		C_a—H_a	1.085	ED, MW
	C_a—C_b	1.211	C_b—C_c	1.453	
	C_c—H_c	1.130	C_c—O	1.214	
	∠C_bC_cO	124.2	∠$C_bC_cH_c$	113.7	
	∠$C_aC_bC_c$	178.6	planar		
Propylene → Propene					
Propylene oxide			C_a—C_b	1.51	MW
			∠$C_aC_bC_c$	121.0	
			dihedral angle between the C_bC_cO plane and the C_aC_b bond	123.8	

Compound	Structure						Method
Propynal → Propiolaldehyde							
Propyne	H_3C_c—C_b≡C_aH		C_c—H	1.105			MW
	C_c—C_b	1.459	C_b—C_a	1.206			
	C_a—H	1.056	∠HC_cC_b	110.2			
Pyrazine			C—C	1.339	C—N	1.403	ED
			C—H	1.115	∠CCN	115.6	
			∠CCH	123.9			
Pyridazine			N—C_a	1.341			ED, MW
			C_a—C_b	1.393			
			N—N	1.330			
			C_b—C_b	1.375			
	∠NCC	123.7	∠NNC	119.3			
Pyridine			N—C_a	1.340			MW
			C_b—C_c	1.394			
			C_b—H_b	1.081			
			C_a—C_b	1.395			
			C_a—H_a	1.084			
			C_c—H_c	1.077			
	∠C_aNC_a	116.8	∠NC_aC_b	123.9			
	∠$C_aC_bC_c$	118.5	∠$C_bC_cC_b$	118.3			
	∠NC_aH_a	115.9	∠$C_cC_bH_b$	121.3			
Pyrimidine			N—C	1.340	C—C	1.393	ED
			∠NCN	127.6	∠CNC	115.5	
			(C_{2v} assumed)				
Pyrrole			N—Ca	1.370			MW
			C_b—C_b	1.417			
			C_a—C_b	1.382			
			N—H	0.996			
			C_a—H_a	1.076			
	C_b—H_b	1.077	∠C_aNC_a	109.8			
	∠NC_aC_b	107.7	∠$C_aC_bC_b$	107.4			
	∠NC_aH_a	121.5	∠C_bC_bH	127.1			
Pyruvonitrile			C—H	1.12			ED, MW
			C—N	1.17			
			C—O	1.208			
			C_b—C_c	1.477			
	C_a—C_b	1.518	∠HCH	109.2			
	∠C_aC_bO	124.5	∠$C_aC_bC_c$	114.2			
	∠CCN	179					
Ruthenocene → Bis (cyclopentadienyl) ruthenium							
Silacyclobutane			Si—C	1.892			ED
			C—C	1.600			
			Si—H	1.47			
	C—H	1.14	∠CSiC	80.7			
	∠SiCC	84.8	∠CCC	99.8			
	dihedral angle between the CCC and CSiC planes			146			
Spiropentane			C_b—C_b	1.52			ED
			C_a—C_b	1.47			
			C—H	1.09			
			∠$C_bC_aC_b$	62			
	∠HCH	118	(D_{2d})				

Compound	Structure					Method
Succinonitrile		C—C	1.561	C—C(N)	1.465	ED
		C—N	1.161	C—H	1.09	
		∠CCC	110.4			
	fraction of the *anti* conformer at 170°C 74%, dihedral angle of CCCC for the *gauche* conformer				75	
Tetrachloroethylene CCl_2=CCl_2	C—Cl	1.718	C—C	1.354		ED
	∠ClCCl	115.7				
Tetracyanoethylene $(CN)_2C$=$C(CN)_2$	C—N	1.162	C—C	1.435		ED
	C=C	1.357	∠CC=C	121.1		
Tetrafluoro-1,3-dithietane			C—S	1.785		ED
			C—F	1.314		
			∠CSC	83.2		
	∠FCS	113.7	(D_{2h} assumed)			
Tetrafluoroethylene CF_2=CF_2	C—C	1.31	C—F	1.319		ED
	∠CCF	123.8	(D_{2h} assumed)			
Tetrahydrofuran 	C—H	1.115	C—O	1.428		ED
	C—C	1.536				
	The skeletal bending vibration of the molecular plane is essentially free pseudorotation					
Tetrahydropyran			C—O	1.420		ED
			C—C	1.531		
			C—H	1.116		
			∠COC	111.5		
			∠OCC	111.8		
	∠CCC (C)	108	∠CCC (O)	111		
	chair form					
Tetrahydrothiophene 	C—S	1.839	C—H	1.120		
	C—C	1.536	∠CSC	93.4		
	∠SCC	106.1	∠CCC	105.0		
Tetramethylgermane $(CH_3)_4Ge$	Ge—C	1.945	C—H	1.12		ED
	∠GeCH	108	(T_d excluding the H atoms)			
Tetramethyllead $(CH_3)_4Pb$	Pb—C	2.238	(T_d excluding the H atoms)			ED
Tetramethylsilane $(CH_3)_4Si$	C—H	1.115	C—Si	1.875		ED
	∠HCH	109.8	(T_d excluding the H atoms)			
Tetramethylstannane $(CH_3)_4Sn$	C—Sn	2.144				ED
	C—H	1.12	(T_d excluding the H atoms)			
1,2,5-Thiadiazole		S—N	1.631	∠NSN	99.6	MW
		C—N	1.328	∠CCN	113.8	
		C—C	1.420	∠CCH	126.2	
		C—H	1.079	planar		
1,3,4-Thiadiazole		S—C	1.721	∠CSC	86.4	MW
		N—N	1.371	∠SCN	114.6	
		C—N	1.302	∠CCN	112.2	
		C—H	1.08	∠SCH	121.9	
		∠NCH	123.5		planar	
Thietane			C—S	1.847		ED, MW
			C—C	1.549		
			C—H (average)	1.100		
	∠CSC	76.8	∠HCH (average)	112		
	dihedral angle between the CCC and CSC planes			154		
Thiirane		C—C	1.484	∠HCH	116	MW
		C—H	1.083	∠CSC	48.3	
		C—S	1.815	∠CCS	65.9	
		dihedral angle between the CH_2 plane and the C—C bond		152		

Compound	Structure				Method
Thioformaldehyde	C—S	1.611	C—H	1.093	MW
CH_2S	∠HCH	116.9			
Thioformamide			$N—H_a$	1.002	MW
			$N—H_b$	1.007	
			C—N	1.358	
	C—S	1.626	$C—H_c$	1.10	
	$∠H_aNH_b$	121.7	$∠H_aNC$	117.9	
	$∠H_bNC$	120.4	∠NCS	125.3	
	$∠NCH_c$	108	$∠SCH_c$	127	
Thiolane → Tetrahydrothiophene					
Thiophene			$C_a—H_a$	1.078	MW
			$C_b—H_b$	1.081	
			$C_a—S$	1.714	
			$C_a—C_b$	1.370	
			$C_b—C_b$	1.423	
			$∠C_aSC_a$	92.2	
	$∠SC_aC_b$	115.5	$∠C_aC_bC_b$	112.5	
	$∠SC_aH_a$	119.9	$∠C_bC_bH_b$	124.3	
Toluene		C—C (ring) 1.399	$C—CH_3$	1.524	ED
		C—H (average) 1.11			
		the difference between the C—H(CH_3) and C—H(ring): about 0.01			
1,1,1-Tribromoethane	C—Br	1.93	C—H	1.095 (assumed)	MW
CH_3CBr_3	C—C	1.51 (assumed)	∠CCBr	108	
	∠BrCBr	111	∠CCH	109.0 (assumed)	
Tribromomethane → Bromoform					
Tri-*tert*-butyl methane	$C_a—C_b$	1.611	C—H	1.111	ED
$HC_a[C_b(C_cH_3)_3]_3$	$C_b—C_c$	1.548	$∠C_aC_bC_c$	113.0	
Tricarbon dioxide	C—O	1.163	C—C	1.289	ED
OCCCO	linear (with a large-amplitude bending vibration)				
Trichloroacetonitrile	C—N	1.165	C—C	1.460	ED
CCl_3CN	C—Cl	1.763	∠ClCCl	110.0	
1,1,1-Trichloroethane	C—H	1.090	C—C	1.541	MW
CH_3CCl_3	C—Cl	1.771	∠HCH	110.0	
	∠CCH	108.9	∠ClCCl	109.4	
	∠CCCl	109.6			
Trichloro(methyl)germane	Ge—Cl	2.132	Ge—C	1.89	ED, MW
CH_3GeCl_3	C—H	1.103 (assumed)	∠ClGeCl	106.4	
	∠GeCH	110.5 (assumed)			
Trichloro(methyl)silane	C—Si	1.876	Si—Cl	2.021	MW
CH_3SiCl_3			(C_{3v})		
Trichloro(methyl)stannane	Sn—Cl	2.304	Sn—C	2.10	ED
CH_3SnCl_3	C—H	1.100	∠CSnCl	113.9	
	∠ClSnCl	104.7	∠SnCH	108	
Triethylenediamine → 1,4-Diazabicyclo [2.2.2]octane					
Trifluoroacetic acid			C—F	1.325	ED
			C—C	1.546	
			$C—O_a$	1.192	
	$C—O_b$	1.35	O—H	0.96 (assumed)	
	$∠CCO_a$	126.8	$∠CCO_b$	111.1	
	∠CCF	109.5			
1,1,1-Trifluoroethane	C—C	1.494	C—F	1.340	ED
CH_3CF_3	C—H	1.081	∠CCF	119.2	
	∠CCH	112			
Trifluoromethane → Fluoroform					

Compound	Structure				Method
1,1,1-Trifluoro-2,2,2-trichloroethane	C—C	1.54	C—F	1.33	MW
CF_3CCl_3	C—Cl	1.77	∠CCF	110	
	∠CCCl	109.6	staggered conformation		
Trimethylaluminium	C—H	1.113	Al—C	1.957	ED
$(CH_3)_3Al$	∠AlCH	111.7	∠CAlC	120	
Trimethylamine	C—N	1.458	C—H	1.100	ED
$(CH_3)_3N$	∠CNC	110.9	∠HCH	110	
Trimethylarsine	C—As	1.979	∠CAsC	98.8	ED
$(CH_3)_3As$	∠AsCH	111.4			
Trimethylbismuth	Bi—C	2.263	C—H	1.07	ED
$(CH_3)_3Bi$	∠CBiC	97.1			
Trimethylborane	C—B	1.578	C—H	1.114	ED
$(CH_3)_3B$	∠CBC	120.0	∠BCH	112.5	
Trimethyleneimine → Azetidine					
Trimethylphosphine	C—P	1.847	C—H	1.091	ED
$(CH_3)_3P$	∠CPC	98.6	∠PCH	110.7	
1,3,5-Trioxane			C—O	1.422	MW
			∠OCO	112.2	
			∠COC	110.3	
Triphenylamine	C—C	1.392	C—N	1.42	ED
$(C_6H_5)_3N$	∠CNC	116	(C_3)		
	torsional dihedral angle of the two phenyl rings 47° (defined to be 0 when the symmetry axis is contained in the phenyl planes)				
Tropone			C_a—O	1.23	ED
			C_a—C_b	1.45	
			C_b—C_c	1.36	
			C_c—C_d	1.46	
			C_d—C_d	1.34	
			∠$C_bC_aC_b$	122	
			∠$C_aC_bC_c$	133	
	∠$C_bC_cC_d$	126	∠$C_cC_dC_d$	130	
				(C_{2v})	
Vinylacetylene			C_b—C_c	1.434	ED, MW
			C_a—C_b	1.344	
			C_c—C_d	1.215	
			C_a—H_a	1.11	
			C_d—H_d	1.09	
			∠$C_aC_bC_c$	123.1	
	∠$C_bC_cC_d$	178	∠$H_aC_aC_b$	119	
	∠$H_bC_aC_b$	122	∠$H_cC_bC_a$	122	
	∠$C_cC_dH_d$	182			
Vinyl chloride			C—C	1.342	ED, MW
			C—Cl	1.730	
			C—H	1.09	
	∠CCCl	122.5	∠CCH_a	124	
	∠CCH_b	120	∠CCH_c	121.1	

DIPOLE MOMENTS

This table gives values of the electric dipole moment for about 800 molecules. When available, values determined by microwave spectroscopy, molecular beam electric resonance, and other high-resolution spectroscopic techniques were selected. Otherwise, the values come from measurements of the dielectric constant in the gas phase or, if these do not exist, in the liquid phase. Compounds are listed by molecular formula in Hill order; compounds not containing carbon are listed first, followed by compounds containing carbon.

The dipole moment μ is given in debye units (D). The conversion factor to SI units is 1 D = 3.33564×10^{-30} C m.

Dipole moments of individual conformers (rotational isomers) are given when they have been measured. The conformers are designated as *gauche*, *trans*, *axial*, etc. The meaning of these terms can be found in the references. In some cases an average value, obtained from measurements on the bulk gas, is also given. Other information on molecules that have been studied by spectroscopy, such as the components of the dipole moment in the molecular framework and the variation with vibrational state and isotopic species, is given in References 1 and 2.

When the accuracy of a value is explicitly stated (i.e., 1.234 ± 0.005), the stated uncertainty generally indicates two or three standard deviations. When no uncertainty is given, the value may be assumed to be precise to a few units in the last decimal place. However, if more than three decimal places are given, the exact interpretation of the final digits may require analysis of the vibrational averaging.

Values measured in the gas phase that are questionable because of undetermined error sources are indicated as approximate (≈). Values obtained by liquid phase measurements, which sometimes have large errors because of association effects, are enclosed in brackets, e.g., [1.8].

REFERENCES

1. Nelson, R. D., Lide, D. R., and Maryott, A. A., *Selected Values of Electric Dipole Moments for Molecules in the Gas Phase*, Natl. Stand. Ref. Data Ser. - Nat. Bur. Stnds. 10, 1967.
2. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series*, II/6 (1974), II/14a (1982), II/14b (1983), II/19c (1992), Springer-Verlag, Heidelberg.
3. Riddick, J. A., Bunger, W. B., and Sakano, T. K., *Organic Solvents, Fourth Edition*, John Wiley & Sons, New York, 1986.

Mol. Form.	Name	μ/D
	Compounds not containing carbon	
AgBr	Silver(I) bromide	5.62 ± 0.03
AgCl	Silver(I) chloride	6.08 ± 0.06
AgF	Silver(I) fluoride	6.22 ± 0.30
AgI	Silver(I) iodide	4.55 ± 0.05
AlF	Aluminum monofluoride	1.53 ± 0.15
$AsCl_3$	Arsenic(III) chloride	1.59 ± 0.08
AsF_3	Arsenic(III) fluoride	2.59 ± 0.05
AsH_3	Arsine	0.217 ± 0.003
BClH2	Chloroborane	0.75 ± 0.05
BF	Fluoroborane(1)	≈0.5
BF_2H	Difluoroborane	0.971 ± 0.010
B_4H_{10}	Tetraborane	0.486 ± 0.002
B_5H_9	Pentaborane(9)	2.13 ± 0.04
B_6H_{10}	Hexaborane	2.50 ± 0.05
BaO	Barium oxide	7.954 ± 0.003
BaS	Barium sulfide	10.86 ± 0.02
BrCl	Bromine chloride	0.519 ± 0.004
BrF	Bromine fluoride	1.422 ± 0.016
BrF_3Si	Bromotrifluorosilane	0.83 ± 0.01
BrF_5	Bromine pentafluoride	1.51 ± 0.15
BrH	Hydrogen bromide	0.8272 ± 0.0003
BrH_3Si	Bromosilane	1.319
BrI	Iodine bromide	0.726 ± 0.003
BrK	Potassium bromide	10.628 ± 0.001
BrLi	Lithium bromide	7.268 ± 0.001
BrNO	Nitrosyl bromide	≈1.8
BrNa	Sodium bromide	9.1183 ± 0.0006
BrO	Bromine monoxide	1.76 ± 0.04
BrO_2	Bromine dioxide	2.8 ± 0.3
BrRb	Rubidium bromide	≈10.9
BrTl	Thallium(I) bromide	4.49 ± 0.05
CaCl	Calcium monochloride	≈3.6
ClCs	Cesium chloride	10.387 ± 0.004
ClF	Chlorine fluoride	0.888061
$ClFO_3$	Perchloryl fluoride	0.023 ± 0.001
ClF_3	Chlorine trifluoride	0.6 ± 0.10
ClF_3Si	Chlorotrifluorosilane	0.636 ± 0.004
$ClGeH_3$	Chlorogermane	2.13 ± 0.02
ClH	Hydrogen chloride	1.1086 ± 0.0003
ClHO	Hypochlorous acid	≈1.3
ClH_3Si	Chlorosilane	1.31 ± 0.01
ClI	Iodine chloride	1.24 ± 0.02
ClIn	Indium(I) chloride	3.79 ± 0.19
ClK	Potassium chloride	10.269 ± 0.001
ClLi	Lithium chloride	7.12887
$ClNO_2$	Nitryl chloride	0.53
ClNS	Thionitrosyl chloride	1.87 ± 0.02
ClNa	Sodium chloride	9.00117
ClO	Chlorine oxide	1.297 ± 0.001
ClRb	Rubidium chloride	10.510 ± 0.005
ClTl	Thallium(I) chloride	4.54299
Cl_2H_2Si	Dichlorosilane	1.17 ± 0.02
Cl_2OS	Thionyl chloride	1.45 ± 0.03
Cl_2O_2S	Sulfuryl chloride	1.81 ± 0.04
Cl_2S	Sulfur dichloride	0.36 ± 0.01
Cl_3FSi	Trichlorofluorosilane	0.49 ± 0.01
Cl_3HSi	Trichlorosilane	0.86 ± 0.01
Cl_3N	Nitrogen trichloride	0.39 ± 0.01
Cl_3OP	Phosphorus(V) oxychloride	2.54 ± 0.05
Cl_3P	Phosphorus(III) chloride	0.56 ± 0.02
CrO	Chromium monoxide	3.88 ± 0.13
CsF	Cesium fluoride	7.884 ± 0.001
CsNa	Cesium sodium	4.75 ± 0.20
CuF	Copper(I) fluoride	5.77 ± 0.29
CuO	Copper(II) oxide	4.5 ± 0.5
FGa	Gallium monofluoride	2.45 ± 0.05
$FGeH_3$	Fluorogermane	2.33 ± 0.12
FH	Hydrogen fluoride	1.826178
FHO	Hypofluorous acid	2.23 ± 0.11
FH_2N	Fluoramide	2.27 ± 0.18
FH_3Si	Fluorosilane	1.2969 ± 0.0006
FI	Iodine fluoride	1.948 ± 0.020

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Mol. Form.	Name	μ/D
FIn	Indium(I) fluoride	3.40 ± 0.07
FK	Potassium fluoride	8.585 ± 0.003
FLi	Lithium fluoride	6.3274 ± 0.0002
FNO	Nitrosyl fluoride	1.730 ± 0.003
FNO_2	Nitryl fluoride	0.466 ± 0.005
FNS	Thionitrosyl fluoride (NSF)	1.902 ± 0.012
FN_3	Fluorine azide	≈1.3
FNa	Sodium fluoride	8.156 ± 0.001
FO	Fluorine oxide	0.0043 ± 0.0004
FRb	Rubidium fluoride	8.5465 ± 0.0005
FS	Sulfur monofluoride	0.794 ± 0.02
FTl	Thallium(I) fluoride	4.2282 ± 0.0008
F_2Ge	Germanium(II) fluoride	2.61 ± 0.02
F_2HN	Difluoramine	1.92 ± 0.02
F_2H_2Si	Difluorosilane	1.55 ± 0.02
F_2N_2	*cis*-Difluorodiazine	0.16 ± 0.01
F_2O	Fluorine monoxide	0.308180
F_2OS	Thionyl fluoride	1.63 ± 0.01
F_2O_2	Fluorine dioxide	1.44 ± 0.07
F_2O_2S	Sulfuryl fluoride	1.12 ± 0.02
F_2S	Sulfur difluoride	1.05 ± 0.05
F_2Si	Difluorosilylene	1.23 ± 0.02
F_3HSi	Trifluorosilane	1.27 ± 0.03
$F_3H_3Si_2$	1,1,1-Trifluorodisilane	2.03 ± 0.10
F_3ISi	Trifluoroiodosilane	1.11 ± 0.03
F_3N	Nitrogen trifluoride	0.235 ± 0.004
F_3NO	Trifluoramine oxide	0.0390 ± 0.0004
F_3OP	Phosphorus(V) oxyfluoride	1.8685 ± 0.0001
F_3P	Phosphorus(III) fluoride	1.03 ± 0.01
F_3PS	Phosphorus(V) sulfide trifluoride	0.64 ± 0.02
F_4N_2	Tetrafluorohydrazine (*gauche*)	0.257 ± 0.002
F_4S	Sulfur tetrafluoride	0.632 ± 0.003
F_4Se	Selenium tetrafluoride	1.78 ± 0.09
F_5I	Iodine pentafluoride	2.18 ± 0.11
GeH_3N_3	Germylazide	2.579 ± 0.003
GeO	Germanium(II) oxide	3.2823 ± 0.0001
GeS	Germanium(II) sulfide	2.00 ± 0.06
GeSe	Germanium(II) selenide	1.65 ± 0.05
GeTe	Germanium(II) telluride	1.06 ± 0.07
HI	Hydrogen iodide	0.448 ± 0.001
HKO	Potassium hydroxide	7.415 ± 0.002
HLi	Lithium hydride	5.884 ± 0.001
HLiO	Lithium hydroxide	4.754 ± 0.002
HN	Imidogen	1.39 ± 0.07
HNO	Nitrosyl hydride	1.62 ± 0.03
HNO_2	Nitrous acid (*cis*)	1.423 ± 0.005
HNO_2	Nitrous acid (*trans*)	1.855 ± 0.016
HNO_3	Nitric acid	2.17 ± 0.02
HN_3	Hydrazoic acid	1.70 ± 0.09
HO	Hydroxyl	1.655 ± 0.001
HS	Mercapto	0.7580 ± 0.0001
H_2O	Water	1.8546 ± 0.0040
H_2O_2	Hydrogen peroxide	1.573 ± 0.001
H_2S	Hydrogen sulfide	0.97833
H_3N	Ammonia	1.4718 ± 0.0002
H_3NO	Hydroxylamine	0.59 ± 0.05
H_3P	Phosphine	0.5740 ± 0.0003
H_3Sb	Stibine	0.12 ± 0.05
H_4N_2	Hydrazine	1.75 ± 0.09
H_6OSi_2	Disiloxane	0.24 ± 0.02
IK	Potassium iodide	≈10.8
ILi	Lithium iodide	7.428 ± 0.001
INa	Sodium iodide	9.236 ± 0.003
IO	Iodine monoxide	2.45 ± 0.05
IRb	Rubidium iodide	≈11.5
ITl	Thallium(I) iodide	4.61 ± 0.07
KLi	Lithium potassium	3.45 ± 0.20
KNa	Potassium sodium	2.693 ± 0.014
LaO	Lanthanum monoxide	3.207 ± 0.011
LiNa	Lithium sodium	0.463 ± 0.002
LiO	Lithium monoxide	6.84 ± 0.03
LiRb	Lithium rubidium	4.0 ± 0.1
MgO	Magnesium oxide	6.2 ± 0.6
NO	Nitric oxide	0.15872
NO_2	Nitrogen dioxide	0.316 ± 0.010
NP	Phosphorus nitride	2.7470 ± 0.0001
NS	Nitrogen sulfide	1.81 ± 0.02
N_2O	Nitrous oxide	0.16083
N_2O_3	Nitrogen trioxide	2.122 ± 0.010
NaRb	Rubidium sodium	3.1 ± 0.3
OP	Phosphorus monoxide	1.88 ± 0.07
OPb	Lead(II) oxide	4.64 ± 0.50
OS	Sulfur monoxide	1.55 ± 0.02
OS_2	Sulfur oxide (SSO)	1.47 ± 0.03
OSi	Silicon monoxide	3.0982
OSn	Tin(II) oxide	4.32 ± 0.22
OSr	Strontium oxide	8.900 ± 0.003
OTi	Titanium(II) oxide	2.96 ± 0.05
OY	Yttrium monoxide	4.524 ± 0.007
OZr	Zirconium(II) oxide	2.55 ± 0.01
O_2S	Sulfur dioxide	1.63305
O_2Se	Selenium dioxide	2.62 ± 0.05
O_2Zr	Zirconium(IV) oxide	7.80 ± 0.02
O_3	Ozone	0.53373
PbS	Lead(II) sulfide	3.59 ± 0.18
SSi	Silicon monosulfide	1.73 ± 0.09
SSn	Tin(II) sulfide	3.18 ± 0.16

Compounds containing carbon

Mol. Form.	Name	μ/D
$CBrF_3$	Bromotrifluoromethane	0.65 ± 0.05
CBr_2F_2	Dibromodifluoromethane	0.66 ± 0.05
$CClF_3$	Chlorotrifluoromethane	0.50 ± 0.01
CClN	Cyanogen chloride	2.8331 ± 0.0002
CCl_2F_2	Dichlorodifluoromethane	0.51 ± 0.05
CCl_2O	Carbonyl chloride	1.17 ± 0.01
CCl_3F	Trichlorofluoromethane	0.46 ± 0.02
CF	Fluoromethylidyne	0.645 ± 0.005
CFN	Cyanogen fluoride	2.120 ± 0.001
CF_2	Difluoromethylene	0.47 ± 0.02
CF_2O	Carbonyl fluoride	0.95 ± 0.01
CF_3I	Trifluoroiodomethane	1.048 ± 0.003
CH	Methylidyne	≈1.46
CHBrClF	Bromochlorofluoromethane	1.5 ± 0.3
$CHBr_3$	Tribromomethane	0.99 ± 0.02
$CHClF_2$	Chlorodifluoromethane	1.42 ± 0.03
$CHCl_2F$	Dichlorofluoromethane	1.29 ± 0.03
$CHCl_3$	Trichloromethane	1.04 ± 0.02
CHFO	Formyl fluoride	2.081 ± 0.001
CHF_2N	Carboimidic difluoride	1.393 ± 0.001
CHF_3	Trifluoromethane	1.65150
CHN	Hydrogen cyanide	2.985188

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Mol. Form.	Name	μ/D
CHN	Hydrogen isocyanide	3.05 ± 0.15
CHNO	Isocyanic acid (HNCO)	≈1.6
CHNO	Fulminic acid	3.09934
CH_2BrCl	Bromochloromethane	[1.66]
CH_2Br_2	Dibromomethane	1.43 ± 0.03
CH_2ClF	Chlorofluoromethane	1.82 ± 0.04
CH_2Cl_2	Dichloromethane	1.60 ± 0.03
CH_2F_2	Difluoromethane	1.9785 ± 0.02
CH_2I_2	Diiodomethane	[1.08]
CH_2N_2	Diazomethane	1.50 ± 0.01
CH_2N_2	Cyanamide	4.28 ± 0.10
CH_2N_4	1H-Tetrazole	2.19 ± 0.05
CH_2O	Formaldehyde	2.332 ± 0.002
CH_2O_2	Formic acid	1.425 ± 0.002
CH_2S	Thioformaldehyde	1.6491 ± 0.0004
CH_2Se	Selenoformaldehyde	1.41 ± 0.01
CH_3BCl_2	Dichloromethylborane	1.419 ± 0.013
CH_3BF_2	Difluoromethylborane	1.668 ± 0.003
CH_3BO	Borane carbonyl	1.698 ± 0.020
CH_3Br	Bromomethane	1.8203 ± 0.0004
CH_3Cl	Chloromethane	1.8963 ± 0.0002
CH_3Cl_3Si	Methyltrichlorosilane	1.91 ± 0.01
CH_3F	Fluoromethane	1.858 ± 0.002
CH_3F_2OP	Methylphosphonic difluoride	3.69 ± 0.26
CH_3F_2P	Methyldifluorophosphine	2.056 ± 0.006
CH_3F_3Si	Trifluoromethylsilane	2.3394 ± 0.0002
CH_3F_3Si	(Trifluoromethyl)silane	2.32 ± 0.02
CH_3I	Iodomethane	1.6406 ± 0.0004
CH_3NO	Formamide	3.73 ± 0.07
CH_3NO_2	Nitromethane	3.46 ± 0.02
CH_3N_3	Methyl azide	2.17 ± 0.04
CH_4O	Methanol	1.70 ± 0.02
CH_4O_2	Methylhydroperoxide	≈0.65
CH_4S	Methanethiol	1.52 ± 0.08
CH_5FSi	Fluoromethylsilane	1.700 ± 0.008
CH_5ISi	Iodomethylsilane	1.862 ± 0.005
CH_5N	Methylamine	1.31 ± 0.03
CH_6OSi	Methyl silyl ether	1.15 ± 0.02
CH_6Si	Methylsilane	0.73456
CH_8B_2	Methyldiborane(6)	0.566 ± 0.006
CIN	Cyanogen iodide	3.67 ± 0.02
CO	Carbon monoxide	0.10980
COS	Carbon oxysulfide	0.715189
COSe	Carbon oxyselenide	0.73 ± 0.02
CS	Carbon monosulfide	1.958 ± 0.005
CSe	Carbon monoselenide	1.99 ± 0.04
C_2BrF	Bromofluoroacetylene	0.448 ± 0.002
C_2ClF_3	Chlorotrifluoroethene	0.40 ± 0.10
C_2ClF_5	Chloropentafluoroethane	0.52 ± 0.05
$C_2Cl_2F_2$	1,1-Dichloro-2,2-difluoroethene	0.50
$C_2Cl_2F_4$	1,2-Dichloro-1,1,2,2-tetrafluoroethane	≈0.5
C_2F_3N	Trifluoroacetonitrile	1.262 ± 0.010
C_2F_3N	Trifluoroisocyanomethane	1.153 ± 0.010
C_2HBr	Bromoacetylene	0.22962
C_2HCl	Chloroacetylene	0.44408
C_2HCl_3	Trichloroethene	[0.8]
C_2HCl_5	Pentachloroethane	0.92 ± 0.05
C_2HF	Fluoroacetylene	0.7207 ± 0.0003
C_2HF_3	Trifluoroethene	1.32 ± 0.03
$C_2HF_3O_2$	Trifluoroacetic acid	2.28 ± 0.25
C_2HI	Iodoacetylene	0.02525
$C_2H_2Br_4$	1,1,2,2-Tetrabromoethane	[1.38]
$C_2H_2Cl_2$	1,1-Dichloroethene	1.34 ± 0.01
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethene	1.90 ± 0.04
$C_2H_2Cl_2O$	Chloroacetyl chloride	2.23 ± 0.11
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane	1.32 ± 0.07
$C_2H_2F_2$	1,1-Difluoroethene	1.3893 ± 0.0002
$C_2H_2F_2$	*cis*-1,2-Difluoroethene	2.42 ± 0.02
$C_2H_2F_4$	1,1,1,2-Tetrafluoroethane	1.80 ± 0.22
$C_2H_2N_2S$	1,2,5-Thiadiazole	1.579 ± 0.007
C_2H_2O	Ketene	1.42215
$C_2H_2O_2$	Glyoxal (*cis*)	4.8 ± 0.2
C_2H_3Br	Bromoethene	1.42 ± 0.03
C_2H_3Cl	Chloroethene	1.45 ± 0.03
$C_2H_3ClF_2$	1-Chloro-1,1-difluoroethane	2.14 ± 0.04
C_2H_3ClO	Acetyl chloride	2.72 ± 0.14
$C_2H_3Cl_3$	1,1,1-Trichloroethane	1.755 ± 0.015
$C_2H_3Cl_3$	1,1,2-Trichloroethane	[1.4]
C_2H_3F	Fluoroethene	1.468 ± 0.003
C_2H_3FO	Acetyl fluoride	2.96 ± 0.03
$C_2H_3F_3$	1,1,1-Trifluoroethane	2.3470 ± 0.005
C_2H_3HgN	Cyanomethylmercury	4.7 ± 0.1
C_2H_3I	Iodoethene	1.311 ± 0.005
C_2H_3N	Acetonitrile	3.92519
C_2H_3NO	Methyl cyanate	4.26 ± 0.18
C_2H_3NO	Methyl isocyanate	≈2.8
C_2H_3NS	Methyl isothiocyanate	3.453 ± 0.003
$C_2H_3N_3$	1H-1,2,4-Triazole	2.7 ± 0.1
C_2H_4BrCl	1-Bromo-2-chloroethane	[1.2]
$C_2H_4Br_2$	1,2-Dibromoethane	[1.19]
C_2H_4ClF	1-Chloro-1-fluoroethane	2.068 ± 0.014
$C_2H_4Cl_2$	1,1-Dichloroethane	2.06 ± 0.04
$C_2H_4Cl_2$	1,2-Dichloroethane	[1.83]
$C_2H_4F_2$	1,1-Difluoroethane	2.27 ± 0.05
$C_2H_4F_2$	1,2-Difluoroethane (*gauche*)	2.67 ± 0.13
C_2H_4O	Acetaldehyde	2.750 ± 0.006
C_2H_4O	Ethylene oxide	1.89 ± 0.01
$C_2H_4O_2$	Acetic acid	1.70 ± 0.03
$C_2H_4O_2$	Methyl formate	1.77 ± 0.04
$C_2H_4O_2$	Glycolaldehyde	2.73 ± 0.05
C_2H_5Br	Bromoethane	2.04 ± 0.02
C_2H_5Cl	Chloroethane	2.05 ± 0.02
C_2H_5ClO	2-Chloroethanol	1.78 ± 0.09
$C_2H_5Cl_3Si$	Trichloroethylsilane	[2.04]
C_2H_5F	Fluoroethane	1.937 ± 0.007
C_2H_5I	Iodoethane	1.976 ± 0.002
C_2H_5N	Ethyleneimine	1.90 ± 0.01
C_2H_5NO	Acetamide	3.68 ± 0.03
C_2H_5NO	*N*-Methylformamide	3.83 ± 0.08
$C_2H_5NO_2$	Nitroethane	3.23 ± 0.03
C_2H_6O	Ethanol (*gauche*)	1.68 ± 0.03
C_2H_6O	Ethanol (*trans*)	1.44 ± 0.03
C_2H_6O	Ethanol (*average*)	1.69 ± 0.03
C_2H_6O	Dimethyl ether	1.30 ± 0.01
C_2H_6OS	Dimethyl sulfoxide	3.96 ± 0.04
$C_2H_6O_2$	Ethylene glycol (*average*)	2.36 ± 0.10
C_2H_6S	Ethanethiol (*gauche*)	1.61 ± 0.08
C_2H_6S	Ethanethiol (*trans*)	1.58 ± 0.08
C_2H_6S	Dimethyl sulfide	1.554 ± 0.004
$C_2H_6S_2$	1,2-Ethanedithiol	2.03 ± 0.08
$C_2H_6S_2$	Dimethyl disulfide	[1.85]

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Mol. Form.	Name	μ/D
C_2H_6Si	Vinylsilane	0.657 ± 0.002
C_2H_7N	Ethylamine (*gauche*)	1.210 ± 0.015
C_2H_7N	Ethylamine (*trans*)	1.304 ± 0.011
C_2H_7N	Ethylamine (*average*)	1.22 ± 0.10
C_2H_7N	Dimethylamine	1.01 ± 0.02
C_2H_7NO	Ethanolamine	[2.27]
$C_2H_8N_2$	1,2-Ethanediamine	1.99 ± 0.10
C_3HF_3	3,3,3-Trifluoro-1-propyne	2.317 ± 0.013
C_3HN	Cyanoacetylene	3.73172
$C_3H_2F_2$	3,3-Difluorocyclopropene	2.98 ± 0.02
C_3H_2O	2-Propynal	2.78 ± 0.02
$C_3H_3Cl_2F$	1,1-Dichloro-2-fluoropropene	2.43 ± 0.02
C_3H_3F	3-Fluoropropyne	1.73 ± 0.02
$C_3H_3F_3$	3,3,3-Trifluoropropene	2.45 ± 0.05
C_3H_3N	Acrylonitrile	3.92 ± 0.07
C_3H_3NO	Oxazole	1.503 ± 0.030
C_3H_3NO	Isoxazole	2.95 ± 0.04
C_3H_4	Propyne	0.784 ± 0.001
C_3H_4	Cyclopropene	0.454 ± 0.010
$C_3H_4F_2$	1,1-Difluoro-1-propene	0.889 ± 0.007
$C_3H_4N_2$	1*H*-Pyrazole	2.20 ± 0.01
$C_3H_4N_2$	Imidazole	3.8 ± 0.4
C_3H_4O	Propargyl alcohol	1.13 ± 0.06
C_3H_4O	Acrolein (*trans*)	3.117 ± 0.004
C_3H_4O	Acrolein (*cis*)	2.552 ± 0.003
C_3H_4O	Cyclopropanone	2.67 ± 0.13
$C_3H_4O_2$	Vinyl formate	1.49 ± 0.01
$C_3H_4O_2$	2-Oxetanone	4.18 ± 0.03
$C_3H_4O_2$	3-Oxetanone	0.887 ± 0.005
$C_3H_4O_3$	Ethylene carbonate	[4.9]
C_3H_5Br	2-Bromopropene	[1.51]
C_3H_5Br	3-Bromopropene	≈1.9
C_3H_5Cl	*cis*-1-Chloropropene	1.67 ± 0.08
C_3H_5Cl	*trans*-1-Chloropropene	1.97 ± 0.10
C_3H_5Cl	2-Chloropropene	1.647 ± 0.010
C_3H_5Cl	3-Chloropropene	1.94 ± 0.10
C_3H_5ClO	Epichlorohydrin	[1.8]
C_3H_5F	*cis*-1-Fluoropropene	1.46 ± 0.03
C_3H_5F	*trans*-1-Fluoropropene	≈1.9
C_3H_5F	2-Fluoropropene	1.61 ± 0.03
C_3H_5F	3-Fluoropropene (*gauche*)	1.939 ± 0.015
C_3H_5F	3-Fluoropropene (*cis*)	1.765 ± 0.014
C_3H_5N	Propanenitrile	4.05 ± 0.03
C_3H_5NO	Ethyl cyanate	4.72 ± 0.09
C_3H_5NO	3-Hydroxypropanenitrile (*gauche*)	3.17 ± 0.02
C_3H_6	Propene	0.366 ± 0.001
$C_3H_6Br_2$	1,2-Dibromopropane	[1.2]
$C_3H_6Cl_2$	1,2-Dichloropropane	[1.85]
$C_3H_6Cl_2$	1,3-Dichloropropane	2.08 ± 0.04
C_3H_6O	Acetone	2.88 ± 0.03
C_3H_6O	Propanal (*gauche*)	2.86 ± 0.01
C_3H_6O	Propanal (*cis*)	2.52 ± 0.05
C_3H_6O	Propanal (*average*)	2.72
C_3H_6O	Allyl alcohol (*gauche*)	1.55 ± 0.08
C_3H_6O	Allyl alcohol (*average*)	1.60 ± 0.08
C_3H_6O	Methyl vinyl ether	0.965 ± 0.002
C_3H_6O	Methyloxirane	2.01 ± 0.02
C_3H_6O	Oxetane	1.94 ± 0.01
$C_3H_6O_2$	Propanoic acid (*cis*)	1.46 ± 0.07
$C_3H_6O_2$	Propanoic acid (*average*)	1.75 ± 0.09
$C_3H_6O_2$	Ethyl formate (*gauche*)	1.81 ± 0.02
$C_3H_6O_2$	Ethyl formate (*trans*)	1.98 ± 0.02
$C_3H_6O_2$	Ethyl formate (*average*)	1.93
$C_3H_6O_2$	Methyl acetate	1.72 ± 0.09
$C_3H_6O_2$	1,3-Dioxolane	1.19 ± 0.06
$C_3H_6O_2S$	Thietane 1,1-dioxide	4.8 ± 0.1
$C_3H_6O_3$	1,3,5-Trioxane	2.08 ± 0.02
C_3H_6S	Thiacyclobutane	1.85 ± 0.09
C_3H_7Br	1-Bromopropane	2.18 ± 0.11
C_3H_7Br	2-Bromopropane	2.21 ± 0.11
C_3H_7Cl	1-Chloropropane (*gauche*)	2.02 ± 0.03
C_3H_7Cl	1-Chloropropane (*trans*)	1.95 ± 0.02
C_3H_7Cl	1-Chloropropane (*average*)	2.05 ± 0.04
C_3H_7Cl	2-Chloropropane	2.17 ± 0.11
C_3H_7F	1-Fluoropropane (*gauche*)	1.90 ± 0.10
C_3H_7F	1-Fluoropropane (*trans*)	2.05 ± 0.04
C_3H_7F	2-Fluoropropane	1.958 ± 0.001
C_3H_7I	1-Iodopropane	2.04 ± 0.10
C_3H_7I	2-Iodopropane	[1.95]
C_3H_7N	Allylamine	≈1.2
C_3H_7N	Cyclopropylamine	1.19 ± 0.01
C_3H_7N	Propyleneimine (*cis*)	1.77 ± 0.09
C_3H_7N	Propyleneimine (*trans*)	1.57 ± 0.03
C_3H_7NO	*N*,*N*-Dimethylformamide	3.82 ± 0.08
C_3H_7NO	*N*-Methylacetamide	[4.3]
$C_3H_7NO_2$	1-Nitropropane	3.66 ± 0.07
$C_3H_7NO_2$	2-Nitropropane	3.73 ± 0.07
C_3H_8	Propane	0.084 ± 0.001
C_3H_8O	1-Propanol (*gauche*)	1.58 ± 0.03
C_3H_8O	1-Propanol (*trans*)	1.55 ± 0.03
C_3H_8O	2-Propanol (*trans*)	1.58 ± 0.03
C_3H_8O	Ethyl methyl ether (*trans*)	1.17 ± 0.02
$C_3H_8O_2$	1,2-Propylene glycol	[2.25]
$C_3H_8O_2$	1,3-Propylene glycol	[2.55]
$C_3H_8O_2$	Ethylene glycol monomethyl ether (*gauche*)	2.36 ± 0.05
$C_3H_8O_2$	Dimethoxymethane	[0.74]
$C_3H_8O_3$	Glycerol	[2.56]
C_3H_8S	1-Propanethiol (*gauche*)	1.683 ± 0.010
C_3H_8S	1-Propanethiol (*trans*)	1.60 ± 0.08
C_3H_8S	2-Propanethiol (*gauche*)	1.53 ± 0.03
C_3H_8S	2-Propanethiol (*trans*)	1.61 ± 0.03
C_3H_8S	Ethyl methyl sulfide (*gauche*)	1.593 ± 0.004
C_3H_8S	Ethyl methyl sulfide (*trans*)	1.56 ± 0.03
C_3H_9N	Propylamine	1.17 ± 0.06
C_3H_9N	Isopropylamine	1.19 ± 0.06
C_3H_9N	Trimethylamine	0.612 ± 0.003
$C_3H_9O_4P$	Trimethyl phosphate	[3.18]
C_4H_4	1-Buten-3-yne	0.22 ± 0.02
C_4H_4	Methylenecyclopropene	1.90 ± 0.01
$C_4H_4N_2$	Succinonitrile	[3.7]
$C_4H_4N_2$	Pyrimidine	2.334 ± 0.010
$C_4H_4N_2$	Pyridazine	4.22 ± 0.02
C_4H_4O	Furan	0.66 ± 0.01
$C_4H_4O_2$	Diketene	3.53 ± 0.07
C_4H_4S	Thiophene	0.55 ± 0.01
C_4H_5N	2-Methylacrylonitrile	3.69 ± 0.18
C_4H_5N	Pyrrole	1.767 ± 0.001
C_4H_5N	Isocyanocyclopropane	4.03 ± 0.10
C_4H_5NO	2-Methyloxazole	1.37 ± 0.07
C_4H_5NO	4-Methyloxazole	1.08 ± 0.05

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Mol. Form.	Name	μ/D
C_4H_5NO	5-Methyloxazole	2.16 ± 0.04
C_4H_5NO	4-Methylisoxazole	3.583 ± 0.005
C_4H_6	1,2-Butadiene	0.403 ± 0.002
C_4H_6	1-Butyne	0.782 ± 0.004
C_4H_6	Cyclobutene	0.132 ± 0.001
C_4H_6O	Divinyl ether	0.78 ± 0.05
C_4H_6O	3-Methoxy-1,2-propadiene	0.963 ± 0.020
C_4H_6O	*trans*-2-Butenal	3.67 ± 0.07
C_4H_6O	2-Methylpropenal	2.68 ± 0.13
C_4H_6O	Cyclobutanone	2.89 ± 0.03
C_4H_6O	2,3-Dihydrofuran	1.32 ± 0.03
C_4H_6O	2,5-Dihydrofuran	1.63 ± 0.01
$C_4H_6O_2$	*trans*-Crotonic acid	[2.13]
$C_4H_6O_2$	Methacrylic acid	[1.65]
$C_4H_6O_2$	Vinyl acetate	[1.79]
$C_4H_6O_2$	Methyl acrylate	[1.77]
$C_4H_6O_2$	γ-Butyrolactone	4.27 ± 0.03
$C_4H_6O_2$	2,3-Dihydro-1,4-dioxin	0.939 ± 0.008
$C_4H_6O_2$	3,6-Dihydro-1,2-dioxin	2.329 ± 0.001
$C_4H_6O_3$	Acetic anhydride	≈2.8
$C_4H_6O_3$	Propylene carbonate	[4.9]
C_4H_6S	2,3-Dihydrothiophene	1.61 ± 0.20
C_4H_6S	2,5-Dihydrothiophene	1.75 ± 0.01
C_4H_7N	Butanenitrile (*gauche*)	3.91 ± 0.04
C_4H_7N	Butanenitrile (*anti*)	3.73 ± 0.06
C_4H_7N	2-Methylpropanenitrile	4.29 ± 0.09
C_4H_7N	2-Isocyanopropane	4.055 ± 0.001
C_4H_7NO	2-Pyrrolidone	[3.5]
C_4H_8	1-Butene (*cis*)	0.438 ± 0.007
C_4H_8	1-Butene (*skew*)	0.359 ± 0.011
C_4H_8	*cis*-2-Butene	0.253 ± 0.005
C_4H_8	Isobutene	0.503 ± 0.010
C_4H_8	Methylcyclopropane	0.139 ± 0.004
$C_4H_8Cl_2$	1,4-Dichlorobutane	2.22 ± 0.11
$C_4H_8Cl_2O$	Bis(2-chloroethyl) ether	[2.58]
C_4H_8O	*cis*-2-Buten-1-ol	1.96 ± 0.03
C_4H_8O	*trans*-2-Buten-1-ol	1.90 ± 0.02
C_4H_8O	2-Methyl-2-propenol (*skew*)	1.295 ± 0.022
C_4H_8O	Ethyl vinyl ether	[1.26]
C_4H_8O	1,2-Epoxybutane	1.891 ± 0.011
C_4H_8O	Butanal	2.72 ± 0.05
C_4H_8O	Isobutanal (*gauche*)	2.69 ± 0.01
C_4H_8O	Isobutanal (*trans*)	2.86 ± 0.01
C_4H_8O	2-Butanone	2.779 ± 0.015
C_4H_8O	Tetrahydrofuran	1.75 ± 0.04
C_4H_8OS	1,4-Oxathiane	0.295 ± 0.003
$C_4H_8O_2$	Butanoic acid	[1.65]
$C_4H_8O_2$	2-Methylpropanoic acid	[1.08]
$C_4H_8O_2$	Propyl formate	[1.89]
$C_4H_8O_2$	Ethyl acetate	1.78 ± 0.09
$C_4H_8O_2$	*cis*-2-Butene-1,4-diol	[2.48]
$C_4H_8O_2$	*trans*-2-Butene-1,4-diol	[2.45]
$C_4H_8O_2$	1,3-Dioxane	2.06 ± 0.04
$C_4H_8O_2S$	Sulfolane	[4.8]
C_4H_8S	3-Methylthietane	2.046 ± 0.009
C_4H_8S	Tetrahydrothiophene	[1.90]
$C_4H_8S_2$	1,3-Dithiane	2.14 ± 0.04
C_4H_9Br	1-Bromobutane	2.08 ± 0.10
C_4H_9Br	2-Bromobutane	2.23 ± 0.11
C_4H_9Br	2-Bromo-2-methylpropane	[2.17]
C_4H_9Cl	1-Chlorobutane	2.05 ± 0.04
C_4H_9Cl	2-Chlorobutane	2.04 ± 0.10
C_4H_9Cl	1-Chloro-2-methylpropane	2.00 ± 0.10
C_4H_9Cl	2-Chloro-2-methylpropane	2.13 ± 0.04
C_4H_9I	1-Iodobutane	[1.93]
C_4H_9I	2-Iodobutane	2.12 ± 0.11
C_4H_9I	1-Iodo-2-methylpropane	[1.87]
C_4H_9N	Pyrrolidine	[1.57]
C_4H_9NO	*N*-Methylpropanamide	3.61
C_4H_9NO	*N*,*N*-Dimethylacetamide	[3.7]
C_4H_9NO	Morpholine	1.55 ± 0.03
C_4H_{10}	Isobutane	0.132 ± 0.002
$C_4H_{10}O$	1-Butanol	1.66 ± 0.03
$C_4H_{10}O$	2-Butanol	[1.8]
$C_4H_{10}O$	2-Methyl-1-propanol	1.64 ± 0.08
$C_4H_{10}O$	2-Methyl-2-propanol	[1.66]
$C_4H_{10}O$	Diethyl ether	1.15 ± 0.02
$C_4H_{10}O$	Methyl propyl ether (*trans-trans*)	1.107 ± 0.013
$C_4H_{10}O$	Isopropyl methyl ether	1.247 ± 0.003
$C_4H_{10}O_2$	1,4-Butanediol	[2.58]
$C_4H_{10}O_2$	Ethylene glycol monoethyl ether	[2.08]
$C_4H_{10}O_3$	Diethylene glycol	[2.31]
$C_4H_{10}S$	1-Butanethiol	[1.53]
$C_4H_{10}S$	2-Methyl-2-propanethiol	1.66 ± 0.03
$C_4H_{10}S$	Diethyl sulfide	1.54 ± 0.08
$C_4H_{11}N$	Butylamine	≈1.0
$C_4H_{11}N$	*sec*-Butylamine	[1.28]
$C_4H_{11}N$	*tert*-Butylamine	[1.29]
$C_4H_{11}N$	Isobutylamine	[1.27]
$C_4H_{11}N$	Diethylamine	0.92 ± 0.05
$C_4H_{11}NO_2$	Diethanolamine	[2.8]
$C_4H_{13}N_3$	Diethylenetriamine	[1.89]
C_5F_5N	Perfluoropyridine	0.98 ± 0.08
C_5H_3NS	2-Thiophenecarbonitrile	4.59 ± 0.02
C_5H_3NS	3-Thiophenecarbonitrile	4.13 ± 0.02
C_5H_4	1,3-Pentadiyne	1.207 ± 0.001
C_5H_4ClN	4-Chloropyridine	0.756 ± 0.005
C_5H_4FN	3-Fluoropyridine	2.09 ± 0.26
C_5H_4O	2,4-Cyclopentadien-1-one	3.132 ± 0.007
C_5H_4OS	4H-Pyran-4-thione	3.95 ± 0.05
$C_5H_4O_2$	Furfural	[3.54]
$C_5H_4O_2$	4H-Pyran-4-one	3.79 ± 0.02
$C_5H_4S_2$	4H-Thiopyran-4-thione	3.9 ± 0.2
C_5H_5N	Pyridine	2.215 ± 0.010
C_5H_6	1,2,3-Pentatriene	0.51 ± 0.05
C_5H_6	1-Penten-3-yne	0.66 ± 0.02
C_5H_6	*cis*-3-Penten-1-yne	0.78 ± 0.02
C_5H_6	*trans*-3-Penten-1-yne	1.06 ± 0.05
C_5H_6	2-Methyl-1-buten-3-yne	0.513 ± 0.02
C_5H_6	1,3-Cyclopentadiene	0.419 ± 0.004
$C_5H_6N_2$	2-Methylpyrimidine	1.676 ± 0.010
$C_5H_6N_2$	5-Methylpyrimidine	2.881 ± 0.006
C_5H_6O	2-Methylfuran	0.65 ± 0.05
C_5H_6O	3-Methylfuran	1.03 ± 0.02
C_5H_6O	3-Cyclopenten-1-one	2.79 ± 0.03
$C_5H_6O_2$	5-Methyl-2(3H)-furanone	4.08 ± 0.02
$C_5H_6O_2$	Furfuryl alcohol	[1.92]
C_5H_6S	2-Methylthiophene	0.674 ± 0.005
C_5H_6S	3-Methylthiophene	0.914 ± 0.015
C_5H_7N	3-Methyl-2-butenenitrile	4.61 ± 0.13
C_5H_7N	Cyclobutanecarbonitrile	4.04 ± 0.04
$C_5H_7NO_2$	Ethyl cyanoacetate	[2.17]

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Mol. Form.	Name	μ/D
C_5H_8	*cis*-1,3-Pentadiene	0.500 ± 0.015
C_5H_8	*trans*-1,3-Pentadiene	0.585 ± 0.010
C_5H_8	2-Methyl-1,3-butadiene	0.25 ± 0.01
C_5H_8	1-Pentyne (*gauche*)	0.769 ± 0.028
C_5H_8	1-Pentyne (*trans*)	0.842 ± 0.010
C_5H_8	Cyclopentene	0.20 ± 0.02
C_5H_8	3,3-Dimethylcyclopropene	0.287 ± 0.003
C_5H_8O	Cyclopropyl methyl ketone	2.62 ± 0.25
C_5H_8O	Cyclopentanone	≈3.3
C_5H_8O	3,4-Dihydro-2H-pyran	1.400 ± 0.008
C_5H_8O	3,6-Dihydro-2H-pyran	1.283 ± 0.005
$C_5H_8O_2$	Ethyl acrylate	[1.96]
$C_5H_8O_2$	Methyl methacrylate	[1.67]
$C_5H_8O_2$	2,4-Pentanedione	[2.78]
$C_5H_8O_2$	Dihydro-3-methyl-2(3H)-furanone	4.56 ± 0.02
$C_5H_8O_2$	Dihydro-5-methyl-2(3H)-furanone	4.71 ± 0.05
$C_5H_8O_2$	Tetrahydro-4H-pyran-4-one	1.720 ± 0.003
C_5H_9N	Pentanenitrile	4.12 ± 0.08
C_5H_9N	2,2-Dimethylpropanenitrile	3.95 ± 0.04
C_5H_9N	1,2,5,6-Tetrahydropyridine	1.007 ± 0.003
C_5H_9NO	*N*-Methyl-2-pyrrolidone	[4.1]
C_5H_{10}	1-Pentene	≈0.5
C_5H_{10}	3-Methyl-1-butene (*gauche*)	0.398 ± 0.004
C_5H_{10}	3-Methyl-1-butene (*trans*)	0.320 ± 0.010
C_5H_{10}	1,1-Dimethylcyclopropane	0.142 ± 0.001
$C_5H_{10}O$	2,2-Dimethylpropanal	2.66 ± 0.05
$C_5H_{10}O$	2-Pentanone	[2.70]
$C_5H_{10}O$	3-Pentanone	[2.82]
$C_5H_{10}O$	Tetrahydropyran (*chair*)	1.58 ± 0.03
$C_5H_{10}O_2$	Pentanoic acid	[1.61]
$C_5H_{10}O_2$	3-Methylbutanoic acid	[0.63]
$C_5H_{10}O_2$	Butyl formate	[2.03]
$C_5H_{10}O_2$	Isobutyl formate	[1.88]
$C_5H_{10}O_2$	Propyl acetate	[1.78]
$C_5H_{10}O_2$	Ethyl propanoate	[1.74]
$C_5H_{10}O_2$	Tetrahydrofurfuryl alcohol	[2.1]
$C_5H_{10}O_3$	Diethyl carbonate	1.10 ± 0.06
$C_5H_{10}O_3$	Ethylene glycol monomethyl ether acetate	[2.13]
$C_5H_{10}O_3$	Ethyl lactate	[2.4]
$C_5H_{10}S$	Thiacyclohexane	1.781 ± 0.010
$C_5H_{11}Br$	1-Bromopentane	2.20 ± 0.11
$C_5H_{11}Cl$	1-Chloropentane	2.16 ± 0.11
$C_5H_{11}Cl$	1-Chloro-3-methylbutane	[1.92]
$C_5H_{11}N$	Piperidine (*equitorial*)	0.82 ± 0.02
$C_5H_{11}N$	Piperidine (*axial*)	1.19 ± 0.02
$C_5H_{11}N$	Piperidine (*average*)	[1.19]
$C_5H_{11}N$	*N*-Methylpyrrolidine	0.572 ± 0.003
C_5H_{12}	Isopentane	0.13 ± 0.05
$C_5H_{12}N_2O$	Tetramethylurea	[3.5]
$C_5H_{12}O$	1-Pentanol	[1.7]
$C_5H_{12}O$	2-Pentanol	[1.66]
$C_5H_{12}O$	3-Pentanol	[1.64]
$C_5H_{12}O$	2-Methyl-1-butanol	[1.88]
$C_5H_{12}O$	2-Methyl-2-butanol	[1.82]
$C_5H_{12}O_2$	1,5-Pentanediol	[2.5]
$C_5H_{12}O_3$	Diethylene glycol monomethyl ether	[1.6]
$C_6H_2F_4$	1,2,3,4-Tetrafluorobenzene	2.42 ± 0.05
$C_6H_2F_4$	1,2,3,5-Tetrafluorobenzene	1.46 ± 0.06
$C_6H_3F_3$	1,2,4-Trifluorobenzene	1.402 ± 0.009
$C_6H_4ClNO_2$	1-Chloro-2-nitrobenzene	4.64 ± 0.09
$C_6H_4ClNO_2$	1-Chloro-3-nitrobenzene	3.73 ± 0.07
$C_6H_4ClNO_2$	1-Chloro-4-nitrobenzene	2.83 ± 0.06
$C_6H_4Cl_2$	*o*-Dichlorobenzene	2.50 ± 0.05
$C_6H_4Cl_2$	*m*-Dichlorobenzene	1.72 ± 0.09
$C_6H_4FNO_2$	1-Fluoro-4-nitrobenzene	2.87 ± 0.06
$C_6H_4F_2$	*o*-Difluorobenzene	2.46 ± 0.05
$C_6H_4F_2$	*m*-Difluorobenzene	1.51 ± 0.02
$C_6H_4N_2$	2-Pyridinecarbonitrile	5.78 ± 0.11
$C_6H_4N_2$	3-Pyridinecarbonitrile	3.66 ± 0.11
$C_6H_4N_2$	4-Pyridinecarbonitrile	1.96 ± 0.03
$C_6H_4O_2$	3,5-Cyclohexadiene-1,2-dione	4.23 ± 0.02
C_6H_5Br	Bromobenzene	1.70 ± 0.03
C_6H_5Cl	Chlorobenzene	1.69 ± 0.03
C_6H_5ClO	*p*-Chlorophenol	2.11 ± 0.11
C_6H_5F	Fluorobenzene	1.60 ± 0.08
C_6H_5I	Iodobenzene	1.70 ± 0.09
C_6H_5NO	2-Pyridinecarboxaldehyde	3.56 ± 0.07
C_6H_5NO	3-Pyridinecarboxaldehyde	1.44
C_6H_5NO	4-Pyridinecarboxaldehyde	1.66
$C_6H_5NO_2$	Nitrobenzene	4.22 ± 0.08
C_6H_6	Fulvene	0.4236 ± 0.013
C_6H_6ClN	*o*-Chloroaniline	[1.77]
C_6H_6O	Phenol	1.224 ± 0.008
C_6H_6O	2-Vinylfuran	0.69 ± 0.07
$C_6H_6O_2$	*p*-Hydroquinone	2.38 ± 0.05
C_6H_6S	Benzenethiol	[1.23]
C_6H_7N	Aniline	1.13 ± 0.02
C_6H_7N	2-Methylpyridine	1.85 ± 0.04
C_6H_7N	3-Methylpyridine	[2.40]
C_6H_7N	4-Methylpyridine	2.70 ± 0.02
C_6H_8O	3-Methyl-2-cyclopenten-1-one	4.33 ± 0.002
$C_6H_8O_4$	Dimethyl maleate	[2.48]
C_6H_8Si	Phenylsilane	0.845 ± 0.012
C_6H_9F	1-Fluorocyclohexene	1.942 ± 0.010
C_6H_{10}	1-Hexyne	0.83 ± 0.05
C_6H_{10}	3,3-Dimethyl-1-butyne	0.661 ± 0.004
C_6H_{10}	Cyclohexene (*half-chair*)	0.332 ± 0.012
$C_6H_{10}F_2$	1,1-Difluorocyclohexane	2.556 ± 0.010
$C_6H_{10}O$	3-Methylcyclopentanone	3.14 ± 0.03
$C_6H_{10}O$	Cyclohexanone	3.246 ± 0.006
$C_6H_{10}O$	Mesityl oxide	[2.79]
$C_6H_{10}O_4$	Diethyl oxalate	[2.49]
$C_6H_{10}O_4$	Ethylene glycol diacetate	[2.34]
$C_6H_{11}Cl$	Chlorocyclohexane (*equitorial*)	2.44 ± 0.07
$C_6H_{11}Cl$	Chlorocyclohexane (*axial*)	1.91 ± 0.02
$C_6H_{11}F$	Fluorocyclohexane (*equitorial*)	2.11 ± 0.04
$C_6H_{11}F$	Fluorocyclohexane (*axial*)	1.81 ± 0.04
$C_6H_{11}N$	4-Methylpentanenitrile	[3.5]
$C_6H_{11}NO$	Caprolactam	[3.9]
$C_6H_{12}O$	Butyl vinyl ether	[1.25]
$C_6H_{12}O$	2-Hexanone	[2.66]
$C_6H_{12}O_2$	Hexanoic acid	[1.13]
$C_6H_{12}O_2$	Pentyl formate	1.90 ± 0.10
$C_6H_{12}O_2$	Butyl acetate	[1.87]
$C_6H_{12}O_2$	*sec*-Butyl acetate	[1.87]
$C_6H_{12}O_2$	Isobutyl acetate	[1.86]
$C_6H_{12}O_2$	Ethyl butanoate	[1.74]
$C_6H_{12}O_2$	Diacetone alcohol	[3.24]
$C_6H_{12}O_3$	Ethylene glycol monoethyl ether acetate	[2.25]

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DIPOLE MOMENTS (continued)

Mol. Form.	Name	μ/D
$C_6H_{12}O_3$	Paraldehyde	1.43 ± 0.07
$C_6H_{13}N$	Cyclohexylamine	[1.26]
$C_6H_{14}O$	Dipropyl ether	1.21 ± 0.06
$C_6H_{14}O$	Diisopropyl ether	1.13 ± 0.10
$C_6H_{14}O$	Butyl ethyl ether	[1.24]
$C_6H_{14}O_2$	2-Methyl-2,4-pentanediol	[2.9]
$C_6H_{14}O_2$	Ethylene glycol monobutyl ether	[2.08]
$C_6H_{14}O_2$	1,1-Diethoxyethane	[1.38]
$C_6H_{14}O_3$	Diethylene glycol monoethyl ether	[1.6]
$C_6H_{14}O_3$	Diethylene glycol dimethyl ether	[1.97]
$C_6H_{15}N$	Dipropylamine	[1.03]
$C_6H_{15}N$	Diisopropylamine	[1.15]
$C_6H_{15}N$	Triethylamine	0.66 ± 0.05
$C_6H_{15}NO_3$	Triethanolamine	[3.57]
$C_6H_{15}O_4P$	Triethyl phosphate	[3.12]
$C_6H_{18}N_3OP$	Hexamethylphosphoric triamide	[5.5]
$C_7H_5Cl_3$	(Trichloromethyl)benzene	[2.03]
$C_7H_5F_3$	(Trifluoromethyl)benzene	2.86 ± 0.06
C_7H_5N	Benzonitrile	4.18 ± 0.08
C_7H_5N	Isocyanobenzene	4.018 ± 0.003
$C_7H_6Cl_2$	2,4-Dichlorotoluene	[1.70]
$C_7H_6Cl_2$	3,4-Dichlorotoluene	[2.95]
$C_7H_6Cl_2$	(Dichloromethyl)benzene	[2.07]
C_7H_6O	2,4,6-Cycloheptatrien-1-one	4.1 ± 0.3
C_7H_6O	Benzaldehyde	[3.0]
$C_7H_6O_2$	Salicylaldehyde	[2.86]
C_7H_7Cl	*o*-Chlorotoluene	1.56 ± 0.08
C_7H_7Cl	*m*-Chlorotoluene	[1.82]
C_7H_7Cl	*p*-Chlorotoluene	2.21 ± 0.04
C_7H_7Cl	(Chloromethyl)benzene	[1.82]
C_7H_7F	*o*-Fluorotoluene	1.37 ± 0.07
C_7H_7F	*m*-Fluorotoluene	1.82 ± 0.04
C_7H_7F	*p*-Fluorotoluene	2.00 ± 0.10
$C_7H_7NO_3$	2-Nitroanisole	[5.0]
C_7H_8	Toluene	0.375 ± 0.010
C_7H_8	2,5-Norbornadiene	0.0587 ± 0.0001
C_7H_8O	*o*-Cresol	[1.45]
C_7H_8O	*m*-Cresol	[1.48]
C_7H_8O	*p*-Cresol	[1.48]
C_7H_8O	Benzyl alcohol	1.71 ± 0.09
C_7H_8O	Anisole	1.38 ± 0.07
C_7H_9N	*o*-Methylaniline	[1.60]
C_7H_9N	*m*-Methylaniline	[1.45]
C_7H_9N	*p*-Methylaniline	[1.52]
C_7H_9N	2,4-Dimethylpyridine	[2.30]
C_7H_9N	2,6-Dimethylpyridine	[1.66]
C_7H_{10}	1,3-Cycloheptadiene	0.740
C_7H_{12}	Methylenecyclohexane	0.62 ± 0.01
$C_7H_{12}O_4$	Diethyl malonate	[2.54]
$C_7H_{14}O$	2-Heptanone	[2.59]
$C_7H_{14}O$	3-Heptanone	[2.78]
$C_7H_{14}O$	2,4-Dimethyl-3-pentanone	[2.74]
$C_7H_{14}O$	*cis*-3-Methylcyclohexanol	[1.91]
$C_7H_{14}O$	*trans*-3-Methylcyclohexanol	[1.75]
$C_7H_{14}O_2$	Pentyl acetate	1.75 ± 0.10
$C_7H_{14}O_2$	Isopentyl acetate	[1.86]
$C_7H_{15}Br$	1-Bromoheptane	2.16 ± 0.11
$C_7H_{16}O$	2-Heptanol	[1.71]
$C_7H_{16}O$	3-Heptanol	[1.71]
C_8H_6	Phenylacetylene	0.656 ± 0.005
C_8H_7N	Benzeneacetonitrile	[3.5]
C_8H_8	Styrene	0.123 ± 0.003
C_8H_8O	Acetophenone	3.02 ± 0.06
$C_8H_8O_2$	Methyl benzoate	[1.94]
$C_8H_8O_3$	Methyl salicylate	[2.47]
C_8H_{10}	Ethylbenzene	0.59 ± 0.05
C_8H_{10}	*o*-Xylene	0.640 ± 0.005
$C_8H_{10}O$	2,4-Xylenol	[1.4]
$C_8H_{10}O$	2,5-Xylenol	[1.45]
$C_8H_{10}O$	2,6-Xylenol	[1.40]
$C_8H_{10}O$	3,4-Xylenol	[1.56]
$C_8H_{10}O$	3,5-Xylenol	[1.55]
$C_8H_{10}O$	Phenetole	1.45 ± 0.15
$C_8H_{10}O_2$	1,2-Dimethoxybenzene	[1.29]
$C_8H_{11}N$	*N*,*N*-Dimethylaniline	1.68 ± 0.17
$C_8H_{11}N$	2,4-Dimethylaniline	[1.40]
$C_8H_{11}N$	2,6-Dimethylaniline	[1.63]
$C_8H_{11}N$	2,4,6-Trimethylpyridine	[2.05]
$C_8H_{16}O$	2-Octanone	[2.70]
$C_8H_{16}O_2$	Octanoic acid	[1.15]
$C_8H_{16}O_2$	*sec*-Hexyl acetate	[1.9]
$C_8H_{16}O_2$	Isobutyl isobutanoate	[1.9]
$C_8H_{16}O_4$	Diethylene glycol monoethyl ether acetate	[1.8]
$C_8H_{17}Cl$	1-Chlorooctane	[2.00]
$C_8H_{18}O$	1-Octanol	[1.76]
$C_8H_{18}O$	2-Octanol	[1.71]
$C_8H_{18}O$	2-Ethyl-1-hexanol	[1.74]
$C_8H_{18}O$	Dibutyl ether	1.17 ± 0.06
$C_8H_{18}S$	Dibutyl sulfide	[1.61]
$C_8H_{19}N$	Dibutylamine	[0.98]
C_9H_7N	Quinoline	2.29 ± 0.11
C_9H_7N	Isoquinoline	2.73 ± 0.14
$C_9H_{10}O_2$	Ethyl benzoate	2.00 ± 0.10
$C_9H_{10}O_2$	Benzyl acetate	[1.22]
C_9H_{12}	Isopropylbenzene	≈0.79
$C_9H_{18}O$	2,6-Dimethyl-4-heptanone	[2.66]
$C_9H_{18}O_2$	Nonanoic acid	[0.79]
$C_{10}H_7Br$	1-Bromonaphthalene	[1.55]
$C_{10}H_7Cl$	1-Chloronaphthalene	[1.57]
$C_{10}H_8$	Azulene	0.80 ± 0.02
$C_{10}H_{14}$	*tert*-Butylbenzene	≈0.83
$C_{10}H_{16}O$	Camphor, (+)	[3.1]
$C_{10}H_{20}O_2$	2-Ethylhexyl acetate	[1.8]
$C_{10}H_{21}Br$	1-Bromodecane	[1.93]
$C_{10}H_{22}O$	Dipentyl ether	[1.20]
$C_{10}H_{22}O$	Diisopentyl ether	[1.23]
$C_{11}H_{12}O_2$	Ethyl *trans*-cinnamate	[1.84]
$C_{12}H_{10}$	Acenaphthene	≈0.85
$C_{12}H_{10}O$	Diphenyl ether	≈1.3
$C_{12}H_{27}BO_3$	Tributyl borate	[0.77]
$C_{12}H_{27}N$	Tributylamine	[0.78]
$C_{12}H_{27}O_4P$	Tributyl phosphate	[3.07]
$C_{14}H_{12}O_2$	Benzyl benzoate	[2.06]
$C_{16}H_{22}O_4$	Dibutyl phthalate	[2.82]
$C_{18}H_{34}O_2$	Oleic acid	[1.18]
$C_{18}H_{34}O_4$	Dibutyl sebacate	[2.48]
$C_{21}H_{21}O_4P$	Tri-*o*-cresyl phosphate	[2.87]
$C_{21}H_{21}O_4P$	Tri-*m*-cresyl phosphate	[3.05]
$C_{21}H_{21}O_4P$	Tri-*p*-cresyl phosphate	[3.18]
$C_{22}H_{44}O_2$	Butyl stearate	[1.88]
$C_{24}H_{38}O_4$	Bis(2-ethylhexyl) phthalate	[2.84]

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STRENGTHS OF CHEMICAL BONDS*

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The strength of a chemical bond, $D°$(R-X), often known as the bond dissociation energy, is defined as the standard enthalpy change of the reaction in which the bond is broken: RX → R + X. It is given by the thermochemical equation, $D°(\text{R-X}) = \Delta_f H°(\text{R}) + \Delta_f H°(\text{X}) - \Delta_f H°(\text{RX})$. Some authors list bond strengths at a temperature of absolute zero but here the values at 298 K are given because more thermodynamic data are available for this temperature. Bond strengths or bond dissociation energies are not equal to, and may differ considerably from, mean bond energies determined solely from thermochemical data on atoms and molecules.

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES

These have usually been measured spectroscopically or by mass spectrometric analysis of hot gases effusing a Knudsen cell. Excellent accounts of these and other methods are given in (i) *Dissociation Energies and Spectra of Diatomic Molecules*, by A. G. Gaydon, 3rd. ed., Chapman & Hall, London, 1968 and (ii) "Mass Spectrometric Determination of Bond Energies of High-Temperature Molecules", K. A. Gingerich, *Chimia*, 26, 619, 1972. The errors quoted in the table are those given in the original paper or review article. The references have been chosen primarily as a key to the literature. It should not be assumed that the author referred to was responsible for the value quoted, as the reference may be to a review article.

Bond strengths reported at a temperature of absolute zero, $D°_0$, have been converted to $D°_{298}$ by the use of enthalpy functions taken mainly from the JANAF Thermochemical Tables, Third Edition, *J. Phys. Chem. Ref. Data*, 14, Suppl. 1, 1985, wherever possible. For most bonds, however, this data is not available and the conversion has been made by the approximate relation:

$$D°_{298} = D°_0 + (3/2)RT$$

The list below does not include the increasing number of bond strengths of diatomic molecules now being calculated by *ab initio* methods.

The Table has been arranged in an alphabetical order of the atoms.

Molecule	$D°_{298}$/kJ mol^{-1}	Ref.
Ag-Ag	160.3 ± 3.4	314
Ag-Al	183.7 ± 9.2	79
Ag-Au	202.9 ± 9.2	4
Ag-Bi	193 ± 42	246
Ag-Br	293 ± 29	120
Ag-Cl	314.2	184
Ag-Cu	174.1 ± 9.2	136
Ag-D	226.8	205
Ag-Dy	130 ± 19	203
Ag-Eu	129.7 ± 12.6	66
Ag-F	354.4 ± 16.3	120
Ag-Ga	180 ± 15	44
Ag-Ge	174.5 ± 20.9	135
Ag-H	215.1 ± 8	217
Ag-Ho	123.4 ± 16.7	62
Ag-I	234 ± 29	120
Ag-In	166.5 ± 4.9	13
Ag-Li	173.6 ± 6.3	276,303
Ag-Mn	100 ± 21	246
Ag-Na	138.1 ± 8.4	291,298
Ag-Nd	<209	221
Ag-O	220.1 ± 20.9	287
Ag-S	217.1	349
Ag-Se	202.5	349
Ag-Si	177.8 ± 10.0	320
Ag-Sn	136.0 ± 20.9	3
Ag-Te	195.8	349
Al-Al	133 ± 6	118
Al-Ar	5.182 ± 0.005	180
Al-As	202.9 ± 7.1	294,301
Al-Au	325.9 ± 6.3	124
Al-Br	429 ± 6	186
Al-Cl	511.3 ± 0.8	312
Al-Co	181.6 ± 0.2	22
Al-Cr	223.6 ± 0.6	19
Al-Cu	227.1 ± 1.2	21
Al-D	290.8	246
Al-F	663.6 ± 6.3	80
Al-H	284.9 ± 6.3	80
Al-I	369.9 ± 2.1	267
Al-Kr	6.047 ± 0.001	180
Al-Li	76.5	39
Al-N	297 ± 96	120
Al-Ni	225 ± 5	20
Al-O	511 ± 3	56,74
Al-P	216.7 ± 12.6	80
Al-Pd	254.4 ± 12.1	64
Al-S	373.6 ± 7.9	376
Al-Sb	216.3 ± 5.9	293
Al-Se	337.6 ± 10.0	376
Al-Si	229.3 ± 30.1	51
Al-Te	267.8 ± 10.0	376
Al-U	326 ± 29	123
Al-V	147.4 ± 1.0	22
Al-Xe	7.43 ± 0.69	43
Ar-Ar	4.73 ± 0.04	181
Ar-He	3.89	246
Ar-Hg	6.15	246
Ar-I	10.0	40
Ar-K	4.2	205
As-As	382.0 ± 10.5	247
As-Cl	448	80
As-D	270.3	205
As-F	410	205
As-Ga	209.6 ± 1.2	83
As-H	274.0 ± 2.9	29
As-I	296.6 ± 28.0	325
As-In	201	297
As-N	489 ± 2	310
As-O	481 ± 8	262
As-P	433.5 ± 12.6	137
As-S	379.5 ± 6.3	262
As-Sb	330.5 ± 5.4	94
As-Se	96	288
As-Tl	198.3 ± 14.6	300
At-At	~80	89
Au-Au	226.2 ± 0.5	210
Au-B	367.8 ± 10.5	145
Au-Ba	254.8 ± 10.0	135
Au-Be	285 ± 8	120
Au-Bi	297 ± 8.4	135
Au-Ca	243	135
Au-Ce	339 ± 21	135
Au-Cl	343 ± 9.6	120
Au-Co	222 ± 17	135
Au-Cr	213 ± 17	135
Au-Cs	255 ± 3.3	41
Au-Cu	228.0 ± 5.0	34,135
Au-D	318.4	205
Au-Dy	259 ± 21	203
Au-Eu	241.0 ± 10.5	66
Au-Fe	187.0 ± 16.7	220
Au-Ga	234 ± 38	135
Au-Ge	274.1 ± 5.0	135
Au-H	292.0 ± 8	217
Au-Ho	267.4 ± 16.7	62,250

* Revised to November 1998.

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

Molecule	D°_{298}/kJ mol^{-1}	Ref.
Au-In	286.0 ± 5.7	13
Au-La	336.4 ± 20.9	127
Au-Li	284.5 ± 6.7	276
Au-Lu	332.2 ± 16.7	132
Au-Mg	243 ± 42	246
Au-Mn	185.4 ± 12.6	342
Au-Na	215.1 ± 12.6	298
Au-Nd	299.2 ± 20.9	127
Au-Ni	247 ± 16	352
Au-O	221.8 ± 20.9	287
Au-Pb	130 ± 42	246
Au-Pd	155 ± 21	135
Au-Pr	310 ± 21	135
Au-Rb	243 ± 2.9	41
Au-Rh	231.0 ± 29	66
Au-S	418 ± 25	131
Au-Sc	280.3 ± 16.7	128
Au-Se	243.1	349
Au-Si	305.4 ± 5.9	139
Au-Sn	254.8 ± 7.1	233
Au-Sr	264 ± 42	246
Au-Tb	289.5 ± 33.5	152,250
Au-Te	317.6	349
Au-U	318 ± 29	123
Au-V	240.6 ± 12.1	172
Au-Y	307.1 ± 8.4	177
B-B	297 ± 21	80
B-Br	396	32
B-C	448 ± 29	246
B-Ce	305 ± 21	246
B-Cl	511.3 ± 4	195
B-D	341.0 ± 6.3	246
B-F	757	257
B-H	340	302
B-I	220.5 ± 0.8	315
B-Ir	514.2 ± 17.2	381
B-La	339 ± 63	246
B-N	389 ± 21	80
B-O	808.8 ± 20.9	287
B-P	346.9 ± 16.7	147
B-Pd	329.3 ± 20.9	381
B-Pt	477.8 ± 16.7	268
B-Rh	475.7 ± 20.9	381
B-Ru	446.9 ± 20.9	381
B-S	580.7 ± 9.2	374
B-Sc	276 ± 63	246
B-Se	461.9 ± 14.6	374
B-Si	317 ± 7	390
B-Te	354.4 ± 20.1	374
B-Th	297	140
B-Ti	276 ± 63	246
B-U	322 ± 33	246
B-Y	293 ± 63	246
Ba-Br	362.8 ± 8.4	104,199,230
Ba-Cl	436.0 ± 8.4	197,199
Ba-D	≤193.7	205
Ba-F	587.0 ± 6.7	101,196
Ba-H	176 ± 14.6	120
Ba-I	320.8 ± 6.3	188
Ba-O	561.9 ± 13.4	287
Ba-Pd	221.8 ± 5.0	125
Ba-Rh	259.4 ± 25.1	125
Ba-S	400.0 ± 18.8	70
Be-Be	59	35,87
Be-Br	381 ± 84	246
Be-Cl	388.3 ± 9.2	108,191,382
Be-D	203.05	205
Be-F	577 ± 42	80,108
Be-H	200.0 ± 1.3	67
Be-O	434.7 ± 13.4	287
Be-S	372 ± 59	120
Bi-Bi	200.4 ± 7.5	307,324
Bi-Br	267.4 ± 4.2	76
Bi-Cl	301 ± 4	78
Bi-D	283.7	266
Bi-F	367 ± 13	400
Bi-Ga	159 ± 17	296
Bi-H	≤283.3	266
Bi-I	218.0 ± 4.6	77
Bi-In	153.6 ± 1.7	321
Bi-Li	154.0 ± 5.0	277,305
Bi-O	337.2 ± 12.6	287
Bi-P	280 ± 13	137
Bi-Pb	141.8 ± 14.6	324
Bi-S	315.5 ± 4.6	375
Bi-Sb	251 ± 4	244
Bi-Se	280.3 ± 5.9	375
Bi-Sn	210.0 ± 8.4	135
Bi-Te	232.2 ± 11.3	375
Bi-Tl	121 ± 13	84
Br-Br	192.807	1
Br-C	280 ± 21	120
Br-Ca	310.9 ± 9.2	319
Br-Cd	159 ± 96	120
Br-Cl	217.53 ± 0.29	59
Br-Co	331 ± 42	246
Br-Cr	328.0 ± 24.3	120
Br-Cs	389.1 ± 4	285,362
Br-Cu	331 ± 25	120
Br-D	370.74	205
Br-F	280 ± 12	211
Br-Fe	247 ± 96	120
Br-Ga	444 ± 17	80
Br-Ge	255 ± 29	120
Br-H	366.35	205
Br-Hg	72.8 ± 4	80
Br-I	179.1 ± 0.4	120,309
Br-In	414 ± 21	80
Br-K	379.9 ± 0.8	362,378
Br-Li	418.8 ± 4	362
Br-Mg	≤327.2	205
Br-Mn	314.2 ± 9.6	120
Br-N	276 ± 21	120
Br-Na	367.4 ± 0.8	362,378
Br-Ni	360 ± 13	120
Br-O	235.5 ± 2.4	46
Br-Pb	247 ± 38	120
Br-Rb	380.7 ± 4	362
Br-Sb	314 ± 59	120
Br-Sc	444 ± 63	246
Br-Se	297 ± 84	246
Br-Si	367.8 ± 10.0	106
Br-Sn	≥552	286
Br-Sr	333.0 ± 9.2	199
Br-Th	364	187
Br-Ti	439	246
Br-Tl	333.9 ± 1.7	28
Br-U	377.4 ± 6.3	260
Br-V	439 ± 42	246
Br-W	329.3	223
Br-Xe	5.94 ± 0.02	58
Br-Y	485 ± 84	246
Br-Zn	142 ± 29	246
C-C	610 ± 2.0	373
C-Ce	444 ± 13	236
C-Cl	397 ± 29	283
C-D	341.4	205
C-F	552	193
C-Ge	460 ± 21	120
C-H	338.4 ± 1.2	205
C-Hf	540 ± 25	357
C-I	209 ± 21	120
C-Ir	632 ± 4	171
C-La	462 ± 20	290
C-Mo	481 ± 15.9	167
C-N	748.0 ± 10	42
C-Nb	569 ± 13.0	167
C-O	1076.5 ± 0.4	80
C-Os	≥594	126
C-P	513.4 ± 8	350
C-Pt	598 ± 5.9	171,379
C-Rh	580.0 ± 3.8	332
C-Ru	616.2 ± 10.5	333
C-S	714.1 ± 1.2	71,354
C-Sc	≤444	148
C-Se	590.4 ± 5.9	343
C-Si	451.5	91,387
C-Tc	565 ± 29	322
C-Th	453 ± 17	166,357
C-Ti	423 ± 29	162,357
C-U	454.8 ± 15.1	165,169
C-V	427 ± 23.8	167
C-Y	418 ± 14	338
C-Zr	561 ± 25	357
Ca-Ca	~17	153
Ca-Cl	409 ± 9	269
Ca-D	≤169.9	205
Ca-F	527 ± 21	101,190
Ca-H	167.8	120
Ca-I	284.7 ± 8.4	188
Ca-Li	84.9 ± 8.4	397

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

Molecule	$D°_{298}$/kJ mol^{-1}	Ref.
Ca-O	402.1 ± 16.7	287,326
Ca-S	337.6 ± 18.8	70,205
Cd-Cd	7.36	251
Cd-Cl	208.4	205
Cd-F	305 ± 21	31
Cd-H	69.0 ± 0.4	120
Cd-I	97.23	215
Cd-In	138	246
Cd-O	235.6 ± 83.7	158,287
Cd-S	208.4 ± 20.9	158
Cd-Se	127.6 ± 25.1	158
Cd-Te	100.0 ± 15.1	158
Ce-Ce	245.2	127
Ce-F	582 ± 42	246
Ce-Ir	586	149
Ce-N	519 ± 21	146
Ce-O	795 ± 8	95
Ce-Os	506 ± 33	126
Ce-Pd	322.2	63
Ce-Pt	556	149
Ce-Rh	548	149
Ce-Ru	531 ± 25	126
Ce-S	569	24
Ce-Se	494.5 ± 14.6	271
Ce-Te	189.4 ± 12.8	252
Cl-Cl	242.580 ± 0.004	205
Cl-Co	337.6 ± 6.7	194
Cl-Cr	377.8 ± 6.7	194
Cl-Cs	448 ± 8	285,363
Cl-Cu	377.8 ± 7.5	184
Cl-D	436.47	205
Cl-Eu	~326	113
Cl-F	256.23	205,279
Cl-Fe	329.7 ± 6.7	194
Cl-Ga	481 ± 13	80
Cl-Ge	~431	205
Cl-H	431.62	205
Cl-Hg	100 ± 8	120
Cl-I	211.3 ± 0.4	120
Cl-In	439 ± 8	80
Cl-K	433.0 ± 8	363
Cl-Li	469 ± 13	80
Cl-Mg	327.6 ± 2.1	105,197,382
Cl-Mn	338.5 ± 6.7	194
Cl-N	333.9 ± 9.6	54
Cl-Na	412.1 ± 8	363
Cl-Ni	377.0 ± 6.7	194
Cl-O	268.85 ± 0.10	2
Cl-P	289 ± 42	246
Cl-Pb	301 ± 29	120
Cl-Ra	343 ± 75	120
Cl-Rb	427.6 ± 8	363
Cl-S	277.0	224
Cl-Sb	360 ± 50	120
Cl-Sc	331	386
Cl-Se	322	246
Cl-Si	406	308,385
Cl-Sm	≥423	399
Cl-Sn	414 ± 17	246
Cl-Sr	406 ± 13	197,199
Cl-Ta	544	23
Cl-Th	489	261
Cl-Ti	405.4 ± 10.5	192
Cl-Tl	372.8 ± 2.1	28
Cl-U	452 ± 8	259
Cl-V	477 ± 63	246
Cl-W	423 ± 42	246
Cl-Xe	6.7	205
Cl-Y	527 ± 84	246
Cl-Yb	~322	113
Cl-Zn	228.9 ± 19.7	73
Cm-O	736	341
Co-Co	167 ± 25	218
Co-Cu	167 ± 17	135
Co-F	435 ± 63	246
Co-Ge	234 ± 21	135
Co-H	226 ± 42	369
Co-I	285 ± 21	246
Co-Nb	267.0 ± 0.1	8
Co-O	384.5 ± 13.4	287
Co-S	331	349
Co-Si	276 ± 17	380
Co-Ti	235.4 ± 0.1	353
Co-Y	253.7 ± 0.1	8
Co-Zr	306.4 ± 0.1	8
Cr-Cr	142.9 ± 5.4	201
Cr-Cu	155 ± 21	222
Cr-F	444.8 ± 19.7	227
Cr-Ge	154 ± 7	202
Cr-H	190.3 ± 7.0	53
Cr-I	287.0 ± 24.3	120
Cr-N	377.8 ± 18.8	152,355
Cr-O	461 ± 9	179
Cr-Pb	105 ± 2	202
Cr-S	331	93
Cr-Sn	141 ± 3	202
Cs-Cs	43.919 ± 0.010	394
Cs-F	519 ± 8	285
Cs-H	175.364	401
Cs-Hg	8	205
Cs-I	337.2 ± 2.1	285,361
Cs-Na	63.2 ± 1.3	86
Cs-O	295.8 ± 62.8	287
Cs-Rb	49.57 ± 0.01	174
Cu-Cu	176.52 ± 2.38	135,323
Cu-D	270.3	205
Cu-Dy	142 ± 21	203
Cu-F	413.4 ± 13	99
Cu-Ga	215.9 ± 15.1	44
Cu-Ge	208.8 ± 21	273
Cu-H	277.8	217,318
Cu-Ho	142 ± 21	203
Cu-I	197 ± 21	120
Cu-In	187.4 ± 7.9	13
Cu-Li	192.9 ± 8.8	276
Cu-Mn	158.6 ± 17	222
Cu-Na	176.1 ± 16.7	299
Cu-Ni	202 ± 10	117
Cu-O	269.0 ± 20.9	287
Cu-S	276	349
Cu-Se	251	349
Cu-Si	221.3 ± 6.3	320
Cu-Sn	169.5 ± 6.7	3,237
Cu-Tb	193 ± 19	203
Cu-Te	278.7	1
D-D	443.533	205
D-F	576.6	205
D-Ga	<272.8	253
D-Ge	≤322	205
D-H	439.433	205
D-Hg	42.05	205
D-In	246.0	205
D-Li	240.1892 ± 0.0046	207,360
D-Lu	302	308
D-Mg	135.1	205
D-Ni	≤302.9	205
D-Pt	≤350.2	205
D-S	351	205
D-Si	302.5	205
D-Sr	≥275.7	205
D-Zn	88.7	205
Dy-F	531	406
Dy-O	607 ± 17	95
Dy-S	414 ± 42	246
Dy-Se	322 ± 42	246
Dy-Te	234 ± 42	246
Er-F	565 ± 17	406
Er-O	615 ± 13	95
Er-S	418 ± 42	246
Er-Se	326 ± 42	246
Er-Te	238 ± 42	246
Eu-Eu	33.5 ± 17	66
Eu-F	544	242
Eu-Li	66.9 ± 2.9	275
Eu-O	479 ± 10	95
Eu-Rh	233.9 ± 33	66
Eu-S	362.3 ± 13.0	271,347
Eu-Se	301 ± 14.6	25,178,271
Eu-Te	243 ± 14.6	25,271
F-F	158.78	205
F-Ga	577 ± 14.6	270
F-Gd	590.4 ± 27.2	405
F-Ge	485 ± 21	98
F-H	569.87 ± 0.06	402
F-Hf	650 ± 15	16
F-Hg	~180	205
F-Ho	540	406
F-I	≤271.5	7,33,60,75

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

Molecule	D°_{298}/kJ mol^{-1}	Ref.
F-In	506 ± 14.6	270
F-K	497.5 ± 2.5	17
F-La	598 ± 42	246
F-Li	577 ± 21	80
F-Lu	333.5	208
F-Mg	461.9 ± 5.0	101,196
F-Mn	423.4 ± 14.6	228
F-Mo	464.8	198
F-N	343	205
F-Na	519	205
F-Nd	545.2 ± 12.6	403
F-Ni	430 ± 20	85
F-O	219.54 ± 10	48
F-P	439 ± 96	120
F-Pb	356 ± 8	408
F-Pm	540 ± 42	246
F-Pr	582 ± 46	246
F-Pu	538.5 ± 29	229
F-Rb	494 ± 21	80
F-Ru	402	185
F-S	342.7 ± 5.0	30,200,231
F-Sb	439 ± 96	120
F-Sc	589.1 ± 13	404
F-Se	339 ± 42	246
F-Si	552.7 ± 2.1	109
F-Sm	565	242
F-Sn	466.5 ± 13	408
F-Sr	541.8 ± 6.7	101,196
F-Ta	573 ± 13	256
F-Tb	561 ± 42	246
F-Th	652	263
F-Ti	569 ± 33	407
F-Tl	445.2 ± 19.2	28
F-Tm	510	242
F-U	659.0 ± 10.5	157,258
F-V	590 ± 63	246
F-W	548 ± 63	246
F-Xe	15.77	317,368
F-Y	605.0 ± 20.9	404
F-Yb	≥521.3	18,113,399
F-Zn	368 ± 63	246
F-Zr	616 ± 15	16
Fe-Fe	75 ± 17	330
Fe-Ge	210.9 ± 29	219
Fe-H	180 ± 25	369
Fe-O	390.4 ± 17.2	287
Fe-S	322	93
Fe-Si	297 ± 25	380
Ga-Ga	112.1 ± 7	337
Ga-H	<274.1	253
Ga-I	339 ± 9.6	120
Ga-Li	133.1 ± 14.6	160
Ga-O	353.5 ± 41.8	287
Ga-P	229.7 ± 12.6	130
Ga-Sb	192.0 ± 12.6	295
Ga-Te	251 ± 25	377
Gd-O	719 ± 10	95
Gd-S	526.8 ± 10.5	116,345
Gd-Se	431 ± 14.6	25
Gd-Te	343 ± 14.6	25
Ge-Ge	263.6 ± 7.1	238
Ge-H	≤321.7	243
Ge-Ni	290.3 ± 10.9	335
Ge-O	659.4 ± 12.6	226,287
Ge-Pd	254.7 ± 10.5	334
Ge-S	534 ± 3	280
Ge-Sc	271.0 ± 11	234
Ge-Se	484.7 ± 1.7	282
Ge-Si	296.4 ± 8.6	391
Ge-Te	397 ± 3	282
Ge-Y	279.8 ± 11.4	235
H-H	435.990	205
H-Hg	39.844	205
H-I	298.407	205
H-In	243.1	205
H-K	174.576	206,401
H-Li	238.049 ± 0.004	393
H-Mg	126.4 ± 2.9	14,15,100
H-Mn	234 ± 29	120
H-N	≤339	205
H-Na	185.69 ± 0.25	274,316
H-Ni	252.3 ± 8	217
H-O	427.6	205
H-P	297	205
H-Pb	≤157	205
H-Pd	234 ± 25	369
H-Pt	≤335	205
H-Rb	167 ± 21	120
H-Rh	247 ± 21	369
H-Ru	234 ± 21	369
H-S	344.3 ± 12.1	212
H-Sc	~180	329
H-Se	314.47 ± 0.96	122
H-Si	≤299.2	205
H-Sn	264 ± 17	120
H-Sr	163 ± 8	120
H-Te	268 ± 2.1	119
H-Ti	204.6 ± 8.8	52
H-Tl	188 ± 8	120
H-V	208.7 ± 7.0	53
H-Yb	159 ± 38	120
H-Zn	85.8 ± 2.1	120
He-He	3.8	205
He-Hg	6.61	246
Hf-C	548 ± 63	246
Hf-N	536 ± 29	152,245
Hf-O	801.7 ± 13.4	287
Hg-Hg	8 ± 2	204
Hg-I	34.69 ± 0.96	388
Hg-K	8.24 ± 0.21	246
Hg-Li	13.8	205
Hg-Na	9.2	205,411
Hg-O	220.9 ± 33.1	158
Hg-Rb	8.4	205
Hg-S	217.1 ± 22.2	158
Hg-Se	144.3 ± 30.1	158
Hg-Te	≤142	246
Hg-Tl	4	183
Ho-Ho	84 ± 17	62
Ho-O	611 ± 17	95
Ho-S	428.4 ± 14.6	345
Ho-Se	335 ± 17	25
Ho-Te	259 ± 17	25
I-I	151.088	205,371
I-In	331	384
I-K	325.1 ± 0.8	361,378
I-Li	345.2 ± 4.2	361
I-Mg	~285	26
I-Mn	282.8 ± 9.6	120
I-N	159 ± 17	246
I-Na	304.2 ± 2.1	361,378
I-Ni	293 ± 21	120
I-O	230	47
I-Pb	193 ± 4	340
I-Rb	318.8 ± 2.1	361
I-Si	293	205
I-Sn	234 ± 42	246
I-Sr	269.9 ± 5.9	239
I-Te	192 ± 42	246
I-Ti	310 ± 42	246
I-Tl	272 ± 8	26
I-Zn	108.29	215
I-Zr	305	241
In-In	100 ± 8	246
In-Li	92.5 ± 14.6	160
In-O	<320.1	287
In-P	197.9 ± 8.4	291
In-S	289 ± 17	69
In-Sb	151.9 ± 10.5	81
In-Se	247 ± 17	69
In-Te	218 ± 17	69
Ir-La	577 ± 13	176
Ir-O	414.6 ± 42.3	287
Ir-Si	462.8 ± 20.9	381
Ir-Th	573	133
Ir-Ti	422 ± 13	289
Ir-Y	456.1 ± 16.7	177
K-K	54.63 ± 0.02	6,265
K-Kr	4.6	205
K-Li	82.0 ± 4.2	103,410
K-Na	65.994 ± 0.008	36,410
K-O	277.8 ± 20.9	287
K-Xe	5.0	205
Kr-Kr	5.23	50,205
Kr-O	<8	246
Kr-Xe	5.505 ± 0.002	9
La-La	247 ± 21	386
La-N	519 ± 42	246
La-O	799 ± 4	95
La-Pt	502 ± 21	272
La-Rh	527 ± 17	65

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

Molecule	$D°_{298}$/kJ mol^{-1}	Ref.
La-S	573.2 ± 1.7	214,359
La-Se	477 ± 17	25,271
La-Te	381 ± 17	25,154
La-Y	202.1	386
Li-Li	110.21 ± 4	383,398
Li-Mg	67.4 ± 6.3	396
Li-Na	87.181 ± 0.001	102,111
Li-O	333.5 ± 8.4	287
Li-Pb	78.7 ± 7.9	277
Li-S	312.5 ± 7.5	232
Li-Sb	172.8 ± 10.0	278
Li-Sm	49.0 ± 4.2	275
Li-Tm	69.0 ± 3.3	275
Li-Yb	37.2 ± 2.9	275
Lu-Lu	142 ± 33	246
Lu-O	678 ± 8	95
Lu-Pt	402 ± 33	141
Lu-S	507.1 ± 14.6	114,345
Lu-Se	418 ± 17	25
Lu-Te	326 ± 17	25
Mg-Mg	8.552 ± 0.004	264,397
Mg-O	363.2 ± 12.6	287
Mg-S	234	70
Mn-Mn	25.9	221
Mn-O	402.9 ± 41.8	225,287
Mn-S	301 ± 17	395
Mn-Se	239.3 ± 9.2	351
Mo-Mo	406 ± 21	168
Mo-Nb	456 ± 25	163
Mo-O	560.2 ± 20.9	287
N-N	945.33 ± 0.59	205
N-O	630.57 ± 0.13	205
N-P	617.1 ± 20.9	72,151
N-Pu	473 ± 63	246
N-S	464 ± 21	246
N-Sb	301 ± 50	120
N-Sc	469 ± 84	246
N-Se	370 ± 11	254
N-Si	470 ± 15	311
N-Ta	611 ± 84	246
N-Th	577.4 ± 33.1	144,152
N-Ti	476.1 ± 33.1	152,356
N-U	531.4 ± 2.1	142
N-V	477.4 ± 17.2	107,152
N-Xe	23.0	182
N-Y	481 ± 63	246
N-Zr	564.8 ± 25.1	143,152
Na-Na	73.0813 ± 0.0001	213
Na-O	256.1 ± 16.7	287
Na-Rb	63.25	392
Nb-Nb	510 ± 10.0	164
Nb-Ni	271.9 ± 0.1	8
Nb-O	771.5 ± 25.1	287
Nb-Ti	302.0 ± 0.1	254
Nd-Nd	<163	246
Nd-O	703 ± 13	95
Nd-S	471.5	25
Nd-Se	385 ± 17	25,156,271
Nd-Te	305 ± 17	25
Ne-Ne	3.93	365
Ni-Ni	200.7 ± 0.2	304
Ni-O	382.0 ± 16.7	287
Ni-Pt	273.7 ± 0.3	367
Ni-S	344.3	93
Ni-Si	318 ± 17	380
Ni-V	206.3 ± 0.1	353
Ni-Y	283.9 ± 0.1	8
Ni-Zr	279.7 ± 0.1	8
Np-O	718.4 ± 41.8	287
O-O	498.36 ± 0.17	38,205
O-Os	575	189
O-P	599.1 ± 12.6	287
O-Pa	788.3 ± 17.2	240
O-Pb	382.0 ± 12.6	287
O-Pd	380.7 ± 83.7	287
O-Pm	674 ± 63	246
O-Pr	753 ± 13	95
O-Pt	391.6 ± 41.8	287
O-Pu	715.9 ± 33.9	287
O-Rb	255 ± 84	37
O-Re	626.8 ± 83.7	287
O-Rh	405.0 ± 41.8	287
O-Ru	528.4 ± 41.8	287
O-S	517.90 ± 0.05	57
O-Sb	434.3 ± 41.8	287
O-Sc	681.6 ± 11.3	287
O-Se	464.8 ± 21.3	287,344
O-Si	799.6 ± 13.4	287
O-Sm	565 ± 13	95
O-Sn	531.8 ± 12.6	287
O-Sr	426.3 ± 6.3	327
O-Ta	799.1 ± 12.6	287
O-Tb	711 ± 13	95
O-Te	376.1 ± 20.9	287
O-Th	878.6 ± 12.1	287
O-Ti	672.4 ± 9.2	287
O-Tm	502 ± 13	95
O-U	759.4 ± 13.4	287
O-V	626.8 ± 18.8	12,287
O-W	672.0 ± 41.8	287
O-Xe	36.4	246
O-Y	719.6 ± 11.3	209,287
O-Yb	397 ± 17	95
O-Zn	159 ± 4	55
O-Zr	776.1 ± 13.4	287
P-P	489.5 ± 10.5	151
P-Pt	≤416.7	348
P-Rh	353.1 ± 17	348
P-S	444 ± 8	92
P-Sb	356.9	249
P-Se	363.6 ± 10.0	92
P-Si	363.6	346
P-Te	297.9 ± 10.0	92
P-Th	550.2 ± 42	135
P-Tl	209 ± 13	293
P-U	297 ± 21	246
P-W	305 ± 4	150
Pb-Pb	86.6 ± 0.8	138,305
Pb-S	346.0 ± 1.7	375
Pb-Sb	161.5 ± 10.5	409
Pb-Se	302.9 ± 4	375
Pb-Te	251 ± 13	375
Pd-Pd	100 ± 15	331
Pd-Si	261 ± 12	336
Pd-Y	238 ± 17	313
Pm-S	423 ± 63	246
Pm-Se	339 ± 63	246
Pm-Te	255 ± 63	246
Po-Po	187.0	205
Pr-S	492.5 ± 4.6	112
Pr-Se	446.4 ± 23.0	155,271
Pr-Te	326 ± 42	246
Pt-Pt	307 ± 2	366
Pt-Si	501.2 ± 18.0	381
Pt-Th	552	133
Pt-Ti	397 ± 13	173
Pt-Y	474.0 ± 12.1	170
Rb-Rb	48.898 ± 0.005	5
Rh-Rh	285.3 ± 0.05	255
Rh-Sc	443.9 ± 10.5	175
Rh-Si	395.0 ± 18.0	381
Rh-Th	515 ± 21	129
Rh-Ti	390.8 ± 14.6	61
Rh-U	519 ± 17	129
Rh-V	364 ± 29	135
Rh-Y	445.2 ± 10.5	175
Ru-Si	397.1 ± 20.9	381
Ru-Th	591.6 ± 42	134
Ru-V	414 ± 29	135
S-S	425.30	205
S-Sb	378.7	110
S-Sc	477 ± 13	359,372
S-Se	371.1 ± 6.7	90
S-Si	623	205
S-Sm	389	112
S-Sn	464 ± 3.3	88
S-Sr	339	45
S-Tb	515 ± 42	246
S-Te	339 ± 21	88
S-Ti	418 ± 3	96,292
S-Tm	368 ± 42	246
S-U	522.6 ± 9.6	359
S-V	450	97,205
S-Y	528.4 ± 10.5	358
S-Yb	167	246
S-Zn	205 ± 13	82,158
S-Zr	575.3 ± 16.7	359
Sb-Sb	299.2 ± 6.3	81,248
Sb-Te	277.4 ± 3.8	306,364
Sb-Tl	126.8 ± 10.5	11,293
Sc-Sc	162.8 ± 21	136

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

Molecule	$D°_{298}$/kJ mol^{-1}	Ref.
Sc-Se	385 ± 17	246
Sc-Si	228.7 ± 14	234
Sc-Te	289 ± 17	246
Se-Se	332.6 ± 0.4	90,375
Se-Si	538 ± 13	370
Se-Sm	331.0 ± 14.6	271
Se-Sn	401.2 ± 5.9	68
Se-Sr	~285	27
Se-Tb	423 ± 42	246
Se-Te	291.6 ± 4	88,90,159
Se-Ti	381 ± 42	246
Se-Tm	276 ± 42	246
Se-V	347 ± 21	246
Se-Y	435 ± 13	246
Se-Zn	170.7 ± 25.9	82,158
Si-Si	325 ± 7	328
Si-Te	452 ± 8	205,281
Si-Y	258.8 ± 17.3	235
Sm-Te	272.4 ± 14.6	271
Sn-Sn	187.1 ± 0.3	284
Sn-Te	359.8	205
Sr-Sr	15.5 ± 0.4	121
Tb-Tb	131.4 ± 25.1	250
Tb-Te	339 ± 42	246
Te-Te	257.6 ± 4.1	389
Te-Ti	289 ± 17	246
Te-Tm	276 ± 42	246
Te-Y	339 ± 13	246
Te-Zn	117.6 ± 18.0	158
Th-Th	≤289	140
Ti-Ti	141.4 ± 21	216
Ti-V	203.2 ± 0.1	353
Ti-Zr	214.3 ± 0.1	254
Tl-Tl	64.4 ± 17	10
U-U	222 ± 21	246
V-V	269.3 ± 0.1	353
V-Zr	260.6 ± 0.3	254
Xe-Xe	6.138 ± 0.001	49,115
Y-Y	159 ± 21	246
Yb-Yb	20.5 ± 17	161
Zn-Zn	29	339
Zr-Zr	298.2 ± 0.1	8

REFERENCES

1. Abbasov, A. S., Azizov, T. Kh., Alleva, N. A., Aliev, I. Ya, Mustafaev, F. M., and Mamedov, A. N., *Zh. Fiz. Khim.*, 50, 2172, 1976.
2. Abramowitz, S. and Chase, M. L., Pure Appl. Chem., 63, 1449, 1991.
3. Ackerman, M., Drowart, J., Stafford, F. E., and Verhaegen, G., *J. Chem. Phys.*, 36, 1557, 1962.
4. Ackerman, M., Stafford, F. E., and Drowart, J., *J. Chem. Phys.*, 33, 1784, 1960.
5. Amiot, C., *J. Chem. Phys.*, 93, 8591, 1990.
6. Amiot, C., *J. Mol. Spectrosc.*, 147, 370, 1991.
7. Appelman, E. H. and Clyne, M. A. A., *J. Chem. Soc. Faraday Trans. 1*, 71, 2072, 1975.
8. Arrington, C. A., Blume, T., Morse, M. D., Doverstal, M., and Sassenberg, U., J. Phys. Chem., 98, 1398, 1994.
9. Balakrishnan, A., Jones, W. J., Mahajan, C. G., and Stoicheff, B. P., *Chem. Phys. Lett.*, 155, 43, 1989.
10. Balducci, G. and Piacente, V., *J. Chem. Soc. Chem. Commun.*, 1287, 1980.
11. Balducci, G., Ferro, D., and Piacente, V., *High Temp. Sci.*, 14, 207, 1981.
12. Balducci, G., Gigli, G., and Guido, M., *J. Chem. Phys.*, 79, 5616, 1983.
13. Balducci, G., Nunzio, P. E., Gigli, G., and Guido, M., *J. Chem. Phys.*, 90, 406, 1989.
14. Balfour, W. J. and Cartwright, H. M., *Astron. Astrophys. Suppl. Ser.*, 26, 389, 1976.
15. Balfour, W. J. and Lingren, B., Can. J. Chem., 56, 767, 1978.
16. Barkovskii, N. V., Tsirel'nikov, V. I., Emel'yanov, A. M., and Khodeev, Yu. S., *Teplofiz. Vys. Temp.*, 29, 474, 1991.
17. Barrow, R. F. and Caunt, A. D., *Proc. R. Soc. London Ser. A*, 219, 120, 1953.
18. Barrow, R. F. and Chojnicki, A. H., *J. Chem. Soc. Faraday Trans. 2*, 71, 728, 1975.
19. Behm, J. M. and Morse, M. D., J. Chem. Phys., 101, 6500, 1994.
20. Behm, J. M., Arrington, C. A., and Morse, M. D., *J. Chem. Phys.*, 99, 6409, 1993.
21. Behm, J. M., Arrington, C. A., Langenberg, J. D., and Morse, M. D., *J. Chem. Phys.*, 99, 6394, 1993.
22. Behm, J. M., Brugh, D. J., and Morse, M. D., J. Chem. Phys., 101, 6487, 1994.
23. Behrens, R. G. and Feber, R. C., *J. Less-Common Met.*, 75, 281, 1980.
24. Bergman, C. and Gingerich, K. A., *J. Phys. Chem.*, 76, 2332, 1972.
25. Bergman, C., Coppens P., Drowart, J., and Smoes, S., *Trans. Faraday Soc.*, 66, 800, 1970.
26. Berkowitz, J. and Chupka, W. A., *J. Chem. Phys.*, 45, 1287, 1966.
27. Berkowitz, J. and Chupka, W. A., *J. Chem. Phys.*, 45, 4289, 1966.
28. Berkowitz, J. and Walter, T., *J. Chem. Phys.*, 49, 1184, 1968.
29. Berkowitz, J., *J. Chem. Phys.*, 89, 7065, 1988.
30. Berneike ,W., Kreuttle, U., and Neuert, H., *Chem. Phys. Lett.*, 76, 525, 1980.
31. Besenbruch, G., Kana'an, A. S., and Margrave, J. L., *J. Phys. Chem.*, 69, 3174, 1965.
32. Bharate, N. S., Bhartiya, J. B., and Behere, S. H., *Proc. Indian Natl. Sci. Acad. Part A*, 57, 419, 1991.
33. Birks, J. W., Gabelnick, S. D., and Johnston, H. S., *J. Mol. Spectrosc.*, 57, 23, 1975.
34. Bishea, G. A. and Morse, M. D., *Chem. Phys. Lett.*, 171, 430, 1990.
35. Bondybey, V. E., *Chem. Phys. Lett.*, 109, 436, 1984.
36. Breford, E. J. and Engelke, F., *J. Chem. Phys.*, 71, 1994, 1979.
37. Brewer, L. and Rosenblatt, G. M., *Adv. High Temp. Sci.*, 2, 1, 1969.
38. Brix, P. and Herzberg, G., *J. Chem. Phys.*, 21, 2240, 1953.
39. Brock, L. R., Pilgrim, J. S., and Duncan, M. A., Chem. Phys. Lett., 230, 93, 1994.
40. Burns, G., LeRoy, L. J., Morris, D. J., and Blake, J. A., *Proc. R. Soc. London Ser. A*, 316, 81, 1970.
41. Busse, V. B. and Weil, K. G., *Ber. Bunsenges. Phys. Chem.*, 85, 309, 1981.

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

42. Calculated from $\Delta_f H°$(CN) = 441.4 ± 4.6 kJ mol^{-1} (Table 4), but see also Costes, M., Naulin, C., and Dorthe, G., *Astron. Astronphys.*, 232, 270, 1990.
43. Callender, C. L., Mitchell, S. A., and Hackett, P. A., *J. Chem. Phys.*, 90, 5252, 1989.
44. Carbonel, M., Bergman, C., and Laffite, M., *Colloq. Int. Cent. Nat. Rech. Sci.*, 201, 311, 1972.
45. Cater, E. D. and Johnson, E. W., *J. Chem. Phys.*, 47, 5353, 1967.
46. Chase, M. L., *J. Phys. Chem. Ref. Data*, 25, 1069, 1996.
47. Chase, M. L., *J. Phys. Chem. Ref. Data*, 25, 1297, 1996.
48. Chase, M. L., *J. Phys. Chem. Ref. Data*, 25, 551, 1996.
49. Chashchina, G. I. and Shreider, E. Ya., *Zh. Prikl. Spektrosk.*, 21, 696, 1974.
50. Chashchina, G. I. and Shreider, E. Ya., *Zh. Prikl. Spektrosk.*, 25, 163, 1976.
51. Chatillon, C., Allibert, M., and Pattoret, A., *C. R. Acad. Sci. Ser. C*, 280, 1505, 1975.
52. Chen, Y. M., Clemmer, D. E., and Armentrout, P. B., *J. Chem. Phys.*, 95, 1228, 1991.
53. Chen, Y.-M., Clemmer, D. E., and Armentrout, P. B., *J. Chem. Phys.*, 98, 4929, 1993.
54. Clarke, T. C. and Clyne, M. A. A., *Trans. Faraday Soc.*, 66, 877, 1970.
55. Clemmer, D. E., Daltaska, N. F., and Armentrout, P. B., *J. Chem. Phys.*, 95, 7263, 1991.
56. Clemmer, D. E., Weber, M. E., and Armentrout, P. B., *J. Phys. Chem.*, 96, 10888, 1992.
57. Clerbaux, C. and Colin, R., *J. Mol. Spectrosc.* 165, 334, 1994.
58. Clevenger, J. O. and Tellinghuisen, J., *J. Chem. Phys.*, 103, 9611, 1995.
59. Clyne, M. A. A. and McDermid, I. S., *Faraday Discuss. Chem. Soc.*, 67, 316, 1979.
60. Clyne, M. A. A. and McDermid, I. S., *J. Chem. Soc. Faraday Trans. 2*, 72, 2252, 1976.
61. Cocke, D. L. and Gingerich, K. A., *J. Chem. Phys.*, 60, 1958, 1974.
62. Cocke, D. L. and Gingerich, K. A., *J. Phys. Chem.*, 75, 3264, 1971.
63. Cocke, D. L. and Gingerich, K. A., *J. Phys. Chem.*, 76, 2332, 1972.
64. Cocke, D. L., Gingerich, K. A., and Chang, C. A., *J. Chem. Soc. Faraday Trans. 1*, 72, 268, 1976.
65. Cocke, D. L., Gingerich, K. A., and Kordis, J., *High Temp. Sci.*, 5, 474, 1973.
66. Cocke, D. L., Gingerich, K. A., and Kordis, J., *High Temp. Sci.*, 7, 61, 1975.
67. Colin, R. and De Greef, D., *Can. J. Phys.*, 53, 2142, 1975.
68. Colin, R. and Drowart, J., *Trans. Faraday Soc.*, 60, 673, 1964.
69. Colin, R. and Drowart, J., *Trans. Faraday Soc.*, 64, 2611, 1968.
70. Colin, R., Goldfinger, P., and Jeunehomme, M., *Trans. Faraday Soc.*, 60, 306, 1964.
71. Coppens, P., Reynaert, J. C., and Drowart, J., *J. Chem. Soc. Faraday Trans. 2*, 75, 292, 1979.
72. Coquart, B. and Prudhomme, J. C., *J. Mol. Spectrosc.*, 87, 75, 1981.
73. Corbett, J. D. and Lynde, R. A., *Inorg. Chem.*, 6, 2199, 1967.
74. Costes, M., Naulin, C., Dorthe, G., Vaucamps, C., Nouchi, G., *Faraday Discuss. Chem. Soc.*, 84, 75, 1987.
75. Coxon, J. A., *Chem. Phys. Lett.*, 33, 136, 1975.
76. Cubicciotti, D., *Inorg. Chem.*, 7, 208, 1968.
77. Cubicciotti, D., *Inorg. Chem.*, 7, 211, 1968.
79. Cubicciotti, D., *J. Phys. Chem.*, 71, 3066, 1967.
80. Cuthill, A. M., Fabian, D. J., and Shu-Shou-Shen, S., *J. Phys. Chem.*, 77, 2008, 1973.
81. De Maria, G., Drowart, J., and Inghram, M. G., *J. Chem. Phys.*, 31, 1076, 1959.
82. De Maria, G., Goldfinger, P., Malaspina, L., and Piacente, V., *Trans. Faraday Soc.*, 61, 2146, 1965.
83. De Maria, G., Malaspina, L., and Piacente, V., *J. Chem. Phys.*, 52, 1019, 1970.
84. De Maria, G., Malaspina, L., and Piacente, V., *J. Chem. Phys.*, 56, 1978, 1972.
85. Devore, T. C., McQuaid, M., and Gole, J. L., *High Temp. Sci.*, 30, 83, 1990.
86. Diemer, U., Weickenmeier, H., Wahl, M., and Demtroeder, W., *Chem. Phys. Lett.*, 104, 489, 1984.
87. Drowart, J. and Goldfinger, P., *Angew. Chem.*, 6, 581, 1967.
88. Drowart, J. and Goldfinger, P., *Q. Rev. (London)*, 20, 545, 1966.
89. Drowart, J. and Honig, R. E., *J. Phys. Chem.*, 61, 980, 1957.
90. Drowart, J. and Smoes, S., *J. Chem. Soc. Faraday Trans. 2*, 73, 1755, 1977.
91. Drowart, J., De Maria, G., and Inghram, M. G., *J. Chem. Phys.*, 29, 1015, 1958.
92. Drowart, J., Myers, C. E., Szwarc, R.,Vander Auwera-Mahieu, A., and Uy, O. M., *High Temp. Sci.*, 5, 482, 1973.
93. Drowart, J., Pattoret, A., and Smoes, S., *Proc. Br. Ceramic Soc.*, No. 8, 67, 1967.
94. Drowart, J., Smoes, S., and Vander Auwera-Mahieu, A., *J. Chem. Thermodyn.*, 10, 453, 1978.
95. Dulick, M., Murad, E., and Barrow, R. F., *J. Chem. Phys.*, 85, 385, 1986.
96. Edwards, J. G., Franklin, H. F., and Gilles, P. W., *J. Chem. Phys.*, 54, 545, 1971.
97. Edwards, J. G., *J. Chem. Phys.*, 96, 866, 1992
98. Ehlert, T. C. and Margrave, J. L., *J. Chem. Phys.*, 41, 1066, 1964.
99. Ehlert, T. C. and Wang, J. S., *J. Phys. Chem.*, 81, 2069, 1977.
100. Ehlert, T. C., Hilmer, R. M., and Beauchamp, E. A., *J. Inorg. Nucl. Chem.*, 30, 3112, 1968.
101. Engelke, F., *Chem. Phys.*, 39, 279, 1979.
102. Engelke, F., Ennen, G., and Meiwes, K. H., *Chem. Phys.*, 66, 391, 1982.

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

103. Engelke, F., Hage, H., and Sprick, U., *Chem. Phys.*, 88, 443, 1984.
104. Estler, C. and Zare, R. N., *Chem. Phys.*, 28, 253, 1978.
105. Farber, M. and Srivastava, R. D., *Chem. Phys. Lett.*, 42, 567, 1976.
106. Farber, M. and Srivastava, R. D., *High Temp. Sci.*, 12, 21, 1980.
107. Farber, M. and Srivastava, R. D., *J. Chem. Soc. Faraday Trans. 1*, 69, 390, 1973.
108. Farber, M. and Srivastava, R. D., *J. Chem. Soc. Faraday Trans. 1*, 70, 1581, 1974.
109. Farber, M. and Srivastava, R. D., *J. Chem. Soc. Faraday Trans. 1*, 74, 1089, 1978.
110. Faure, F. M., Mitchell, M. J., and Bartlett, R. W., *High Temp. Sci.*, 4, 181, 1972.
111. Fellows, C. E., *J. Chem. Phys.*, 94, 5855, 1991.
112. Fenochka, B. V. and Gorkienko, S. P., *Zh. Fiz. Khim*, 47, 2445, 1973.
113. Filippenko, N. V., Morozov, E. V., Giricheva, N. L., and Krasnev, K. S., *Izv. Vyssh. Ucheb. Zaved Khim.Technol.*, 15, 1416, 1972.
114. Franzen, H. and Hariharan, A. V., *J. Chem. Phys.*, 70, 4907, 1979.
115. Freeman, D. E., Yoshino, K., and Tanaka, Y., *J. Chem. Phys.*, 61, 4880, 1974.
116. Fries, J. A. and Cater, E. D., *J. Chem. Phys.*, 68, 3978, 1978.
117. Fu, Z. and Morse, M. D., *J. Chem. Phys.*, 90, 3417, 1989.
118. Fu, Z., Lemire, G. W., Bishea, G. A., and Morse, M. D., *J. Chem. Phys.*, 93, 8420, 1990.
119. Gal, J. F., Maria, P. C., and Decouzon, M., *Int. J. Mass Spectrom. Ion Processes*, 93, 87, 1989.
120. Gaydon, A. G., *Dissociation Energies and Spectra of Diatomic Molecules, 3rd ed.*, Chapman & Hall, London, 1968.
121. Gerber, G. and Moeller, R., *Contrib. Symp. At. Surf. Phys.*, 168, 1982.
122. Gibson, S. T., Greene, J. P., and Berkowitz, J., *J. Chem. Phys.*, 85, 4815, 1986.
123. Gingerich, K. A. and Blue, G. D., *J. Chem. Phys.*, 47, 5447, 1967.
124. Gingerich, K. A. and Blue, G. D., *J. Chem. Phys.*, 59, 186, 1973.
125. Gingerich, K. A. and Choudary, U. V., *J. Chem. Phys.*, 68, 3265, 1978.
126. Gingerich, K. A. and Cocke, D. L., *Inorg. Chim. Acta*, 28, L171, 1978.
127. Gingerich, K. A. and Finkbeiner, H. C., *J. Chem. Phys.*, 54, 2621, 1971.
128. Gingerich, K. A. and Finkbeiner, H. C., *Proc. 9th Rare Earth Res. Conf.*, 2, 795, 1971.
129. Gingerich, K. A. and Gupta, S. K., *J. Chem. Phys.*, 69, 505, 1978.
130. Gingerich, K. A. and Piacente, V., *J. Chem. Phys.*, 54, 2498, 1971.
131. Gingerich, K. A., *Chem. Commun.*, 580, 1970.
132. Gingerich, K. A., *Chem. Phys. Lett.*, 13, 262, 1972.
133. Gingerich, K. A., *Chem. Phys. Lett.*, 23, 270, 1973.
134. Gingerich, K. A., *Chem. Phys. Lett.*, 25, 523, 1974.
135. Gingerich, K. A., *Chem. Soc. Faraday, Symp.*, No.14, 109, 1980.
136. Gingerich, K. A., *Chimia*, 26, 619, 1972.
137. Gingerich, K. A., Cocke, D. L., and Kordis, J., *J. Phys. Chem.*, 78, 603, 1974.
138. Gingerich, K. A., Cocke, D. L., and Miller, F., *J. Chem. Phys.*, 64, 4027, 1976.
139. Gingerich, K. A., Haque, R., and Kingcade, J. E., *Thermochim. Acta*, 30, 61, 1979.
140. Gingerich, K. A., *High Temp. Sci.*, 1, 258, 1969.
141. Gingerich, K. A., *High Temp. Sci.*, 3, 415, 1971.
142. Gingerich, K. A., *J. Chem. Phys.*, 47, 2192, 1967.
143. Gingerich, K. A., *J. Chem. Phys.*, 49, 14, 1968.
144. Gingerich, K. A., *J. Chem. Phys.*, 49, 19, 1968.
145. Gingerich, K. A., *J. Chem. Phys.*, 54, 2646, 1971.
146. Gingerich, K. A., *J. Chem. Phys.*, 54, 3720, 1971.
147. Gingerich, K. A., *J. Chem. Phys.*, 56, 4239, 1972.
148. Gingerich, K. A., *J. Chem. Phys.*, 74, 6407, 1981.
149. Gingerich, K. A., *J. Chem. Soc. Faraday Trans. 2*, 70, 471, 1974.
150. Gingerich, K. A., *J. Phys. Chem.*, 68, 768, 1964.
151. Gingerich, K. A., *J. Phys. Chem.*, 73, 2734, 1969.
152. Gingerich, K. A., *NBS Spec. Publ. (U. S.)*, 561, 289, 1979.
153. Gondal, M. A., Khan, M. A., and Rais, M. H., Chem. Phys. Lett., 243, 94, 1995.
154. Gordienko, S. P. and Fenochka, B. V., *Izv. Akad. Nauk. SSSR Neorg. Mater.*, 18, 1811, 1982.
155. Gordienko, S. P., Fenochka, B. V., Viksman, G. Sh., Klockkova, L. A., and Mikhlina, T. M., *Izv. Akad. Nauk. SSSR Neorg. Mater.*, 18, 18, 1982.
156. Gordienko, S. P., *Izv. Akad. Nauk. SSSR Neorg. Mater.*, 20, 1472, 1984.
157. Gorokhov, L. N., Smirnov, V. K., and Khodeev, Yu. S., *Zh. Fiz. Khim.*, 58, 1603, 1984.
158. Grade, M. and Hirschwald, W., *Ber. Bunsenges. Phys. Chem.*, 86, 899, 1982.
159. Grade, M., Wienecke, J., Rosinger, W., and Hirschwald, W., *Ber. Bunsenges. Phys. Chem.*, 87, 355, 1983.
160. Guggi, D. J., Neubert, A., and Zmbov, K. F., *Conf. Int. Thermodyn. Chim. [C. R.] 4th*, 3, 124, 1975.
161. Guido, M. and Balducci, G., *J. Chem. Phys.*, 57, 5611, 1972.
162. Gupta, S. K. and Gingerich, K. A., *High Temp. - High Pressures*, 12, 273, 1980.

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

163. Gupta, S. K. and Gingerich, K. A., *J. Chem. Phys.*, 69, 4318, 1978.
164. Gupta, S. K. and Gingerich, K. A., *J. Chem. Phys.*, 70, 5350, 1979.
165. Gupta, S. K. and Gingerich, K. A., *J. Chem. Phys.*, 71, 3072, 1979.
166. Gupta, S. K. and Gingerich, K. A., *J. Chem. Phys.*, 72, 2795, 1980.
167. Gupta, S. K. and Gingerich, K. A., *J. Chem. Phys.*, 74, 3584, 1981.
168. Gupta, S. K., Atkins, R. M., and Gingerich, K. A., *Inorg. Chem.*, 17, 3211, 1978.
169. Gupta, S. K., Kingcade, J. E., and Gingerich, K. A., *Adv. Mass Spectrom.*, 8A, 445, 1980.
170. Gupta, S. K., Nappi, B. M., and Gingerich, K. A., *Inorg. Chem.*, 20, 966, 1981.
171. Gupta, S. K., Nappi, B. M., and Gingerich, K. A., *J. Phys. Chem.*, 85, 971, 1981.
172. Gupta, S. K., Pelino, M., and Gingerich, K. A., *J. Chem. Phys.,* 70, 2044, 1979.
173. Gupta, S. K., Pelino, M., and Gingerich, K. A., *J. Phys. Chem.*, 83, 2335, 1979.
174. Gustavsson, T., Amiot, C., Verges, J., *Mol. Phys.,* 64, 279, 1988.
175. Haque, R. and Gingerich, K. A., *J. Chem. Thermodyn.,* 12, 439, 1980.
176. Haque, R., Pelino, M., and Gingerich, K. A., *J. Chem. Phys.*, 71, 2929, 1979.
177. Haque, R., Pelino, M., and Gingerich, K. A., *J. Chem. Phys.*, 73, 4045, 1980.
178. Hariharan, A. V. and Eick, H. A., *J. Chem. Thermodyn.*, 6, 373, 1974.
179. Hedgecock, I. M., Naulin, C., and Costes, M., Chem. Phys., 207, 379, 1996.
180. Heidecke, S. A., Fu, Z., Colt, J. R., and Morse, M. D., J. Chem. Phys., 97, 1692, 1992.
181. Herman, P. R., La Rocque, P. E., and Stoicheff, B., *J. Chem. Phys.,* 89, 4535, 1988.
182. Herman, R. and Herman, L., *J. Phys. Radium.,* 24, 73, 1963.
183. Herzberg, G., *Molecular Spectra and Molecular Structure*. *I. Spectra of Diatomic Molecules*, 2nd ed.,Van Nostrand, New York, 1950.
184. Hildenbrand, D. L. and Lau, K. H., *High Temp. Mater. Sci.*, 35, 11, 1996.
185. Hildenbrand, D. L. and Lau, K. H., *J. Chem. Phys.*, 89, 5825, 1988.
186. Hildenbrand, D. L. and Lau, K. H., *J. Chem. Phys.*, 91, 4909, 1989.
187. Hildenbrand, D. L. and Lau, K. H., *J. Chem. Phys.*, 93, 5983, 1990.
188. Hildenbrand, D. L. and Lau, K. H., *J. Chem. Phys.*, 96, 3830, 1992.
189. Hildenbrand, D. L. and Lau, K. H., *J. Phys. Chem.*, 96, 2325, 1992.
190. Hildenbrand, D. L. and Murad, E., *J. Chem. Phys.*, 44, 1524, 1966.
191. Hildenbrand, D. L. and Theard, L. P., *J. Chem. Phys.*, 50, 5350, 1969.
192. Hildenbrand, D. L., *High Temp. Mater. Sci.*, 35, 151, 1996.
193. Hildenbrand, D. L., *Chem. Phys. Lett.*, 32, 523, 1975.
194. Hildenbrand, D. L., *J. Chem. Phys.,* 103, 2634, 1995.
195. Hildenbrand, D. L., *J. Chem. Phys.,* 105, 10507, 1996.
196. Hildenbrand, D. L., *J. Chem. Phys.*, 48, 3657, 1968.
197. Hildenbrand, D. L., *J. Chem. Phys.*, 52, 5751, 1970.
198. Hildenbrand, D. L., *J. Chem. Phys.*, 65, 614, 1976.
199. Hildenbrand, D. L., *J. Chem. Phys.*, 66, 3526, 1977.
200. Hildenbrand, D. L., *J. Phys. Chem.*, 77, 897, 1973.
201. Hilpert, K. and Ruthardt, K., *Ber. Bunsenges. Phys. Chem.*, 91, 724, 1987.
202. Hilpert, K. and Ruthardt, K., *Ber. Bunsenges. Phys. Chem.*, 93, 1070, 1989.
203. Hilpert, K., *Ber. Kernforschungsanlage Juelich*, JUEL-1744, 272, 1981.
204. Hilpert, K., *J. Chem. Phys.*, 77, 1425, 1982.
205. Huber, K. P. and Herzberg, G., *Molecular Spectra and Molecular Structure Constants of Diatomic Molecules*, Van Nostrand, New York, 1979.
206. Hussein, K., Effantin, C., D'Incan, J., Verges, J., and Barrow, R. F., *Chem. Phys. Lett.*, 124, 105, 1986.
207. Ihle, H. R. and Wu, C. H., *J. Chem. Phys.*, 63, 1605, 1975.
208. Ishwar, N. B., Varma, M. P., and Jha, B. L., *Acta Phys. Pol. A*, A61, 503, 1982.
209. Ishwar, N. B., Varma, M. P., and Jha, B. L., *Indian J. Pure Appl. Phys.*, 20, 992, 1982.
210. James, A. M., Kowalczyk, P., Simard, B., Pinegar, J. C., Morse, M. D., J. Mol. Spectrosc., 168, 248, 1994.
211. Jeyagopal, T., Rajavel, S. R. K., Ramakrishnan, M., and Rajamanickam, N., *Acta Phys. Hung.*, 68, 145, 1990.
212. Johns, J. W. C. and Ramsey, D. A., *Can. J. Phys.*, 39, 210, 1961.
213. Jones, K. M., Maleki, S., Bize, S., Lett, P. D., Williams, C. J., Richling, H., Knöckel, H., Tiemann, E., Wang, H., Gould, P. L., and Stwalley, W. C., Phys. Rev., A, 54, R1006, 1996.
214. Jones, R. W. and Gole, J. L., *Chem. Phys.*, 20, 311, 1977.
215. Jordan, K. J., Lipson, R. H., McDonald, N. A., and Le Roy, R. J., *J. Phys. Chem.*, 96, 4778, 1992.
216. Kant, A. and Lin, S.-S., *J. Chem. Phys.*, 51, 1644, 1969.
217. Kant, A. and Moon, K. A., *High Temp. Sci.*, 11, 55, 1979.
218. Kant, A. and Strauss, B. H., *J. Chem. Phys.*, 41, 3806, 1964.
219. Kant, A. and Strauss, B., *J. Chem. Phys.*, 49, 3579, 1968.
220. Kant, A., *J. Chem. Phys.,* 49, 5144, 1968.
221. Kant, A., Lin, S.-S, and Strauss, B., *J. Chem. Phys.*, 49, 1983, 1968.

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

222. Kant, A., Strauss, B., and Lin, S.-S., *J. Chem. Phys.*, 52, 2384, 1970.
223. Kaposi, O., *Magy. Kem. Foly.*, 83, 356, 1977.
224. Kaufel, R., Vahl, G., Nunkwitz, R., and Baumgaertel, H., *Z. Anorg. Allg. Chem.*, 481, 207, 1981.
225. Kazenas ,E., Tagirov, V. K., and Zviadadze, G. N., *Izv. Akad. Nauk. SSSR Met.*, 58, 1984.
226. Kazenas, E. K., Bol'shikh, M. A., and Petrov, A. A., *Izvestiya Rossiiskoi Akademii Nauk. Metally,* (3), 29, 1996.
227. Kent, R. A. and Margrave, J. L., *J. Am. Chem. Soc.*, 87, 3582, 1965.
228. Kent, R. A., Ehlert, T. C., and Margrave, J. L., *J. Am. Chem. Soc.*, 86, 5090, 1964.
229. Kent, R. A., *J. Am. Chem. Soc.*, 90, 5657, 1968.
230. Khitrov, A. N., Ryabova, V. G., and Gurvich, L. V., *Teplofiz. Vys. Tempo.*, 11, 1126, 1973.
231. Kiang, T. and Zare, R. N., *J. Am. Chem. Soc.*, 102, 4024, 1980.
232. Kimura, H., Asano, M., and Kubo, K., *J. Nucl. Mater.*, 97, 259, 1981.
233. Kingcade, J. E. Jr. and Gingerich, K. A., *J. Chem. Phys.*, 84, 3432, 1986.
234. Kingcade, J. E. Jr. and Gingerich, K. A., *J. Chem. Soc. Faraday Trans. 2*, 85, 195, 1989.
235. Kingcade, J. E. Jr., and Gingerich, K. A., *J. Chem. Phys.*, 84, 4574, 1986.
236. Kingcade, J. E., Cocke, D. L., and Gingerich, K. A., *High Temp. Sci.*, 16, 89, 1983,
237. Kingcade, J. E., Dufner, D. C., Gupta, S. K., and Gingerich, K. A., *High Temp. Sci.*, 10, 213, 1978.
238. Kingcade, J. E., Nagarathna, H. M., Shim, I., and Gingerich, K. A., *J. Phys. Chem.*, 90, 2830, 1986.
239. Kleinschmidt, P. D. and Hildenbrand, D. L., *J. Chem. Phys.*, 68, 2819, 1978.
240. Kleinschmidt, P. D. and Ward, J. W., *J. Less-Common. Met.*, 121, 61, 1986.
241. Kleinschmidt, P. D., Cubicciotti, D., and Hildenbrand, D. L., *J. Electrochem. Soc.*, 125, 1543, 1978; *Proc. Electrochem. Soc.*, 78, 217, 1978.
242. Kleinschmidt, P. D., Lau, K. H., and Hildenbrand, D. L., *J. Chem. Phys.*, 74, 653, 1981.
243. Klynning, L. and Lindgren, B., *Arkiv. Fysik.*, 32, 575, 1966.
244. Kohl, F. J. and Carlson, K. D., *J. Am. Chem. Soc.*, 90, 4814, 1968.
245. Kohl, F. J. and Stearns, C. A., *J. Phys. Chem.*, 78, 273, 1974.
246. Kondratiev, V. N., *Bond Dissociation Energies, Ionization Potentials and Electron Affinities*, Mauka Publishing House, Moscow, 1974.
247. Kordis, J. and Gingerich, K. A., *J. Chem. Eng. Data*, 18, 135, 1973.
248. Kordis, J. and Gingerich, K. A., *J. Chem. Phys.*, 58, 5141, 1973.
249. Kordis, J. and Gingerich, K. A., *J. Phys. Chem.*, 76, 2336, 1972.
250. Kordis, J., Gingerich, K. A., and Seyse, R. J., *J. Chem. Phys.*, 61, 5114, 1974.
251. Kowalski, A., Czaikowski, M., and Breckenridge, W. H., *Chem. Phys. Lett.*, 119, 368, 1985.
252. Koyama, T. and Yamawaki, M., *J. Nucl. Mater.*, 152, 30, 1988.
253. Kronekvist, M., Lagerqvist, A., and Neuhaus, H., *J. Mol. Spectrosc.*, 39, 516, 1971.
254. Langenberg, J. D. and Morse, M. D., *Chem. Phys. Lett.*, 239, 25, 1995.
255. Langenberg, J. D. and Morse, M. D., *J. Chem. Phys.*, 100, 2331, 1998.
256. Lau, K. H. and Hildenbrand, D. L., *J. Chem. Phys.*, 71, 1572, 1979.
257. Lau, K. H. and Hildenbrand, D. L., *J. Chem. Phys.*, 72, 4928, 1980.
258. Lau, K. H. and Hildenbrand, D. L., *J. Chem. Phys.*, 76, 2646, 1982.
259. Lau, K. H. and Hildenbrand, D. L., *J. Chem. Phys.*, 80, 1312, 1984.
260. Lau, K. H. and Hildenbrand, D. L., *J. Chem. Phys.*, 86, 2949, 1987.
261. Lau, K. H. and Hildenbrand, D. L., *J. Chem. Phys.*, 92, 6124, 1990.
262. Lau, K. H., Brittain, R. D., and Hildenbrand, D. L., *Chem. Phys. Lett.*, 81, 227, 1981; *J. Phys. Chem.*, 86, 4429, 1982.
263. Lau, K. H., Brittain, R. D., and Hildenbrand, D. L., *J. Chem. Phys.*, 90, 1158, 1989.
264. Li, K. C. and Stwalley, W. C., *J. Chem. Phys.*, 59, 4423, 1973.
265. Li, L., Lyyra, A. M., Luh, W. T., and Stwalley, W. C., *J. Chem. Phys.*, 93, 8452, 1990.
266. Lindgren, B. and Nilsson, Ch., *J. Mol. Spectrosc.*, 55, 407, 1975.
267. Martin, E. and Barrow, R. F., *Phys. Scr.*, 17, 501, 1978.
268. McIntyre, N. S., Vander Auwera-Mahieu, A., and Drowart, J., *Trans. Faraday Soc.*, 64, 3006, 1968.
269. Menendez, M., Garay, M., Verdasco, E., and Gonzalez, U. A., *J. Chem. Phys.*, 99, 2760, 1993.
270. Murad, E., Hildenbrand, D. L., and Main, R. P., *J. Chem. Phys.*, 45, 263, 1966.
271. Nagai, S., Shinmei, M., and Yokokawa, T., *J. Inorg. Nucl. Chem.*, 36, 1904, 1974.
272. Nappi, B. M. and Gingerich, K. A., *Inorg. Chem.*, 20, 522, 1981.
273. Neckel, A. and Sodeck, G., *Monatsch. Chem.*, 103, 367, 1972.
274. Nedelec, O. and Giroud, M., *J. Chem. Phys.*, 79, 2121, 1983.
275. Neubert, A. and Zmbov, K. F., *Chem. Phys.*, 76, 469, 1983.
276. Neubert, A. and Zmbov, K. F., J. *Chem. Soc. Faraday Trans. 1*, 70, 2219, 1974.
277. Neubert, A., Ihle, H. R., and Gingerich, K. A., *J. Chem. Phys.*, 73, 1406, 1980.
278. Neubert, A., Zmbov, K. F., Gingerich, K. A., and Ihle, H. R., *J. Chem. Phys.*, 77, 5218, 1982.
279. Nordine, P. C., *J. Chem. Phys.*, 61, 224, 1974.
280. O'Hare, P. A. G. and Curtiss, L. A., *J. Chem. Thermodyn.*, 27, 643, 1995.
281. O'Hare, P. A. G., *J. Phys. Chem. Ref. Data*, 22, 1455, 1993.

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

282. O'Hare, P. A. G., Zywocinski, A., and Curtiss, L. A., *J. Chem. Thermodyn.,* 28, 459, 1996.
283. Ovcharenko, I. E., Ya, Kuzyankow, Y., and Tatevaskii, V. M., *Opt. Spectrosk.,* 19, 528, 1965.
284. Pak, K., Cai, M. F., Dzugan, T. P., and Bondybey, V. E., *Faraday Discuss. Chem. Soc.*, 86, 153, 1988.
285. Parks, E. K. and Wexler, S., *J. Phys. Chem.,* 88, 4492, 1984.
286. Parr, T. P., Behrens, R., Freedman, A., and Heron, R. R., *Chem. Phys. Lett.,* 56, 71, 1978.
287. Pedley, J. B. and Marshall, E. M., *J. Phys. Chem. Ref. Data*, 12, 967, 1984.
288. Pelevin, O. V., Mil'vidskii, M. G., Belyaev, A. I., and Khotin, B. A., *Izv. Akad. Nauk. SSSR Neorg. Mater.*, 2, 924, 1966.
289. Pelino, M. and Gingerich, K. A., *J. Chem. Phys.*, 90, 1286, 1989.
290. Pelino, M., and Gingerich, K. A., *J. Chem. Phys.*, 93, 1581, 1989.
291. Pelino, M., Piacente, V., and Ascenzo, G., *Thermochim. Acta,* 31, 383, 1979.
292. Pelino, M., Viswanadham, P., and Edwards, J. G., *J. Phys. Chem.*, 83, 2964, 1979.
293. Piacente, V. and Balducci, G., *Adv. Mass Spectrom.*, 7A, 626, 1978.
294. Piacente, V. and Balducci, G., *Dyn. Mass Spectrom.*, 4, 295, 1976.
295. Piacente, V. and Balducci, G., *High Temp. Sci.*, 6, 254, 1974.
296. Piacente, V. and Desideri, A., *J. Chem. Phys.*, 57, 2213, 1972.
297. Piacente, V. and Gigli, R., *J. Chem. Phys.*, 77, 4790, 1982.
298. Piacente, V. and Gingerich, K. A., *High Temp. Sci.*, 9, 189, 1977.
299. Piacente, V. and Gingerich, K. A., *Z. Naturforsch. Teil A*, 28, 316, 1973.
300. Piacente, V. and Malaspina, L., *J. Chem. Phys.*, 56, 1780, 1972.
301. Piacente, V., *J. Chem. Phys.*, 70, 5911, 1979.
302. Pianalto, F. S., O'Brien, L. C., Keller, P. C., and Bernath, P. F., *J. Mol. Spectrosc.*, 129, 348, 1988.
303. Pilgrim, J. C. and Duncan, M. A., *Chem. Phys. Lett.*, 232, 335, 1995.
304. Pinegar, J. C., Langenberg, J. D., Arrington, C.A., Spain, E. M., and Morse, M. D., *J. Chem. Phys.*, 102, 666, 1995.
305. Pitzer, K. S., *J. Chem. Phys.*, 74, 3078, 1981.
306. Porter, R. F. and Spencer, C. W. J., *J. Chem. Phys.*, 32, 943, 1960.
307. Prasad, R., Venugopal, V., and Sood, D. D., *J. Chem. Thermodyn.,* 9, 593, 1977.
308. Rajamanickam, N., Dhuvaragaikannan, N., and Raja Mohamed, K., *Acta Physica Hungarica,* 74, 385, 1994.
309. Rajamanickam, N., Palaniselvam, K., Rajavel, S. R. K., Rajesh, M., and Sureshkumar, G., *Acta Phys. Hung.*, 70, 141, 1991.
310. Rajamanickam, N., Senthilkumar, R. N., Ganesan, S., Gopalakrishnan, N., Rajkumer, J., Jegadesan, V., and Dandapani, C., *Acta Phys. Hung.*, 70, 71, 1991.
311. Rajamanickan, N., *Acta Ciencia Indica Phys.*, 14, 18, 1988.
312. Ram, R. S., Rai, S. B., Ram, R. S., Upadhya, K. N., J. *Chim. Phys. Phys-Chim. Biol.*, 76, 560, 1979.
313. Ramakrishnan, E. S., Shim, I., and Gingerich, K. A., *J. Chem. Soc. Faraday Trans. 2,* 80, 395, 1984.
314. Ran, Q., Schmude, R. W., Gingerich, K. A., Wilhite, D. W., and Kincade, J. E., *J. Phys. Chem.*, 97, 8535, 1993.
315. Rao, P. S. and Rao, T. V. R., *J. Quant. Spectrosc. Radiat. Transfer*, 27, 207, 1982.
316. Rao, S. P. and Rao, T. V. R., *Acta Ciencia Indica Phys.*, 7, 58, 1981.
617. Rao, T. V. R., Reddy, R. R., and Rao, P. S., *Indian J. Pure Appl. Phys.*, 19, 1219, 1981.
318. Rao, V. M., Rao, M. L. P., and Rao, P. T., *J. Quant. Spectrosc. Radiat. Transfer*, 25, 547, 1981.
319. Reddy, R. R., Reddy, A. S. R., and Rao, T. V. R., *Acta Phys. Slovaca,* 36, 273, 1986.
320. Riekert, G., Lamparter, P., and Steeb, S., *Z. Metallkd.*, 72, 765, 1981.
321. Riekert, G., Rainer-Harbach, G., Lamparter, P., and Steeb, S., *Z. Metallkd.*, 76, 406, 1981.
322. Rinehart, G. H. and Behrens, R. G., *J. Phys. Chem.*, 83, 2052, 1979.
323. Rohlfing, E. A. and Valentine, J. J., *J. Chem. Phys.*, 84, 6560, 1986.
324. Rovner, L., Drowart, A., and Drowart, J., *Trans. Faraday Soc.*, 63, 2910, 1967.
325. Rusin, A. D., Zhukov, E., Agamirova, L. M., and Kalinnikov, V. T., *Zh. Neorg. Khim.*, 24, 1457, 1979.
326. Samoilova, I. O. and Kazenas, E. K., *Izvestiya Rossiiskoi Akademii Nauk. Metally*, (1), 33, 1995.
327. Samoilova, I. O. and Kazenas, E. K., *Izvestiya Rossiiskoi Akademii Nauk. Metally*, (3), 36, 1994.
328. Schumde, R. W. Jr., Ran, Q., Gingerich, K. A., and Kingcade, J. E. Jr., *J. Chem. Phys.*, 102,2574, 1995.
329. Scott, P. R. and Richards, W. G., *J. Phys. B*, 7,1679, 1974.
330. Shim, I. and Gingerich, K. A., *J. Chem. Phys.*, 77, 2490, 1982.
331. Shim, I. and Gingerich, K. A., *J. Chem. Phys.*, 80, 5107, 1984.
332. Shim, I., and Gingerich, K. A., *J. Chem. Phys.*, 81, 5937, 1984.
333. Shim, I., Finkbeiner, H. C., and Gingerich, K. A., *J. Phys. Chem.*, 91, 3171, 1987.
334. Shim, I., Kingcade, J. E. Jr., and Gingerich, K. A., *J. Chem. Phys.*, 85, 6629, 1986.
335. Shim, I., Kingcade, J. E. Jr., and Gingerich, K. A., *J. Chem. Phys.*, 89, 3104, 1988.
336. Shim, I., Kingcade, J. E. Jr., and Gingerich, K. A., *Z. Phys. D - Atoms Molecules and Clusters,* 7, 261, 1987.
337. Shim, I., Mandix, K., and Gingerich, K. A., *J. Phys. Chem.*, 95, 5435, 1991.
338. Shim, I., Pelino, M., and Gingerich, K. A., *J. Chem. Phys.*, 97, 9240, 1992.
339. Siegel, B., *Q. Rev. (London)*, 19, 77, 1965.
340. Simons, J. W., Oldenberg, R. C., and Baughaim, S. L., *J. Phys. Chem.*, 91, 3840, 1987.

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

341. Smith, P. K. and Peterson, D. E., *J .Chem. Phys.*, 52, 4963, 1970.
342. Smoes, S. and Drowart, J., *Chem. Commun.*, p.534, 1968.
343. Smoes, S. and Drowart, J., *J. Chem. Soc. Faraday Trans. 2*, 73, 1746, 1977.
344. Smoes, S. and Drowart, J., *J. Chem. Soc. Faraday Trans. 2*, 80, 1171, 1984.
345. Smoes, S., Coppens, P., Bergman, C., and Drowart, J., *Trans. Faraday Soc.*, 65, 682, 1969.
346. Smoes, S., Depiere, D., and Drowart, J., *Rev. Int. Hautes Temp. Refractaires Paris*, 9, 171, 1972.
347. Smoes, S., Drowart, J., Welter, J. M., *J. Chem. Thermodyn.*, 9, 275, 1977; *Adv. Mass Spectrom.*, 7A, 622, 1978.
348. Smoes, S., Huguet, R., and Drowart, J., *Z. Naturforsch. Teil A*, 26, 1934, 1971.
349. Smoes, S., Mandy, F., Vander Auwera-Mahieu, A., and Drowart, *J., Bull. Soc. Chim. Belg.*, 81, 45, 1972.
350. Smoes, S., Myers, C. E., and Drowart, J., *Chem. Phys. Lett.*, 8, 10, 1971.
351. Smoes, S., Pattje, W. R., and Drowart, J., *High Temp. Sci.*, 10, 109, 1978.
352. Spain, E. M. and Morse, M. D., *J. Chem. Phys.*, 97, 4605, 1992.
353. Spain, E. M. and Morse, M. D., *J. Phys. Chem.*, 96, 2479, 1992.
354. Sreedhara Murthy, N., *Indian J. Phys.*, 62B, 92, 1988.
355. Srivastara, R. D. and Farber, M., *High Temp. Sci.*, 5, 489, 1973.
356. Stearns, C. A. and Kohl, F. J., *High Temp. Sci.*, 2, 146, 1970.
357. Stearns, C. A. and Kohl, F. J., *High Temp. Sci.*, 6, 284, 1974.
358. Steiger, R. A. and Cater, E. D., *High Temp. Sci.*, 7, 204, 1975.
359. Steiger, R. P. and Cater, E. D., *High Temp. Sci.*, 7, 288, 1975.
360. Stwalley, W. C., Way, K. R., and Velasco, R., *J. Chem. Phys.*, 60, 3611, 1974.
361. Su, T.-M. R. and Riley, S. J., *J. Chem. Phys.*, 71, 3194, 1979.
362. Su, T.-M. R. and Riley, S. J., *J. Chem. Phys.*, 72, 1614, 1980.
363. Su, T.-M. R. and Riley, S. J., *J. Chem. Phys.*, 72, 6632, 1980.
364. Sullivan, C. L., Zehe, M. J., and Carlson, K. D., *High Temp. Sci.*, 6, 80, 1974.
365. Tanaka, Y., Yushina, K., and Freeman, D. E., *J. Chem. Phys.*, 59, 564, 1973.
366. Taylor, S., Lemire, G. W., Hamrick, Y. M., Fu, Z., and Morse, M. D., *J. Chem. Phys.*, 89, 5517, 1988.
367. Taylor, S., Spain, E. M., and Morse, M. D., *J. Chem. Phys.*, 92, 2698, 1990.
368. Tellinghuisen, J., Tisone, G. C., Hoffmann, J. M., and Hays, A. K., *J. Chem. Phys.*, 64, 4796, 1976.
369. Tolbert, M. A. and Beauchamp, J. L., *J. Phys. Chem.*, 90, 5015, 1986.
370. Tomaszkiewicz, I., Susman, S., Volin, K. J., and O'Hare, P. A. G., *J. Chem. Thermodyn.*, 26, 1081, 1994.
371. Tromp, J. W., LeRoy, R. J., Gerstenkorn, S., and Luc, P., *J. Mol. Spectrosc.*, 100, 82, 1983.
372. Tuenge, R. T., Laabs, F., and Franzen, H. F., *J. Chem. Phys.*, 65, 2400, 1976.
373. Urdahl, R. S., Bao, Y., and Jackson, W. M., *Chem. Phys. Lett.*, 178, 425, 1991.
374. Uy, O. M. and Drowart, J., *High Temp. Sci.*, 2, 293, 1970.
375. Uy, O. M. and Drowart, J., *Trans. Faraday Soc.*, 65, 3221, 1969.
376. Uy, O. M. and Drowart, J., *Trans. Faraday Soc.*, 67, 1293, 1971.
377. Uy, O. M., Muenow, D. W., Ficalora, P, J., and Margrave, J. L., *Trans. Faraday Soc.*, 64, 2998, 1968.
378. Van Veen, N. J. A., DeVries, M., and DeVries, A. E., *Chem. Phys. Lett.*, 64, 213, 1979.
379. Vander Auwera-Mahieu, A. and Drowart, J., *Chem. Phys. Lett.*, 1, 311, 1967.
380. Vander Auwera-Mahieu, A., McIntyre, N. S., and Drowart, J., *Chem. Phys. Lett.*, 4, 198, 1969.
381. Vander Auwera-Mahieu, A., Peeters, R., McIntyre, N. S., and Drowart, J., *Trans. Faraday Soc.*, 66, 809, 1970.
382. Varma, M. P., Ishwar, N. B., and Jha, B. L., *Indian J. Pure Appl. Phys.*, 20, 828, 1982.
383. Velasco, R., Ottinger, C., and Zare, R. N., *J. Chem. Phys.*, 51, 5522, 1969.
384. Vempati, S. N. and Jones, W. E., *J. Mol. Spectrosc.*, 127, 232, 1988.
385. Venkataramanaiah, M. and Lakshman, S. V. J., *J. Quant. Spectrosc. Radiat. Transfer*, 26, 11, 1981.
386. Verhaegen, G., Smoes, S., and Drowart, J., *J. Chem. Phys.*, 40, 239, 1964.
387. Verhaegen, G., Stafford, F. E., and Drowart, J., *J. Chem. Phys.*, 40, 1622, 1964.
388. Viswanathan, K. S. and Tellinghuisen, J., *J. Mol. Spectrosc.*, 98, 185, 1983.
389. Viswanathan, R., Baba, M. S., Raj, D. D. A., Balasubramanian, R., Narasimhan, T. S. L., and Mathews, C. K., *Spectrochim. Acta*, Part B, 49B, 243, 1994.
390. Viswanathan, R., Schmude, R. W., and Gingerich, K. A., *J. Phys. Chem.*, 100, 10784, 1996.
391. Viswanathan, R., Schumde, R. W., and Gingerich, K. A., *J. Chem. Thermodyn.*, 27, 763, 1995.
392. Wang, Y. C., Kajitani, M., Kasahara, S., Bata, M., Ishikawa, K., and Kato, H., *J. Chem. Phys.*, 95, 6229, 1991.
393. Way, K. R. and Stwalley, W. C., *J. Chem. Phys.*, 59, 5298, 1973.
394. Weickenmeier, W., Diemer, U., Wahl, M., Raab, M., Demtroeder, W., and Mueller, W., *J. Phys.Chem.*, 82, 5354, 1985.
395. Wiedemeier, H. and Gilles, P. W., *J. Chem. Phys.*, 42, 2765, 1965.
396. Wu, C. H. and Ihle, H. R., *Adv. Mass Spectrom.*, 8A, 374, 1980.
397. Wu, C. H., Ihle, H. R., and Gingerich, K. A., *Int. J. Mass Spectrom. Ion Phys.*, 47, 235, 1983.
398. Wu, C. H., *J. Chem. Phys.*, 65, 3181, 1976; 65, 2040, 1976.

Table 1
BOND STRENGTHS IN DIATOMIC MOLECULES (continued)

399. Yokozeki, A. and Menzinger, M., *Chem. Phys.*, 14, 427, 1976.
400. Yoo, R. K., Ruscic, B., and Berkowitz, J., *Chem. Phys.*, 166, 215, 1992.
401. Zemke, W. T. and Stwalley, W. C., *Chem. Phys. Lett.*, 143, 84, 1988.
402. Zemke, W. T., Stwalley, W. C., Langhoff, S. R., Valderrama, G. L., and Berry, M. J., *J. Chem. Phys.*, 95, 7846, 1991.
403. Zmbov, K. F. and Margrave, J. L., *J. Chem. Phys.*, 45, 3167, 1966.
404. Zmbov, K. F. and Margrave, J. L., *J. Chem. Phys.*, 47, 3122, 1967.
405. Zmbov, K. F. and Margrave, J. L., J. *Inorg. Nucl. Chem.*, 29, 59, 1967.
406. Zmbov, K. F. and Margrave, J. L., *J. Phys. Chem.*, 70, 3379, 1966.
407. Zmbov, K. F. and Margrave, J. L., *J. Phys. Chem.*, 71, 2893, 1967.
408. Zmbov, K. F., Hastie, J. W., and Margrave, J. L., *Trans. Faraday Soc.*, 64, 861, 1968.
409. Zmbov, K. F., Neubert, A., and Ihle, H. R., *Z. Naturforsch., A*, 36A, 914, 1981.
410. Zmbov, K. F., Wu, C. H., and Ihle, H. R., *J. Chem. Phys.*, 67, 4603, 1977.
411. Zollweg, R. J., *Contrib. Pap. Int. Conf. Phenom. Ioniz. Gases.* 11th, 402, 1973.

Table 2
ENTHALPY OF FORMATION OF GASEOUS ATOMS FROM ELEMENTS IN THEIR STANDARD STATES

For elements that are diatomic gases in their standard states these are readily obtained from the bond strength. For elements that are crystalline in their standard states they are derived from vapor pressure data.

Atom	$\Delta_f H^\circ_{298}$/kJ mol^{-1}	Ref.	Atom	$\Delta_f H^\circ_{298}$/kJ mol^{-1}	Ref.	Atom	$\Delta_f H^\circ_{298}$/kJ mol^{-1}	Ref.
			Hf	619 ± 4	1	Re	774 ± 6.3	1
Ag	284.9 ± 0.8	2	Hg	61.38 ± 0.04	2	Rh	556 ± 4	1
Al	330.0 ± 4.0	2	I	106.76 ± 0.04	2	Ru	650.6 ± 6.3	1
As	302.5 ± 13	1	In	243 ± 4	1	S	277.17 ± 0.15	2
Au	368.2 ± 2.1	1	Ir	669 ± 4	1	Sb	264.4 ± 2.5	1
B	565 ± 5	2	K	89.0 ± 0.8	2	Sc	377.8 ± 4	1
Ba	177.8 ± 4	1	Li	159.3 ± 1.0	2	Se	227.2 ± 4	1
Be	324 ± 5	2	Mg	147.1 ± 0.8	2	Si	450 ± 8	2
Bi	209.6 ± 2.1	1	Mn	283.3 ± 4	1	Sn	301.2 ± 1.5	2
Br	111.87 ± 0.12	2	Mo	658.1 ± 2.1	1	Sr	163.6 ± 2.1	1
C	716.68 ± 0.45	2	N	472.68 ± 0.40	2	Ta	782.0 ± 2.5	1
Ca	177.8 ± 0.8	2	Na	107.5 ± 0.7	2	Te	196.6 ± 2.1	1
Cd	111.80 ± 0.20	2	Nb	721.3 ± 4	1	Th	602 ± 6	2
Ce	423 ± 13	1	Ni	430.1 ± 2.1	1	Ti	473 ± 3	2
Cl	121.301 ± 0.008	2	O	249.18 ± 0.10	2	Tl	182.21 ± 0.4	1
Co	428.4 ± 4	1	Os	787 ± 6.3	1	U	533 ± 8	2
Cr	397 ± 4	1	P	316.5 ± 1.0	2	V	514.2 ± 1.3	1
Cs	76.5 ± 1.0	2	Pb	195.2 ± 0.8	2	W	849.8 ± 4	1
Cu	337.4 ± 1.2	2	Pd	376.6 ± 2.1	1	Y	424.7 ± 2.1	1
Er	317.1 ± 4	1	Pt	565.7 ± 1.3	1	Yb	152.09 ± 0.8	1
F	79.38 ± 0.30	2	Pu	364.4 ± 17	1	Zn	130.40 ± 0.40	2
Ge	372 ± 3	2	Rb	80.9 ± 0.8	2	Zr	608.8 ± 4	1
H	217.998 ± 0.006	2						

REFERENCES

1. Brewer, L. and Rosenblatt, G. M., *Adv. High Temp. Chem.*, 2, 1, 1969.
2. Cox, J. D., Wagman, D. D., and Medvedev, V. A., Eds., *CODATA Key Values for Thermodynamics*, Hemisphere Publishing Corporation, New York, 1989.

STRENGTHS OF CHEMICAL BONDS (continued)

Table 3
BOND STRENGTHS IN POLYATOMIC MOLECULES

The values below refer to a temperature of 298 K and have mostly been determined by kinetic methods (see (i) S. W. Benson, *J. Chem. Educ.*, 42, 502, 1965, (ii) J. A. Kerr, *Chem. Rev.*, 66, 465, 1966 and (iii) D. F. McMillen and D. M. Golden, *Ann. Rev. Phys. Chem.*, 33, 493, 1982, for a full description of the methods). An increasing number of bond strengths are being determined from gas-phase acidity cycles and from photoionization mass spectrometry (see J. Berkowitz, G. B. Ellison and D. Gutman, *J. Phys. Chem.*, 98, 2744, 1994).

Bond strengths in polyatomic molecules are notoriously difficult to measure accurately since the mechanisms of the kinetic systems involved in many of the measurements are seldom straightforward. Thus much controversy has taken place in the literature over the past 15 years concerning C-H bond strengths in simple alkanes, for which we recommend data based largely on kinetic studies involving time-resolved flow tube experiments with mass spectrometric determination of reactant radical concentrations (see Berkowitz, J., Ellison, G. B., and Gutman, D., *J. Phys. Chem.*, 98, 2744, 1994.). These alkane bond strengths and the enthalpies of formation of the corresponding radicals are significantly larger than values derived from experiments in very low pressure reactors (see Dobis, O. and Benson, S. W., *J. Phys. Chem.*, 101, 6030, 1997; and Benson, S. W. and Dobis, O., *J. Phys. Chem.*, 102, 5175, 1998). Other examples illustrating the difficulties involved are concerned with the C-H bond strengths in ethene and methanol or the corresponding enthalpies of formation of the vinyl and hydroxymethyl radicals and changes to the recommendations could well arise.

Some of the bond strengths have been calculated from the enthalpies of formation of the species involved according to the equations:

$$D°(R–X) = \Delta_f H°(R) + \Delta_f H°(X) – \Delta_f H°(RX)$$
$$D°(R–R) = 2\ \Delta_f H°(R) – \Delta_f H°(RR)$$

The enthalpies of formation of the atoms and radicals are taken from Tables 2 and 4 and for the molecules from the appropriate References following Table 3.

An attempt has been made to list all the important values obtained by methods that are considered to be valid. The references are intended to serve as a guide to the literature.

Bond	$D°_{298}$/kJ mol^{-1}	Ref.
H-CH	424.0 ± 4.2	1
H-CH_2	462.0 ± 4.0	1
H-CH_3	438.9 ± 0.4	16
H-CCH	556.1 ± 2.9	4,37
H-$CHCH_2$	465.3 ± 3.4	37,81
H-C_2H_5	423.0 ± 1.6	16
H-Cycloprop-2-en-1-yl	379.1 ± 17	63
H-CH_2CCH	374.0 ± 8	63
H-CH_2CHCH_2	361.9 ± 8.8	16,35
H-Cyclopropyl	444.8 ± 1.3	63
H-n-C_3H_7	423.3 ± 2.1	82
H-i-C_3H_7	409.1 ± 2.0	82
H-CH_2CCCH_3	364.8 ± 8	63
H-$CH(CH_3)CCH$	347.7 ± 9.2	63
H-Cyclobutyl	403.8 ± 4	63
H-Cyclopropylmethyl	407.5 ± 6.7	63
H-$CH(CH_3)CHCH_2$	345.2 ± 5.4	63
H-$CH_2CHCHCH_3$	358.2 ± 6.3	63
H-$CH_2C(CH_3)CH_2$	358.2 ± 4	91,95
H-n-C_4H_9	425.4 ± 2.1	82
H-i-C_4H_9	425.2 ± 2.1	82
H-s-C_4H_9	411.2 ± 2.0	82
H-t-C_4H_9	404.3 ± 1.3	82
H-Cyclopenta-1,3-dien-5-yl	346.7	1,12
H-Spiropentyl	413.4 ± 4	63
H-Cyclopent-1-en-3-yl	344.3 ± 4	63
H-$CH_2CHCHCHCH_2$	347 ± 13	63
H-$CH(C_2H_3)_2$	319.7	63,92
H-$CH(CH_3)CCCH_3$	365.3 ± 11.3	63
H-$C(CH_3)_2CCH$	338.9 ± 9.6	63
H-$C(CH_3)_2CHCH_2$	323.0 ± 6.3	63
H-Cyclopentyl	403.5 ± 2.5	22,74
H-$CH_2C(CH_3)_3$	418 ± 8	63
H-$C(CH_3)_2C_2H_5$	404.0 ± 6.3	1,74,89
H-C_6H_5	473.1 ± 3.0	46
H-Cyclohexa-1,3-dien-5-yl	305 ± 21	63
H-Cyclohexa-1,4-dien-3-yl	305.4 ± 8.4	45
H-Cyclohexyl	399.6 ± 4	63
H-$C(CH_3)_2CCCH_3$	344.3 ± 11.3	63
H-$CH_2C(CH_3)C(CH_3)_2$	326.4 ± 4.6	63
H-$C(CH_3)_2C(CH_3)CH_2$	319.2 ± 4.6	63
H-$CH_2C_6H_5$	375.7 ± 1.7	35
H-Cyclohepta-1,3,5-trien-7-yl	305.4 ± 8	63
H-Norbornyl	404.6 ± 10.5	63
H-Cycloheptyl	387.0 ± 4	63
H-$CH(CH_3)C_6H_5$	357.3 ± 6.3	63
H-Inden-1-yl	351 ± 13	63
H-$C(CH_3)_2C_6H_5$	353.1 ± 6.3	63
H-1-Naphthylmethyl	356.1 ± 6.3	63
H-$CH(C_6H_5)_2$	340.6	80
H-9,10-Dihydroanthracen-9-yl	315.1 ± 6.3	63
H-$C(CH_3)(C_6H_5)_2$	339 ± 8	63
H-9-Anthracenylmethyl	342.3 ± 6.3	63
H-9-Phenanthrenylmethyl	356.1 ± 6.3	63
H-CN	527.6 ± 1.7	16
H-CH_2CN	392.9 ± 8.4	16
H-CH_2NC	380.7 ± 8.8	16
H-$CH(CH_3)CN$	376.1 ± 9.6	63
H-$C(CH_3)_2CN$	361.9 ± 8.4	63
H-CH_2NH_2	390.4 ± 8.4	63
H-CH_2NHCH_3	364 ± 8	63
H-$CH_2N(CH_3)_2$	351 ± 8	63
H-CHO	368.5 ± 1.0	23
H-CHCO	440.6 ± 8.8	16
H-$COCH_3$	373.8 ± 1.5	67
H-$COCHCH_2$	364.4 ± 4.2	63
H-COC_2H_5	371.3	1,12
H-COC_6H_5	363.6 ± 4	63

Table 3
BOND STRENGTHS IN POLYATOMIC MOLECULES (continued)

Bond	$D°_{298}$/kJ mol^{-1}	Ref.
H-$COCF_3$	380.7 ± 8	63
H-CH_2CHO	394.6 ± 9.2	16
H-CH_2COCH_3	411.3 ± 7.5	63
H-$CH(CH_3)COCH_3$	386.2 ± 5.9	63
H-CH_2OCH_3	402.2	1,12
H-$CH(CH_3)OC_2H_5$	383.7 ± 1.7	55
H-Tetrahydrofuran-2-yl	385 ± 4	63
H-2-Furylmethyl	361.9 ± 8	63
H-CH_2OH	401.8 ± 1.5	50
H-$CH(CH_3)OH$	401.4	1,12
H-$CH(OH)CHCH_2$	341.4 ± 7.5	63
H-$C(CH_3)_2OH$	381 ± 4	63
H-$CH_2OCOC_6H_5$	419.2 ± 5.4	63
H-$COOCH_3$	387.9 ± 4	63
H-CH_2F	423.8 ± 4	77
H-CHF_2	431.8 ± 4	77
H-CF_3	449.5	3,61
H-CHFCl	421.7 ± 5.4	97
H-CF_2Cl	421.3 ± 8.3	64
H-$CHFCl_2$	413.8 ± 5.0	97
H-CH_2Cl	419.0 ± 2.3	84
H-$CHCl_2$	402.5 ± 2.7	84
H-CH_2CH_2Cl	423.1 ± 2.4	85
H-$CH(CH_3)Cl$	406.6 ± 1.5	84
H-$C(CH_3)Cl_2$	390.6 ± 1.5	84
H-CCl_3	392.5 ± 2.5	48
H-CH_2Br	425.1 ± 4.2	97
H-$CHBr_2$	417.2 ± 7.5	97
H-CBr_3	401.7 ± 6.7	63
H-CH_2I	431 ± 8	63
H-CHI_2	431 ± 8	63
H-$CHCF_2$	448 ± 8	90
H-CFCHF	448 ± 8	90
H-$CFCF_2$	452 ± 8	90
H-CH_2CF_3	446.4 ± 4.6	63
H-CF_2CH_3	416.3 ± 10.5	63
H-C_2F_5	429.7 ± 2.1	63
H-CFCFCl	444 ± 8	90
H-$CHClCF_3$	425.9 ± 6.3	63
H-CClCFCl	439 ± 8	90
H-$CClCH_2$	>433.5	81
H-CClCHCl	435 ± 8	90
H-CCl_2CHCl_2	393 ± 8	63
H-C_2Cl_5	393.5 ± 6.0	66
H-$CClBrCF_3$	404.2 ± 6.3	63
H-n-C_3F_7	435 ± 8	63
H-i-C_3F_7	433.5 ± 2.5	38
H-$CHClCHCH_2$	370.7 ± 5.9	63
H-C_6F_5	476.6	63
H-$CH_2Si(CH_3)_3$	415.1 ± 4	99
H-CSH	399.6 ± 5.0	16
H-CH_2SH	392.9 ± 8.4	16
H-CH_2SCH_3	384.9 ± 5.9	49
H-NH_2	452.7 ± 1.3	16
H-$NHCH_3$	418.4 ± 10.5	63
H-$N(CH_3)_2$	382.8 ± 8	63
H-NHC_6H_5	368.2 ± 8	63
H-$N(CH_3)C_6H_5$	366.1 ± 8	63
H-NO	195.35 ± 0.25	32
H-NO_2	327.6 ± 2.1	63
H-NF_2	316.7 ± 10.5	63
H-$NHNH_2$	366.1	44
H-NH_3	385 ± 21	63
H-OH	498 ± 4	63
H-OCH_3	436.0 ± 3.8	16
H-OC_2H_5	437.7 ± 3.4	16
H-$OC(CH_3)_3$	439.7 ± 4	63
H-$OCH_2C(CH_3)_3$	428.0 ± 6.3	63
H-OC_6H_5	361.9 ± 8	63
H-O_2H	369.0 ± 4.2	88
H-O_2CH_3	370.3 ± 2.1	56
H-$O_2C(CH_3)_3$	374.0 ± 0.8	47
H-$OCOCH_3$	442.7 ± 8	63
H-$OCOC_2H_5$	445.2 ± 8	63
H-OCO-n-C_3H_7	443.1 ± 8	63
H-ONO	327.6 ± 2.1	15
H-ONO_2	423.4 ± 2.1	15
H-SiH	351	63
H-SiH_2	268	63
H-SiH_3	384.1 ± 2.0	83
H-SiH_2CH_3	374.9	99
H-$SiH(CH_3)_2$	374.0	99
H-$Si(CH_3)_3$	377.8	63,99
D-$Si(CH_3)_3$	389 ± 7.1	36
H-$SiH_2C_6H_5$	369.0	63,99
H-SiF_3	418.8	63,99
H-$SiCl_3$	382.0	63,99
H-Si_2H_5	361.1	63
H-$Si(CH_3)_2Si(CH_3)_3$	356.9 ± 8.4	45
H-$Si(Si(CH_3)_3)_3$	330.5 ± 8.4	45
H-PH_2	351.0 ± 2.1	16
H-SH	381.6 ± 2.9	65
H-SCH_3	365.3 ± 2.5	65
H-SC_6H_5	348.5 ± 8	63
H-SO	172.8	100
H-GeH_3	349.0 ± 8	16
H-GeH_2I	331 ± 8	68
H-$Ge(CH_3)_3$	339 ± 8	34
H-AsH_2	319.2 ± 0.8	16
H-SeH	334.93 ± 0.75	16
H-$Sn(n\text{-}C_4H_9)_3$	308.4 ± 8.4	19
H-SbH_2	288.3 ± 2.1	16
H-TeH	277.0 ± 5.0	16
HC≡CH	965 ± 8	1,24,74
H_2C=CH_2	728.3 ± 6	1,74
CH_3-CH_3	376.0 ± 2.1	1,74,86
CH_3-CH_2CCH	318.0 ± 8	63
CH_3-CH_2CCCH_3	308.4 ± 6.3	63
CH_3-$CH(CH_3)CCH$	305.4	63
CH_3-$C(CH_3)CCH_2$	320.1 ± 9.2	63
CH_3-$CH_2CHCHCH_3$	305.0 ± 3.3	63
CH_3-$CH_2C(CH_3)CH_2$	301.2 ± 3.3	91
CH_3-$CH(CH_3)CCCH_3$	320.9 ± 6.3	63
CH_3-$C(CH_3)_2CCH$	295.8 ± 6.3	63

Table 3
BOND STRENGTHS IN POLYATOMIC MOLECULES (continued)

Bond	D°_{298}/kJ mol^{-1}	Ref.
$n-C_3H_7-CH_2CCH$	306.3 ± 6.3	63
$CH_3-C(CH_3)_2CHCH_2$	284.9 ± 6.3	63
$n-C_3H_7-CH_2CHCH_2$	295.8	96
$CH_3-C(CH_3)_2CCCH_3$	303.3 ± 6.3	63
$CHCCH_2-s-C_4H_9$	300.0 ± 6.3	63
$CH_3-CH_2C_6H_5$	332.2 ± 4	63
$CH_3-CH(CH_3)C_6H_5$	312.1 ± 6.3	63
$C_2H_5-CH_2C_6H_5$	294.1 ± 4	63
CH_3-1-Naphthylmethyl	305.0 ± 6.3	63
$CH_3-C(CH_3)_2C_6H_5$	308.4 ± 6.3	63
$CHCCH_2-CH_2C_6H_5$	256.9 ± 8	63
$n-C_3H_7-CH_2C_6H_5$	292.9 ± 4	63
CH_3-9-Anthracenylmethyl	282.8 ± 6.3	63
CH_3-9-Phenanthrenylmethyl	305.0 ± 6.3	63
$CH_3-CH(C_6H_5)_2$	301 ± 8	63
$CH_3-C(CH_3)(C_6H_5)_2$	289 ± 8	63
CH_3-CN	509.6 ± 8	63
C_2H-CN	602 ± 4	70
$C_2H_5-CH_2NH_2$	332.2 ± 8	63
CH_3-CH_2CN	336.4 ± 4	93
$C_2H_5-CH_2CN$	321.7 ± 7.1	63
$CH_3-CH(CH_3)CN$	329.7 ± 8	63
$C_2H_5-CH_2CN$	321.7 ± 7.1	63
$CH_3-C(CH_3)_2CN$	312.5 ± 6.7	63
$CH_3-C(CH_3)(CN)C_6H_5$	250.6	63
$C_6H_5CH_2-CH_2NH_2$	284.5 ± 8	63
$C_6H_5CH_2-C_5H_4N$	362.8	80
$CN-CN$	536 ± 4	30
CH_3-2-Furylmethyl	314 ± 8	63
$CH_3-COC_6H_5$	355.6 ± 9.2	102
$C_6H_5CH_2-COCH_2C_6H_5$	273.6 ± 8	63
$CH_3CO-COCH_3$	282.0 ± 9.6	63
$C_6H_5CH_2-COOH$	280	63
$C_6H_5CO-COC_6H_5$	277.8	63
$(C_6H_5)_2CH-COOH$	248.5 ± 13	63
$CF_3-COC_6H_5$	308.8 ± 8	63
$CF_2=CF_2$	319.2 ± 13	103
CH_2F-CH_2F	368 ± 8	51
CH_3-CF_3	423.4 ± 4.6	79
CF_3-CF_3	413.0 ± 10.5	63
$C_6F_5-C_6F_5$	487.9 ± 24.7	78
CH_3-BF_2	~473	63
$C_6H_5-BCl_2$	~510	63
$CH_2CHCH_2-Si(CH_3)_3$	293	63
$s-C_4H_9-Si(CH_3)_3$	414	63
$CH_3-NHC_6H_5$	298.7 ± 8	63
$C_6H_5CH_2-NH_2$	297.5 ± 4	63
$CH_3-N(CH_3)C_6H_5$	296.2 ± 8	63
$C_6H_5CH_2-NHCH_3$	287.4 ± 8	63
$C_6H_5CH_2-N(CH_3)_2$	259.8 ± 8	63
$CH_2=N_2$	<175	58
$CH_3-N_2CH_3$	219.7	13
$C_2H_5-N_2C_2H_5$	209.2	13
$i-C_3H_7-N_2i-C_3H_7$	198.7	13
$n-C_4H_9-N_2n-C_4H_9$	209.2	13
$i-C_4H_9-N_2i-C_4H_9$	205.0	13
$s-C_4H_9-N_2s-C_4H_9$	195.4	13
$t-C_4H_9-N_2t-C_4H_9$	182.0	13
$C_6H_5CH_2-N_2CH_2C_6H_5$	157.3	13
$CF_3-N_2CF_3$	231.0	13
CH_3-NO	167.4 ± 3.3	63
$i-C_3H_7-NO$	152.7 ± 13	63
$t-C_4H_9-NO$	165.3 ± 6.3	63
C_6H_5-NO	212.5 ± 4	63
$NC-NO$	120.5 ± 10.5	43
CF_3-NO	179.1 ± 8	63
C_6F_5-NO	208.4 ± 4	63
CCl_3-NO	134 ± 13	63
$t-C_4H_9-NOt-C_4H_9$	121	21
CH_3-NO_2	254.4	63
$CH_2C(CH_3)-NO_2$	245.2	63
$i-C_3H_7-NO_2$	246.9	63
$t-C_4H_9-NO_2$	244.8	63
$C_6H_5-NO_2$	298.3 ± 4	63
$C(NO_2)_3-NO_2$	169.5 ± 4	63
$CH_3-OC(CH_3)CH_2$	277.4	101
$CH_3-OC_6H_5$	238 ± 8	73
$CH_3-OCH_2C_6H_5$	280.3	26
$C_2H_5-OC_6H_5$	264 ± 6.3	63
$CH_2CHCH_2-OC_6H_5$	208.4 ± 8	63
$O=CO$	532.2 ± 0.4	29
CH_3-O_2	137.0 ± 3.8	53
$C_2H_5-O_2$	148.4 ± 8.4	53
$CH_2CHCH_2-O_2$	76.2 ± 2.1	62
$i-C_3H_7-O_2$	155.4 ± 9.6	53
$t-C_4H_9-O_2$	152.8 ± 7.4	53
$C_6H_5CH_2-O_2CCH_3$	280 ± 8	63
$C_6H_5CH_2-O_2CC_6H_5$	289	13
$CH_3-O_2SCH_3$	279.5	63
$CH_2CHCH_2-O_2SCH_3$	207.5	63
$C_6H_5CH_2-O_2SCH_3$	221.3	63
$CF_3-O_2CF_3$	361.5	10
CH_2Cl-O_2	122.4 ± 10.5	53
$CHCl_2-O_2$	108.2 ± 8.2	53
CCl_3-O_2	92.0 ± 6.4	53
$CH_3CHCl-O_2$	131.2 ± 1.8	53
$CH_3CCl_2-O_2$	112.2 ± 2.2	53
$(CH_3)_2CCl-O_2$	136.0 ± 3.8	53
CH_3-SH	312.5 ± 4.2	65
$t-C_4H_9-SH$	286.2 ± 6.3	63
C_6H_5-SH	361.9 ± 8	63
CH_3-SCH_3	307.9 ± 3.3	65
$CH_3-SC_6H_5$	290.4 ± 8	63
$C_6H_5CH_2-SCH_3$	256.9 ± 8	63
$S-CS$	430.5 ± 13	63
$F-CH_3$	472	1,61
$F-CN$	469.9 ± 5.0	63
$F-COF$	535 ± 12	18
$F-CHFCl$	465.3 ± 9.6	97
$F-CF_2Cl$	490 ± 25	41
$F-CFCl_2$	462.3 ± 10.0	97
$F-CF_2CH_3$	522.2 ± 8	63

Table 3
BOND STRENGTHS IN POLYATOMIC MOLECULES (continued)

Bond	$D°_{298}$/kJ mol^{-1}	Ref.
F-C_2F_5	530.5 ± 7.5	63
Cl-CN	421.7 ± 5.0	63
Cl-COC_6H_5	310 ± 13	63
Cl-CSCl	265.3 ± 2.1	71
Cl-CF_3	360.2 ± 3.3	27
Cl-CHFCl	354.4 ± 11.7	97
Cl-CF_2Cl	346.0 ± 13.4	97
Cl-$CFCl_2$	305 ± 8	40
Cl-CH_2Cl	350.2 ± 0.8	97
Cl-$CHCl_2$	338.5 ± 4.2	97
Cl-CCl_3	305.9 ± 7.5	63
Cl-C_2F_5	346.0 ± 7.1	27
Cl-CF_2CF_2Cl	326 ± 8	63
Cl-$SiCl_3$	464	99
Br-CH_3	292.9 ± 5.0	39
Br-C_6H_5	336.8 ± 8	63
Br-CN	367.4 ± 5.0	63
Br-CH_2COCH_3	261.5	101
Br-COC_6H_5	268.6	13
Br-CHF_2	289 ± 8	63
Br-CF_3	296.2 ± 1.3	3
Br-CF_2CH_3	287.0 ± 5.4	76
Br-C_2F_5	287.4 ± 6.3	63
Br-n-C_3F_7	278.2 ± 10.5	63
Br-i-C_3F_7	274.1 ± 4.6	63
Br-$CH_2C_6F_5$	225 ± 6	54
Br-$CHClCF_3$	274.9 ± 6.3	63
Br-CCl_3	231.4 ± 4	63
Br-$CClBrCF_3$	251.0 ± 6.3	63
Br-CH_2Br	296.7 ± 1.3	97
Br-$CHBr_2$	292.0 ± 8	97
Br-CBr_3	235.1 ± 7.5	63
Br-NO_2	82.0 ± 7.1	57
Br-NF_2	≤222	25
I-$CHCH_2$	259.0 ± 4.2	20
I-n-C_4H_9	205.0 ± 4	63
I-Norbornyl	261.5 ± 10.5	69
I-CN	305 ± 4	30
I-CF_3	227.2 ± 1.3	3
I-CF_2CH_3	218.0 ± 4.2	63
I-CH_2CF_3	235.6 ± 4	63
I-C_2F_5	218.8 ± 2.9	2
I-n-C_3F_7	208.4 ± 4.2	63
I-i-C_3F_7	215.1 ± 2.9	2
I-n-C_4F_9	205.0 ± 4.2	72
I-$C(CF_3)_3$	206	33
I-C_6H_5	273.6 ± 8	63
I-C_6F_5	277.0	63
C_5H_5-FeC_5H_5	381 ± 13	59
CH_3-$ZnCH_3$	285 ± 17	63
C_2H_5-ZnC_2H_5	238 ± 17	63
CH_3-$Ga(CH_3)_2$	264 ± 17	63
C_2H_5-$Ga(C_2H_5)_2$	209 ± 17	63
CH_3-$Ge(CH_3)_3$	347 ± 17	63
CH_3-$As(CH_3)_2$	280 ± 17	63
CH_3-$CdCH_3$	251 ± 17	63
CH_3-$In(CH_3)_2$	205 ± 17	63
CH_3-$Sn(CH_3)_3$	297 ± 17	63
C_2H_5-$Sn(C_2H_5)_3$	264 ± 17	63
CH_3-$Sb(CH_3)_2$	255 ± 17	63
C_2H_5-$Sb(C_2H_5)_2$	243 ± 17	63
CH_3-$HgCH_3$	255 ± 17	63
C_2H_5-HgC_2H_5	205 ± 17	63
CH_3-$Tl(CH_3)_2$	167 ± 17	63
CH_3-$Pb(CH_3)_3$	238 ± 17	63
C_2H_5-$Pb(C_2H_5)_3$	230 ± 17	63
CH_3-$Bi(CH_3)_2$	218 ± 17	63
CO-$Cr(CO)_5$	155 ± 8	60
CO-$Fe(CO)_4$	172 ± 8	60
CO-$Mo(CO)_5$	167 ± 8	60
CO-$W(CO)_5$	192 ± 8	60
BH_3-BH_3	146	13
NH_2-NH_2	275.3	63
NH_2-$NHCH_3$	268.2 ± 8	63
NH_2-$N(CH_3)_2$	246.9 ± 8	63
NH_2-NHC_6H_5	218.8 ± 8	63
ON-NO_2	40.6 ± 2.1	63
O_2N-NO_2	56.9	63
NF_2-NF_2	88 ± 4	63
O-N_2	167	1,14
O-NO	305	1,14
O-NO_2	208.7 ± 1.1	31
HO-NO	206.3	63
HO-NO_2	206.7	63
HO_2-NO_2	96 ± 8	63
CH_3O-NO	174.9 ± 3.8	9,11
C_2H_5O-NO	175.7 ± 5.4	8,11
CH_3COO_2-NO_2	118.8 ± 3.0	17
n-C_3H_7O-NO	167.8 ± 7.5	11
i-C_3H_7O-NO	171.5 ± 5.4	7,11
n-C_4H_9O-NO	177.8 ± 6.3	11
i-C_4H_9O-NO	175.7 ± 6.3	11
s-C_4H_9O-NO	173.6 ± 3.3	5,11
t-C_4H_9O-NO	171.1 ± 3.3	6,11
HO-$NCHCH_3$	207.9	13
Cl-NF_2	~134	1,75
I-NO	77.8 ± 0.4	42
I-NO_2	76.6 ± 4	98
HO-OH	213 ± 4	63
HO-$OCH_2C(CH_3)_3$	193.7 ± 7.9	63
CH_3O-OCH_3	157.3 ± 8	63
C_2H_5O-OC_2H_5	158.6 ± 4	63
n-C_3H_7O-On-C_3H_7	155.2 ± 4	63
i-C_3H_7O-Oi-C_3H_7	157.7 ± 4	63
s-C_4H_9O-Os-C_4H_9	152.3 ± 4	63
t-C_4H_9O-Ot-C_4H_9	159.0 ± 4	63
$C_2H_5C(CH_3)_2O$-$OC(CH_3)_2C_2H_5$	164.4 ± 4	63
$(CH_3)_3CCH_2O$-$OCH_2C(CH_3)_3$	152.3 ± 4	63
CF_3O-OCF_3	193.3	63
$(CF_3)_3CO$-$OC(CF_3)_3$	148.5 ± 4.6	63
t-C_4H_9O-$OSi(CH_3)_3$	197	63
SF_5O-OSF_5	155.6	63

Table 3
BOND STRENGTHS IN POLYATOMIC MOLECULES (continued)

Bond	$D°_{298}$/kJ mol^{-1}	Ref.	Bond	$D°_{298}$/kJ mol^{-1}	Ref.
t-C_4H_9O-$OGe(C_2H_5)_3$	192	63	O=PF_3	544 ± 21	52
t-C_4H_9O-$OSn(C_2H_5)_3$	192	63	O=PCl_3	510 ± 21	52
$FClO_2$-O	244.3	13	O=PBr_3	498 ± 21	52
CF_3O-O_2CF_3	126.8 ± 8	63	HO-$Si(CH_3)_3$	536	63
SF_5O-O_2SF_5	126.8	63	HS-SH	276 ± 8	63
CH_3CO_2-O_2CCH_3	127.2 ± 8	63	CH_3S-SCH_3	272.8 ± 3.8	65
$C_2H_5CO_2$-$O_2CC_2H_5$	127.2 ± 8	63	F-SF_5	420 ± 10	94
n-$C_3H_7CO_2$-O_2Cn-C_3H_7	127.2 ± 8	63	I-SH	206.7 ± 8	63
O-SO	552 ± 8	29	I-SO	180	63
F-OCF_3	182.0 ± 2.1	28	I-SCH_3	206.3 ± 7.1	87
HO-Cl	251 ± 13	52	I-$Si(CH_3)_3$	322	99
O-ClO	247 ± 13	29	H_3Si-SiH_3	310	63,99
HO-Br	234 ± 13	52	$(CH_3)_3Si$-$Si(CH_3)_3$	336.8	63,99
HO-I	234 ± 13	52	$(C_6H_5)_3Si$-$Si(C_6H_5)_3$	368 ± 29	63,99

REFERENCES

1. A value calculated from one of the thermochemical equations above, taking enthalpy data fro atoms from Table 2 and for radicals from Table 4.
2. Ahonkhai, S. I. and Whittle, E., *Int. J. Chem. Kinet.*, 16, 543, 1984.
3. Asher, R. L. and Ruscic, B., *J. Chem. Phys.*, 106, 210, 1997.
4. Baldwin, D. P., Buntine, M. A., and Chandler, D.W., *J. Chem. Phys.*, 93, 6578, 1990.
5. Batt, L. and McCulloch, R. D., *Int. J. Chem. Kinet.*, 8, 911, 1976.
6. Batt, L. and Milne, R. T. , *Int. J. Chem. Kinet.*, 8, 59, 1976.
7. Batt, L. and Milne, R. T. , *Int. J. Chem. Kinet.*, 9, 141, 1977.
8. Batt, L. and Milne, R. T. , *Int. J. Chem. Kinet.*, 9, 549, 1977.
9. Batt, L. and Milne, R. T., and McCulloch, R. D., *Int. J. Chem. Kinet.*, 9, 567, 1977.
10. Batt, L. and Walsh, R., *Int. J. Chem. Kinet.*, 15, 605, 1983.
11. Batt, L., Christie, K., Milne, R. T., and Summers, A. J., *Int. J. Chem. Kinet.*, 6, 877, 1974.
12. Baulch, D. L., Bowman, C. T., Cobos, C. J., Cox, R. A., Just, Th., Kerr, J. A., Pilling, M. J., Stocker, D., Troe, J., Tsang, W., Walker, R. W., and Warnatz, J., *J. Phys. Chem. Ref. Data*, in press.
13. Benson, S. W. and O'Neal, H. E., *Kinetic data on Gas Phase Unimolecular Reactions*, National Bureau of Standards, NSRDS-NBS, Washington, D. C., 21, 1970.
14. Benson, S. W., *J. Chem. Educ.*, 42, 502, 1965.
15. Benson, S. W., *Thermochemical Kinetics, 2nd ed.*, John Wiley & Sons, New York, 1976.
16. Berkowitz, J., Ellison, G. B., and Gutman, D., *J. Phys. Chem.*, 98, 2744, 1994.
17. Bridier, I., Caralp, F., Loirat, H., Lesclaux, R., Veyret, B., Becker, K. H., Reimer, A., and Zabel, F., *J. Phys. Chem.*, 95, 3594, 1991.
18. Buckley, T. J., Johnson, R. D., Huie, R. E., Zhang, Z., Kuo, S. C., and Klemm, B., *J. Phys. Chem.*, 99, 4879, 1995
19. Burkey, T. J., Majewski, M., and Griller, D., *J. Am. Chem. Soc.*, 108, 2218, 1986.
20. Cao, J. R., Zhang, J. M., Zhong, X., Huang, Y. H., Fang, W. Q., Wu, X. J., and Zhu, Q. H., *Chem. Phys.*, 138, 377, 1989.
21. Carmichael, P. J., Gowenlock, B. G., and Johnson, C. A. F., *J. Chem. Soc. Perkin Trans. 2*, 1853, 1973.
22. Castelhano, A. L. and Griller, D., *J. Am. Chem. Soc.*, 104, 3655, 1982.
23. Chuang, M.-C., Foltz, M. F., and Moore, C. B., *J. Chem. Phys.*, 87, 3855, 1987.
24. Chupka, W. A. and Liftshitz, C., *J. Chem. Phys.*, 48, 1109, 1968.
25. Clyne, M. A. A. and Connor, J., *J. Chem. Soc. Faraday Trans. 1*, 68, 1220, 1972.
26. Colussi, A. J., Zabel, F., and Benson, S. W., *Int. J. Chem. Kinet.*, 9, 161, 1977.
27. Coomber, J. W. and Whittle, E., *Trans. Faraday Soc.*, 63, 2656, 1967.
28. Czarnarski, J., Castellano, E., and Schumacher, H. J., *Chem. Comm.*, p. 1255, 1968.
29. Darwent, D. deB., *Bond Dissociation Energies in Simple Molecules*, National Bureau of Standards, NSRDS-NBS, 31 Washington, D. C., 1970.
30. Davis, D. D. and Okabe, H., *J. Chem. Phys.*, 49, 5526, 1968.
31. Davis, H. F., Kim, B., Johnston, H. S., and Lee, Y. T., *J. Chem. Phys.*, 97, 2172, 1993.
32. Dixon, R. N., *J. Chem. Phys.*, 104, 6905, 1996.
33. Dobychin, S. L., Mashendzhinov, V. I., Mishin, V. I., Semenov, V. N., and Shpak, V. S., *Doklady Akademii Nauk SSSR*, 312, 1166 1991.
34. Doncaster, A. M. and Walsh, R., *J. Phys. Chem.*, 83, 578, 1979.
35. Ellison, G. B., Davico, G. E., Bierbaum, V. M., and DePuy, C. H., *Int. J. Mass Spectrom. Ion Proc.*, 156, 109, 1997.

Table 3
BOND STRENGTHS IN POLYATOMIC MOLECULES (continued)

36. Ellul, E., Potzinger, P., Reimann, B., and Camilleri, P., *Ber. Bunsenges. Phys. Chem.*, 85, 407, 1981.
37. Ervin, K. M., Gronert, S., Barlow, S. E., Gilles, M. K., Harrison, A. G., Bierbaum, V. M., DePuy, C. H., Lineberger, W. C., and Ellison, G. B., *J. Am. Chem. Soc.*, 112, 5750, 1990.
38. Evans, B. S., Weeks, I., and Whittle, E., *J. Chem. Soc. Faraday Trans. 1*, 79, 1471, 1983.
39. Ferguson, K. C., Okafo, E. N., and Whittle, E., *J. Chem. Soc. Faraday Trans. 1*, 69, 295, 1973.
40. Foon, R. and Tait, K. B., *J. Chem. Soc. Faraday Trans. 1*, 68, 104, 1972.
41. Foon, R. and Tait, K. B., *J. Chem. Soc. Faraday Trans. 1*, 68, 1121, 1972.
42. Forte, E., Hippler, H., and van den Bergh, H., *Int. J. Chem. Kinet.*, 13, 1227, 1981.
43. Gowenlock, B. G., Jonhson, C. A. F., Keary, C. M., and Pfaf, J., *J. Chem. Soc. Perkin Trans. 2*, 71, 351, 1975.
44. Grela, M. A. and Colussi, A. J., *Int. J. Chem. Kinet.*, 20, 713, 1988.
45. Griller, D. and Wayner, D. D. M., *Pure Appl. Chem.*, 61, 717, 1989.
46. Heckmann, E., Hippler, H., and Troe, J., *26th Symp. (Int.) Combust.*, Combustion Institute, Pittsburgh, Pennsylvania, pp 543, 1996.
47. Heneghan, S. P. and Benson, S. W., *Int. J. Chem. Kinet.*, 15, 815, 1983.
48. Hudgens, J. W., Johnson, R. D., Timonen, R. S., Seetula, J. A., and Gutman, D., *J. Phys. Chem.*, 95, 4400, 1991.
49. Jefferson, A., Nicovich, J. M., and Wine, P. H., *J. Phys. Chem.*, 98, 7128, 1994.
50. Johnson, R. D. and Hudgens, J. W., *J. Phys Chem.*, 100, 19874, 1996.
51. Kerr, J. A. and Timlin, D. M., *Int. J. Chem. Kinet.*, 3, 427, 1971.
52. Kerr, J. A., *Chem. Rev.*, 66, 465, 1966.
53. Knyazev, V. D. and Slagle, I. R., *J. Phys. Chem.*, 102, 1770, 1998.
54. Kominar, R. J., Krech, M. J., and Price, S. J. W., *Can. J. Chem.*, 58, 1906, 1980.
55. Kondo, O. and Benson, S. W., *Int. J. Chem. Kinet.*, 16, 949, 1984.
56. Kondo, O. and Benson, S. W., *J. Phys. Chem.*, 88, 6675, 1984.
57. Kreutter, K. D., Nicovich, J. M., and Wine, P. H., *J. Phys. Chem.*, 95, 4020, 1991.
58. Laufer, A. H. and Okabe, H., *J. Am. Chem. Soc.*, 93, 4137,1971.
59. Lewis, K. E. and Smith, G. P., *J. Am. Chem. Soc.*, 106, 4650, 1984.
60. Lewis, K. E., Golden, D. M., and Smith, G. P., *J. Am. Chem. Soc.*, 106, 3905, 1984.
61. Lias, S. G., Bartmess, J. E., Liebman, J. F., Holmes, J. L., Levin, R. D., and Mallard, W. G., *J. Phys. Chem. Ref. Data 17*, Suppl. 1, 1988.
62. Lightfoot, P. D., Cox, R. A., Crowley, J. N., Destriau, M., Hayman G. D., Jenkin, M. E., Mootrgat, G. K., and Zabel, F., *Atmos. Environ.*, 26A, 1805, 1992.
63. McMillen, D. F. and Golden, D. M., *Ann. Rev. Phys. Chem.*, 33, 493, 1982.
64. Miyokawa, K. and Tschuikow-Roux, E., *J. Phys. Chem.*, 96, 7328, 1992.
65. Nicovich, J. M., Kreutter, K. D., van Dijk, C. A., and Wine, P. H., *J. Phys. Chem.*, 96, 2518, 1992.
66. Nicovich, J. M., Wang, S., McKee, M. L., and Wine, P. H., *J. Phys. Chem.*, 100, 680, 1996.
67. Niiranen, J. T., Gutman, D., and Krasnoperov, L. N., *J. Phys. Chem.*, 96, 5881, 1992.
68. Noble, P. N. and Walsh, R., *Int. J. Chem. Kinet.*, 15, 561, 1983.
69. O'Neal, H. E., Bagg, J. W., and Richardson, W. H., *Int. J. Chem. Kinet.*, 2, 493, 1970.
70. Okabe, H. and Dibeler, V. H., *J. Chem. Phys.*, 59, 2430, 1973.
71. Okabe, H., *J. Chem. Phys.*, 66, 2058, 1977.
72. Okafo, E. N. and Whittle, E., *Int. J. Chem. Kinet.*, 7, 287, 1975.
73. Paul, S. and Back, M. H., *Can J. Chem.*, 53, 3330, 1975.
74. Pedley, J. B. and Rylance, J., "Sussex - N.P.L. Computer Analysed Thermochemical Data; Organic and Organometallic Compounds", University of Sussex, 1977.
75. Petry, R. C., *J. Am. Chem. Soc.*, 89, 4600, 1967.
76. Pickard, J. M. and Rodgers, A. S., *Int. J. Chem. Kinet.*, 9, 759, 1977.
77. Pickard, J. M. and Rodgers, A. S., *Int. J. Chem. Kinet.*, 15, 569, 1983.
78. Price, S. J. W. and Sapiano, H. J., *Can. J. Chem.*, 57, 1468, 1979.
79. Rogers, A. S. and Ford, W. G. F., *Int. J. Chem. Kinet.*, 5, 965, 1973.
80. Rossi, M., McMillen, D. F., and Golden, D. M., *J. Phys. Chem.*, 88, 5031, 1984.
81. Russell, J. J., Senkan, S. M., Seetula, J. A., and Gutman, D., *J. Phys. Chem.*, 93, 5184, 1989.
82. Seetula, J. A., and Slagle, I. R., *J. Chem. Soc. Faraday Trans.*, 93, 1709, 1997.
83. Seetula, J. A., Feng, Y., Gutman, D., Seakins, P. W., and Pilling, M. J., *J. Phys. Chem.*, 95, 1658, 1991.
84. Seetula, J. A., *J. Chem. Soc. Faraday Trans.*, 92, 3069, 1996.
85. Seetula, J. A., *J. Chem. Soc. Faraday Trans.*, 94, 891, 1998.
86. Seetula, J. A., Russell, J. J., and Gutman, D., *J. Am. Chem. Soc.*, 112, 1347, 1990.
87. Shum, L. G. S. and Benson, S. W., *Int. J. Chem.*, 15, 433, 1983.
88. Shum, L. G. S. and Benson, S. W., *J. Phys. Chem.*, 87, 3479, 1983.
89. Stein, S. E., SRD Thermochemical Database, 25. N.I.S.T. Structures and Properties Database and Estimation Program, U.S. Department of Commerce, 1992.

Table 3
BOND STRENGTHS IN POLYATOMIC MOLECULES (continued)

90. Steinkruger, F. J. and Rowland, F. S., *J. Phys. Chem.*, 85, 136, 1981.
91. Trenwith, A. B. and Wrigley, S. P., *J. Chem. Soc. Faraday Trans. 1*, 73, 817, 1977.
92. Trenwith, A. B., *J. Chem. Soc. Faraday Trans. 1*, 78, 3131, 1982.
93. Trenwith, A. B., *J. Chem. Soc. Faraday Trans. 1*, 79, 2755, 1983.
94. Tsang, W. and Herron, J. T., *J. Chem. Phys.*, 96, 4272, 1992.
95. Tsang, W., *Int. J. Chem. Kinet.*, 5, 929, 1973.
96. Tsang, W., *Int. J. Chem. Kinet.*, 10, 1119, 1978.
97. Tschuikow-Roux, E. and Paddison, S., *Int. J. Chem. Kinet.*, 19, 15, 1987.
98. van den Bergh, H. and Troe, J., *J. Chem. Phys.*, 64, 736, 1976.
99. Walsh, R., *Acc. Chem. Res.*, 14, 246, 1981.
100. White, J. N. and Gardiner, W. C., *Chem. Phys. Lett.*, 58, 470, 1978.
101. Zabel, F., Benson, S. W., and Golden, D. M., *Int. J. Chem. Kinet.*, 10, 295, 1978.
102. Zhao, H.-Q., Cheung, Y.-S., Liao, C.-L., Liao, C.-X., Ng, C. Y., and Li, W.-K., *J. Chem. Phys.*, 107, 7230, 1997.
103. Zmbov, K. F., Uy, O. M., and Margrave, J. L., *J. Am. Chem. Soc.*, 90, 5090, 1968.

Table 4
ENTHALPIES OF FORMATION OF FREE RADICALS

The enthalpies of formation of the free radicals are related to the corresponding bond strengths by the equations

$$D°(\text{R-X}) = \Delta_f H°(\text{R}) + \Delta_f H°(\text{X}) - \Delta_f H°(\text{RX})$$

or

$$D°(\text{R-R}) = 2\Delta_f H°(\text{R}) - \Delta_f H°(\text{RR})$$

For an excellent review of the methods of determining the enthalpies of formation of free radicals the reader is referred to "Thermochemistry of Free Radicals" by H. E. O'Neal and S. W. Benson in *Free Radicals*, Kochi, J. K., Ed., John Wiley & Sons, New York, 1973, 275 and the article by J. Berkowitz, G. B. Ellison, and D. Gutman, *J. Phys. Chem.*, 98, 2744, 1994.

Radical	$\Delta_f H°_{298}$/kJ mol^{-1}	Ref.
CH	596.4 ± 1.2	6
CH_2(triplet)	390.4 ± 4	15,34
CH_2(singlet)	428.3 ± 4	15
CH_3	146.4 ± 0.4	10
CH≡C	566.1 ± 2.9	5,27
CH_2=CH	300.0 ± 3.4	27,64
C_2H_5	120.9 ± 1.6	10
Cycloprop-2-en-1-yl	439.7 ± 17.2	48
CH≡CCH_2	340.6 ± 8.4	48
CH_2=$CHCH_2$	170.7 ± 8.8	10,26
CH_3CH=CH	262.7	77
Cyclopropyl	279.9 ± 1.1	48
n-C_3H_7	100.8 ± 2.1	65
i-C_3H_7	86.6 ± 2.0	65
CH_3C≡CCH_2	293.7	48
CH_2=$CHCHCH_3$	125.5 ± 6.3	48
CH≡$CCHCH_3$	295.0 ± 9.2	48
Cyclobutyl	214.2 ± 4.2	48
Cyclopropylmethyl	213.8 ± 6.7	48
CH_2=C(CH_3)CH_2	127.2 ± 5.4	48
CH_3CH=$CHCH_2$	125.5 ± 6.3	48
n-C_4H_9	80.9 ± 2.2	65
i-C_4H_9	72.7 ± 2.2	65
s-C_4H_9	66.7 ± 2.1	65
t-C_4H_9	51.8 ± 1.3	65
Cyclopenta-1,3-dien-5-yl	263.0	8
Spiropentyl	380.7 ± 4	48
Cyclopent-1-en-3-yl	160.7 ± 4	48
CH_2=CHCH=$CHCH_2$	205 ± 13	48
$(C_2H_3)_2$CH	205 ± 13	48
CH_3C≡$CCHCH_3$	272.8 ± 9.6	48
CH≡C$C(CH_3)_2$	257.3 ± 8.4	48
CH_2=CH$C(CH_3)_2$	77.4 ± 6.3	48
Cyclopentyl	107.1 ± 2.5	17
$(CH_3)_3CCH_2$	36.4 ± 8	48
$C_2H_5C(CH_3)_2$	32.2 ± 6.3	71
C_6H_5	338 ± 3	35
Cyclohexa-1,3-dien-5-yl	197 ± 21	48
Cyclohexyl	58.2 ± 4	48
CH_3C≡C$C(CH_3)_2$	221.8 ± 9.6	48
$(CH_3)_2$C=C(CH_3)CH_2	39.8 ± 6.3	48
CH_2=C(CH_3)$C(CH_3)_2$	37.7 ± 6.3	48
$C_6H_5CH_2$	208.0 ± 2.5	26
Cyclohepta-1,3,5-trien-7-yl	271.1 ± 8	48
$CH_3CH_2CH_2C(CH_3)_2$	3.4 ± 8.4	69
Norbornyl	136.4 ± 10.5	48
Cycloheptyl	51.1 ± 4	48
$C_6H_5CHCH_3$	169.0	48
$C_6H_5C(CH_3)_2$	134.7	48
1-Naphthylmethyl	252.7	48
$(C_6H_5)_2$CH	289	63
9,10-Dihydroanthracen-9-yl	256.9 ± 6.3	48

Table 4
ENTHALPIES OF FORMATION OF FREE RADICALS (continued)

Radical	$\Delta_f H^\circ_{298}$/kJ mol^{-1}	Ref.
9-Anthracenylmethyl	337.6	48
9-Phenanthrenylmethyl	311.3	48
CH_2CN	243.1 ± 11.3	10
CH_2NC	326.4 ± 11.3	10
CH_3CHCN	209.2 ± 9.6	48
$(CH_3)_2CCN$	166.5 ± 8.4	48
$C_6H_5C(CH_3)CN$	248.5	48
CH_2NH_2	149.4 ± 8	48
CH_3NHCH_2	126 ± 8	48
$(CH_3)_2NCH_2$	109 ± 8	48
CN	441.4 ± 4.6	10
CHN_2	494.42	30
CHO	43.1	9,22
CHCO	175.3 ± 8.4	10
CH_3CO	-10.0 ± 1.2	56
$CH_2{=}CHCO$	72.4	48
C_2H_5CO	-32.3	8
C_6H_5CO	123.0 ± 9.6	78
CH_2CHO	10.5 ± 9.2	10
CH_3COCH_2	-23.9 ± 10.9	48
$CH_3COCHCH_3$	-70.3 ± 7.1	48
CH_3OCH_2	-0.1	8
$C_2H_5OCHCH_3$	-84.5	42
Tetrahydrofuran-2-yl	-18.0 ± 6.3	48
CH_2OH	-17.8 ± 1.3	39
CH_2CH_2OH	-36.0	31
$CH{=}CHOH$	113.0	31
CH_3CHOH	-51.6	8
$CH_2{=}CHCHOH$	0.0	48
$(CH_3)_2COH$	-111.3 ± 4.6	48
COOH	-217 ± 10	32
$COOCH_3$	-169.0 ± 4	48
$C_6H_5COOCH_2$	-69.9 ± 8.4	48
CF	261.5 ± 4.6	3
CHF	143.1 ± 12.6	61
CH_2F	-31.8 ± 8.4	59
FCO	-152.1 ± 12	14
CHF_2	-238.9 ± 4	59
CF_2	-184.1 ± 8.4	61
CF_3	-466.1 ± 3.8	3
CHCl	336.4 ± 11.7	61
CH_2Cl	117.3 ± 3.1	67
CFCl	31.0 ± 13.4	61
CHFCl	-60.7 ± 10.0	73
CF_2Cl	-279.1 ± 8.3	49
ClCO	-21.8	55
$CHCl_2$	89.0 ± 3.0	67
$CFCl_2$	-89.1 ± 10.0	73
CCl_2	230.1 ± 8.4	61
CCl_3	71.1 ± 2.5	37
CH_2Br	169.0 ± 4.2	73
$CHBr_2$	188.3 ± 9.2	73
CBr_3	207.1 ± 8	73
CH_2I	230.1 ± 6.7	48
CHI_2	333.9 ± 9.2	48
CH_3CF_2	-302.5 ± 8	48
CF_3CH_2	-517.1 ± 5.0	48
C_2F_5	-892.9 ± 4	48
$CCl{=}CH_2$	>251	64
CH_3CHCl	76.5 ± 1.6	67
CH_3CCl_2	48.4 ± 7.6	40,67
CH_2CH_2Cl	93.0 ± 3.4	68
$CHCl_2CCl_2$	23.4 ± 8	48
CF_2ClCF_2	-686 ± 17	48
C_2Cl_5	33.5 ± 5.4	54
C_6F_5	-547.7 ± 8	48
$(CH_3)_3SiCH_2$	-34.7	48
CS	278.5 ± 3.8	62
HCS	300.4 ± 8.4	10
CH_2SH	151.9 ± 8.4	10
CH_3SCH_2	136.8 ± 5.9	38
NH	352.3 ± 9.6	60
NH_2	188.7 ± 1.3	10
HNO	112.9	25
NF_2	34 ± 4	48
N_2H_3	243.5	33
N_3	469 ± 21	48
CH_2NH	104.6 ± 13	33
CH_3NH	177.4 ± 8	48
$(CH_3)_2N$	145.2 ± 8	48
C_6H_5NH	237.2 ± 8	48
$C_6H_5NCH_3$	233.5 ± 8	48
NCO	127.0	13,79
CNO	407.01	41
CH_3N_2	215.5 ± 7.5	2
$C_2H_5N_2$	187.4 ± 10.5	2
i-$C_3H_7N_2$	158.6 ± 9.2	2
OH	39.3	48
CH_3O	17.2 ± 3.8	10
C_2H_5O	-15.5 ± 3.4	10
n-C_3H_7O	-41.4	48
i-C_3H_7O	-52.3	48
n-C_4H_9O	-62.8	48
s-C_4H_9O	-69.5 ± 3.3	48
t-C_4H_9O	-90.8	48
C_6H_5O	47.7	48
CF_3O	-655.6	7
FO	109 ± 10	21
ClO	101.63 ± 0.1	1
BrO	125.8 ± 2.4	19
IO	126 ± 18	20
HO_2	14.6	70
CH_3O_2	9.0 ± 5.1	40
$C_2H_5O_2$	-27.4 ± 9.9	40
$CH_2{=}CHCH_2O_2$	87.9 ± 5.5	43
i-$C_3H_7O_2$	-68.8 ± 11.3	16,40
t-$C_4H_9O_2$	-101.0 ± 9.2	40
$HOCH_2O_2$	-162.1 ± 2.1	43
CF_3O_2	-614.0	43
CF_2ClO_2	-406.5	43
$CFCl_2O_2$	-213.7	43
CH_2ClO_2	-5.1 ± 13.6	40

Table 4
ENTHALPIES OF FORMATION OF FREE RADICALS (continued)

Radical	$\Delta_f H^\circ_{298}$/kJ mol^{-1}	Ref.	Radical	$\Delta_f H^\circ_{298}$/kJ mol^{-1}	Ref.
$CHCl_2O_2$	-19.2 ± 11.2	40	SiF_3	-1025	48,76
CCl_3O_2	-20.9 ± 8.9	40	SiCl	195.8	48,76
CH_3CHClO_2	-54.7 ± 3.4	40	$SiCl_2$	-163.6	48,76
$CH_3CCl_2O_2$	-63.8 ± 9.8	40	$SiCl_3$	-318	48,76
CH_3CO_2	-207.5 ± 4	48	SiH_3SiH	269.9 ± 14.6	74
CH_3COO_2	-172 ± 20	12	Si_2H_5	223.0	48,76
$C_2H_5CO_2$	-228.5 ± 4	48	PH_2	138.5 ± 2.5	10
n-$C_3H_7CO_2$	-249.4 ± 4	48	HS	143.0 ± 2.8	53
FO_2	26.1	45,58	CH_3S	124.6 ± 1.8	53
ClO_2	97.5	4,52	C_6H_5S	229.7 ± 8	48
OClO	95.6	28,51	SO	5.0	18
NO_3	73.7 ± 1.4	24	HSO	-4	44
sym-ClO_3	232.6	23	HSO_2	-222	11
SiH	377	48,76	CH_3SO_2	-239.3	57
SiH_2	269.0 ± 1.3	29,47	$HOSO_2$	-385	46
SiH_3	200.5 ± 2.5	66	SO_3	-395.7	75
CH_3Si	310	76	SF_4	-746 ± 12	72
CH_3SiH	213.0 ± 14.6	74	SF_5	-879.9 ± 20	72
CH_3SiH_2	152.7	48,76	CH_3S_2	68.6 ± 8	36
$(CH_3)_2Si$	109	76	$C_2H_5S_2$	43.5 ± 8	36
$(CH_3)_2SiH$	59.8	48,76	i-$C_3H_7S_2$	13.8 ± 8	36
$(CH_3)_3Si$	-3.3	48,76	t-$C_4H_9S_2$	-19.3 ± 8	36
$C_6H_5Si(CH_3)_2$	163	57	$HOCS_2$	110.5	50
$(C_6H_5)_2SiCH_3$	326	57	GeH_3	222 ± 8	10
$(C_6H_5)_3Si$	486.2	57	AsH_2	167.8 ± 1.3	10
SiF	-19.3	48,76	HSe	144.8 ± 2.1	10
SiF_2	-587.9	48,76	SbH_2	215.5 ± 2.5	10
			HTe	158.6 ± 5.0	10

REFERENCES

1. Abramowitz, S. and Chase, M. W., *Pure Appl. Chem.*, 63, 1448, 1991.
2. Acs, G. and Peter, A., *Int. J. Chem. Kinet.*, 19, 929, 1987.
3. Asher, R. L. and Ruscic, B., *J. Chem. Phys.*, 106, 210, 1997.
4. Baer, S., Hippler, H., Rabu, R., Siefke, M., Seitzinger, N., and Troe, J., *J. Chem. Phys.*, 95, 6463, 1991.
5. Baldwin, D. P., Buntine, M. A., and Chandler, D. W., *J. Chem. Phys.*, 93, 6578, 1990.
6. Based on $D°$(C-H), see Table 1 and $\Delta_f H°$(C) and $D_f H°$(H), see Table 2.
7. Batt, L. and Walsh, R., Int. J. Chem. Kinet., 14, 933, 1982.
8. Baulch, D. L., Bowman, C. T., Cobos, C. J., Cox, R. A., Just, Th., Kerr, J. A., Pilling, M. J., Stocker, D., Troe, J., Tsang, W., Walker, R. W., and Warnatz, J., *J. Phys. Chem. Ref. Data,* in press.
9. Becerra,R., Carpenter, I. W., and Walsh, R., *J. Phys. Chem.,* A 101, 4185, 1997.
10. Berkowitz, J., Ellison, G. B., and Gutman, D., *J. Phys. Chem.,* 98, 2744, 1994.
11. Boyd, R. J., Gupta, A., Langler, R. F., Lownie, S. P., and Pincock, J. A., *Can. J. Chem.,* 58, 331, 1980.
12. Bridier, I., Caralp, F., Loirat, H., Lesclaux, R., Veyret, B., Becker, K. H., Reimer, A., and Zabel, F., *J. Phys. Chem.*, 95, 3594, 1991.
13. Brown, S. S., Berghout, H. L., and Crim, F. F., *J. Chem. Phys.,* 105, 8103, 1996.
14. Buckley, T. J., Johnson, R. D., Huie, R. E., Zhang, Z., Kuo, S. C., and Klemm, B., *J. Phys. Chem.*, 99, 4879, 1995.
15. Bunker, P. R. and Sears, T. J., *J. Chem. Phys.*, 83, 4866, 1985.
16. Calculated taking $\Delta_f H°$(i-C_3H_7) = 86.6 kJ mol^{-1}.
17. Castelhano, A. L. and Griller, D., *J. Am. Chem. Soc.*, 104, 3655, 1982; value adjusted to $\Delta_f H°(CH_3)$ = 146 kJ mol^{-1} and error limits assigned here.
18. Chase, M. W. Jr., Davies, C. A., Downey, J.R. Jr., Frurip, D. J., McDonald, R. A., and Syverud, A. N., *J. Phys. Chem. Ref. Data,* 14, Suppl. 1, 1985.
19. Chase, M. W., *J. Phys. Chem. Ref. Data,* 25, 1069, 1996.
20. Chase, M. W., *J. Phys. Chem. Ref. Data,* 25, 1297, 1996.
21. Chase, M. W., *J. Phys. Chem. Ref. Data,* 25, 551, 1996.
22. Chuang, M.-C., Foltz, M. F., and Moore, C. B., *J. Chem. Phys.,* 87, 3855, 1987.
23. Colussi, A. J., *J. Phys. Chem.,* 94, 8922, 1990.
24. Davis, H. F., Kim, B., Johnston, H. S., and Lee, Y. T., *J. Phys. Chem.,* 97, 2172, 1993.

Table 4
ENTHALPIES OF FORMATION OF FREE RADICALS (continued)

25. Dixon, R. N., *J. Chem. Phys.*, 104, 6905, 1996.
26. Ellison, G. B., Davico, G. E., Bierbaum, V. M., and DePuy, C. H., *Int. J. Mass Spectrom. Ion Proc.*, 156, 109, 1996.
27. Ervin, K. M., Gronert, S., Barlow, S. E., Gilles, M. K., Harrison, A. G., Bierbaum, V. M., DePuy, C. H., Lineberger, W. C., and Ellison, G. B., *J. Am. Chem. Soc.*, 112, 5750, 1990.
28. Flesch, R., E. Rühl, K. Hottmann, and H. Baumgartel, *J. Phys. Chem.*, 97, 837 (1993).
29. Frey, H. M., Walsh, R., and Watts, I. M., *J. Chem. Soc. Chem. Comm.*, 1189, 1986.
30. Fulle, D. and Hippler, H., *J. Chem. Phys.*, 105, 5423, 1996.
31. Fulle, D., Hamann, H. F., Hippler, H., and Jansch, C. P., *Ber. Bunsenges. Phys. Chem.*, 101, 1433, 1997.
32. Fulle, D., Hamann, H. F., Hippler, H., and Troe, *J. Chem. Phys.*, 105, 983, 1996.
33. Grela, M. A. and Colussi, A. J., *Int. J. Chem. Kinet.*, 20, 713, 1988.
34. Gurvich, l.V., Veyts, I.V., Alcock, C.B., *Thermodynamic Properties of Individual Substances, 4th ed.*, Hemisphere, New York, 1991, Vol. 2.
35. Heckmann, E., Hippler, H., and Troe, J., *26th Symp. (Int.) Combust.*, The Combustion Institute, Pittsburgh, Pennsylvania, pp 543, 1996.
36. Howari, J. A. Griller, D., and Lossing, F. P., *J. Am. Chem. Soc.*, 108, 3273, 1986.
37. Hudgens, J. W., Johnson, R. D., Timonen, R. S., Seetula, J. A., and Gutman, D., *J. Phys. Chem.*, 95, 4400, 1991.
38. Jefferson, A., Nicovich, J. M., and Wine, P. H., *J. Phys. Chem.*, 98, 7128, 1994.
39. Johnson, R. D. and Hudgens, J. W., *J. Phys. Chem.*, 100, 19874, 1996.
40. Knyazev, V. D., and Slagle, I. R., *J. Phys. Chem.*, 102, 1770, 1998.
41. Koch, W. and Frenking, G., *J. Phys. Chem.*, 91, 49, 1987.
42. Kondo, O. and Benson, S. W., *Int. J. Chem. Kinet.*, 16, 949, 1984.
43. Lightfoot, P. D., Cox, R. A., Crowley, J. N., Destriau, M., Hayman, G.D., Jenkin, M. E., Moortgat, G. K., and Zabel, F., *Atmos Environ.*, 26A, 1805, 1992.
44. Lovejoy, E. R., Wang, N. S., and Howard, C. J., *J. Phys. Chem.*, 91, 5749, 1987.
45. Lyman, J. L. and Holland, R., *J. Phys. Chem.*, 92, 7232, 1988.
46. Margitan, J. J., *J. Phys. Chem.*, 88, 3314, 1984.
47. Martin, J. G., Ring, M. A., and O'Neal, H. E., *Int. J. Chem. Kinet.*, 19, 715, 1987.
48. McMillen, D. F. and Golden, D. M., *Ann. Rev. Phys. Chem.*, 33, 493, 1982.
49. Miyokawa, K. and Tschuikow-Roux, E., *J. Phys. Chem.*, 96, 7328, 1992.
50. Murrells, T. P., Lovejoy, E.R., and Ravishankara, A. R., *J. Phys. Chem.*, 80, 4065, 1984.
51. Nickolaisen, S. L., R. R. Friedl, and S. P. Sander, *J. Phys. Chem.*, 98, 155 (1994).
52. Nicovich, J. M., Kreutter, K. D., Shockelford, C. J., and Wine, P. H., *Chem. Phys. Lett.*, 179, 367, 1991.
53. Nicovich, J. M., Kreutter, K. D., van Dijk, C. A., and Wine, P. H., *J. Phys. Chem.*, 96, 2518, 1992.
54. Nicovich, J. M., Wang, S., McKee, M. L., and Wine, P. H., *J. Phys. Chem.*, 100, 680, 1996.
55. Nicovich, J.M., Kreutter, K. D., and Wine, P.H., *J. Chem. Phys.*, 92, 3539 (1990).
56. Niiranen, J. T., Gutman, D., and Krasnoperov, L. N., *J. Phys. Chem.*, 96, 5881, 1992.
57. O'Neal, H. E. and Benson, S. W., in *Free Radicals*, Kochi, J. K., Ed., John Wiley & Sons, New York, 1973, 275.
58. Pagsberg, P., Ratajczak, E., Sillesen, A., and Jodkowski, J. T., *Chem. Phys. Lett.*, 141, 88, 1987.
59. Pickard, J. M. and Rodgers, A. S., *Int. J. Chem. Kinet.*, 15, 569, 1983.
60. Piper, L. G., *J. Chem. Phys.*, 70, 3417, 1979.
61. Poutsma, J. C., Paulino, J. A., and Squires, R. R., *J. Phys. Chem. A*, 101, 5327, 1997.
62. Prinslow, D. A. and Armentrout, P. B., *J. Chem. Phys.*, 94, 3563, 1991.
63. Rossi, M., McMillen, D. F., and Golden, D. M., *J. Phys. Chem.*, 88, 5031, 1984.
64. Russell, J. R., Senkan, S. M., Seetula, J. A., and Gutman, D., *J. Phys. Chem.*, 93, 5184, 1989.
65. Seetula, J. A. and Slagle I. R., *J. Chem. Soc. Faraday Trans.*, 93, 1709, 1997.
66. Seetula, J. A., Feng, Y., Gutman, D., Seakins, P. W., and Pilling, M. J., *J. Phys. Chem.*, 95, 1658, 1991.
67. Seetula, J. A., *J. Chem. Soc. Faraday Trans.*, 92, 3069, 1996.
68. Seetula, J. A., *J. Chem. Soc. Faraday Trans.*, 94, 891, 1998.
69. Seres, L., Gorgenyi, M., and Farkas, J., *Int. J. Chem. Kinet.*, 15, 1133, 1983.
70. Shum, L. G. S. and Benson, S. W., *J. Phys. Chem.*, 87, 3479, 1983.
71. Stein, S. E., SRD Thermochemical Database, 25. N.I.S.T. Structures and Properties Database and Estimation Program, U.S. Department of Commerce, 1992.
72. Tsang, W. and Herron, J. T., *J. Chem. Phys.*, 96, 4272, 1992.
73. Tschuikow-Roux, E. and Paddison, S., *Int. J. Chem. Kinet.*, 19, 15, 1987.
74. Vanderwielen, A. J., Ring, M. A., and O'Neal, H. E., *J. Am. Chem. Soc.*, 97, 993, 1975.
75. Wagman, D. D., Evans, W. H., Parker, V. B., Schumm, R. H., Halow, I., Bailey, S. M., Churney, K. L., and Nuttall, R.L., *J. Phys. Chem. Ref. Data*, 11, Suppl. 2, 1978.
76. Walsh, R., *Acc. Chem. Res.*, 14, 246, 1981.
77. Wu, C. H. and Kern, R. D., *J. Phys. Chem.*, 91, 6291, 1987.
78. Zhao, H.-Q., Cheung, Y.-S., Liao, C.-L., Liao, C.-X., Ng, C. Y., and Li, W.-K., *J. Chem. Phys.*, 107, 7230, 1997.
79. Zyrianov, M., Droz-Georget, T., Sanov, A., and Reisler, H., *J. Chem. Phys.*, 105, 8111, 1996.

STRENGTHS OF CHEMICAL BONDS (continued)

Table 5
BOND STRENGTHS OF SOME ORGANIC MOLECULES

Bond strengths at 298 K expressed in kJ/mol^{-1} for some organic molecules of the general formula R-X are presented below. Some are experimental values taken from the preceding tables; the remainder are calculated from the enthalpies of formation of atoms (Table 2) and of radicals (Table 4), and the enthalpies of formation of the parent compounds from sources indicated by the references below. The table also includes bond strengths for the inorganic molecules, hydrogen, the hydrogen halides, water and ammonia.

	H	**F**	**Cl**	**Br**	**I**	**OH**	**NH_2**	**CH_3O**	**CH_3**	**CH_3CO**	**NO**	**CF_3**	**CCl_3**
H	435.990	569.87	431.62	366.35	298.407	498	453	436	439	374	195	450	393
CH_3	439	472	350[e]	293	239[e]	387[e]	358[e]	348[e]	377[e]	354[e]	167	423	362[e]
C_2H_5	423	463[d]	354[e]	295[e]	236[e]	395[e]	357[e]	355[e]	371[e]	349[e]	—	—	—
i-C_3H_7	409	460[e]	353[e]	298[e]	234[e]	399[e]	359[e]	356[e]	367[e]	339[e]	153	—	—
t-C_4H_9	404	—	355[e]	296[e]	231[e]	404[e]	362[e]	353[e]	366[e]	332[e]	165	—	—
C_6H_5	473	533[e]	407[e]	346[f]	280[e]	474[e]	439[e]	423[e]	434[e]	415[e]	213	—	—
$C_6H_5CH_2$	376	—	310[e]	256[f]	215[f]	348[e]	302[e]	—	332	297[e]	—	—	—
CCl_3	393	419[e]	288[e]	224[e]	167[e]	—	—	—	362[e]	—	134	335[b]	286[e]
CF_3	450	547[e]	362[e]	294[e]	227	—	—	—	423	—	179	413	335[b]
C_2F_5	430	531[e]	347[e]	283[e]	219	—	—	—	—	—	—	—	—
CH_3CO	374	512[e]	354[f]	292[e]	223[e]	462[e]	417[e]	421[e]	354[e]	282	—	—	—
CN	528	470	422	367	305	—	—	—	514[e]	—	121	—	—
C_6F_5	473	487[e]	383[e]	—	277[a]	499[e]	—	—	441[e]	—	208[a]	—	—

REFERENCES

[a] Choo, K. Y., Mendenhall, G. D., Golden, D.M., and Benson, S. W., *Int. J. Chem. Kinet*., 6, 813, 1974.

[b] Kolesov, V. P. and Papina, T. S., *Russ. Chem. Rev*., 52, 425, 1983.

[c] Kudchadker, S. A. and Kudchadker, A. P., *J. Phys. Chem. Ref. Data*, 1, 1285, 1978.

[d] Lias, S. G., Bartmess, J. E., Liebman, J. F., Holmes, J. L., Levin, R. D., and Mallard, W. G., *J. Phys. Chem. Ref. Data*, 17, Suppl. No. 1, 1988.

[e] Lide, D. R., Ed., *Handbook of Chemistry and Physics, 80th Edition,* CRC Press, Boca Raton, FL, 1999.

[f] Pedley, J. B. and Rylance, J., *Sussex.N.P.L. Computer Analysed Thermochemical Data: Organic and Organometallic Compounds*, University of Sussex, 1977.

ELECTRONEGATIVITY

Electronegativity is a parameter originally introduced by Pauling which describes, on a relative basis, the tendency of an atom in a molecule to attract bonding electrons. While electronegativity is not a precisely defined molecular property, the electronegativity difference between two atoms provides a useful measure of the polarity and ionic character of the bond between them. This table gives the electronegativity *X*, on the Pauling scale, for the most common oxidation state. Other scales are described in the references.

REFERENCES

1. Pauling, L., *The Nature of the Chemical Bond, Third Edition*, Cornell University Press, Ithaca, New York, 1960.
2. Allen, L.C., *J. Am. Chem. Soc.*, 111, 9003, 1989.
3. Allred, A.L., *J. Inorg. Nucl. Chem.*, 17, 215, 1961.

Z	Symbol	*X*	*Z*	Symbol	*X*	*Z*	Symbol	*X*
1	H	2.20	33	As	2.18	65	Tb	—
2	He	—	34	Se	2.55	66	Dy	1.22
3	Li	0.98	35	Br	2.96	67	Ho	1.23
4	Be	1.57	36	Kr	—	68	Er	1.24
5	B	2.04	37	Rb	0.82	69	Tm	1.25
6	C	2.55	38	Sr	0.95	70	Yb	—
7	N	3.04	39	Y	1.22	71	Lu	1.0
8	O	3.44	40	Zr	1.33	72	Hf	1.3
9	F	3.98	41	Nb	1.6	73	Ta	1.5
10	Ne	—	42	Mo	2.16	74	W	1.7
11	Na	0.93	43	Tc	2.10	75	Re	1.9
12	Mg	1.31	44	Ru	2.2	76	Os	2.2
13	Al	1.61	45	Rh	2.28	77	Ir	2.2
14	Si	1.90	46	Pd	2.20	78	Pt	2.2
15	P	2.19	47	Ag	1.93	79	Au	2.4
16	S	2.58	48	Cd	1.69	80	Hg	1.9
17	Cl	3.16	49	In	1.78	81	Tl	1.8
18	Ar	—	50	Sn	1.96	82	Pb	1.8
19	K	0.82	51	Sb	2.05	83	Bi	1.9
20	Ca	1.00	52	Te	2.1	84	Po	2.0
21	Sc	1.36	53	I	2.66	85	At	2.2
22	Ti	1.54	54	Xe	2.60	86	Rn	—
23	V	1.63	55	Cs	0.79	87	Fr	0.7
24	Cr	1.66	56	Ba	0.89	88	Ra	0.9
25	Mn	1.55	57	La	1.10	89	Ac	1.1
26	Fe	1.83	58	Ce	1.12	90	Th	1.3
27	Co	1.88	59	Pr	1.13	91	Pa	1.5
28	Ni	1.91	60	Nd	1.14	92	U	1.7
29	Cu	1.90	61	Pm	—	93	Np	1.3
30	Zn	1.65	62	Sm	1.17	94	Pu	1.3
31	Ga	1.81	63	Eu	—			
32	Ge	2.01	64	Gd	1.20			

FORCE CONSTANTS FOR BOND STRETCHING

Representative force constants (*f*) for stretching of chemical bonds are listed in this table. Except where noted, all force constants are derived from values of the harmonic vibrational frequencies ω_e. Values derived from the observed vibrational fundamentals ν, which are noted by a, are lower than the harmonic force constants, typically by 2 to 3% in the case of heavy atoms (often by 5 to 10% if one of the atoms is hydrogen). Values are given in the SI unit newton per centimeter (N/cm), which is identical to the commonly used cgs unit mdyn/Å.

REFERENCES

1. Huber, K. P., and Herzberg, G., *Molecular Spectra and Molecular Structure. IV. Constants of Diatomic Molecules*, Van Nostrand Reinhold, New York, 1979.
2. Shimanouchi, T., *The Molecular Force Field*, in Eyring, H., Henderson, D., and Yost, W., Eds., *Physical Chemistry: An Advanced Treatise*, Vol. IV, Academic Press, New York, 1970.
3. Tasumi, M., and Nakata, M., *Pure and Appl. Chem.*, 57, 121—147, 1985.

Bond	Molecule	*f*/(N/cm)	Note
H-H	H_2	5.75	
Be-H	BeH	2.27	
B-H	BH	3.05	
C-H	CH	4.48	
	CH_4	5.44	b
	C_2H_6	4.83	a,b,c
	CH_3CN	5.33	b
	CH_3Cl	5.02	a,b,c
	CCl_2=CH_2	5.57	b
	HCN	6.22	
N-H	NH	5.97	
O-H	OH	7.80	
	H_2O	8.45	
P-H	PH	3.22	
S-H	SH	4.23	
	H_2S	4.28	
F-H	HF	9.66	
Cl-H	HCl	5.16	
Br-H	HBr	4.12	
I-H	HI	3.14	
Li-H	LiH	1.03	
Na-H	NaH	0.78	
K-H	KH	0.56	
Rb-H	RbH	0.52	
Cs-H	CsH	0.47	
C-C	C_2	12.16	
	CCl_2=CH_2	8.43	
	C_2H_6	4.50	a,c
	CH_3CN	5.16	
C-F	CF	7.42	
	CH_3F	5.71	a,c
C-Cl	CCl	3.95	
	CH_3Cl	3.44	a,c
	CCl_2=CH_2	4.02	b
C-Br	CH_3Br	2.89	a,c
C-I	CH_3I	2.34	a,c
C-O	CO	19.02	
	CO_2	16.00	
	OCS	16.14	
	CH_3OH	5.42	a,c
C-S	CS	8.49	
	CS_2	7.88	
	OCS	7.44	
C-N	CN	16.29	
	HCN	18.78	
	CH_3CN	18.33	
	CH_3NH_2	5.12	a,c
C-P	CP	7.83	
Si-Si	Si_2	2.15	
Si-O	SiO	9.24	
Si-F	SiF	4.90	
Si-Cl	SiCl	2.63	
N-N	N_2	22.95	
	N_2O	18.72	
N-O	NO	15.95	
	N_2O	11.70	
P-P	P_2	5.56	
P-O	PO	9.45	
O-O	O_2	11.77	
	O_3	5.74	a
S-O	SO	8.30	
	SO_2	10.33	a
S-S	S_2	4.96	
F-F	F_2	4.70	
Cl-F	ClF	4.48	
Br-F	BrF	4.06	
Cl-Cl	Cl_2	3.23	
Br-Cl	BrCl	2.82	
Br-Br	Br_2	2.46	
I-I	I_2	1.72	
Li-Li	Li_2	0.26	
Li-Na	LiNa	0.21	
Na-Na	Na_2	0.17	
Li-F	LiF	2.50	
Li-Cl	LiCl	1.43	
Li-Br	LiBr	1.20	
Li-I	LiI	0.97	
Na-F	NaF	1.76	
Na-Cl	NaCl	1.09	
Na-Br	NaBr	0.94	
Na-I	NaI	0.76	
Be-O	BeO	7.51	
Mg-O	MgO	3.48	
Ca-O	CaO	3.61	

[a] Derived from fundamental frequency, without anharmonicity correction.
[b] Average of symmetric and antisymmetric (or degenerate) modes.
[c] Calculated from Local Symmetry Force Field (see Reference 2).

FUNDAMENTAL VIBRATIONAL FREQUENCIES OF SMALL MOLECULES

This table lists the fundamental vibrational frequencies of selected three-, four-, and five-atom molecules. Both stable molecules and transient free radicals are included. The data have been taken from evaluated sources. In general, the selected values are based on gas-phase infrared, Raman, or ultraviolet spectra; when these were not available, liquid-phase or matrix-isolation spectra were used.

Molecules are grouped by structural type. Within each group, related molecules appear together for convenient comparison.

The vibrational modes are described by their approximate character in terms of stretching, bending, deformation, etc. However, it should be emphasized that most such descriptions are only approximate, and that the true normal mode usually involves a mixture of motions. Abbreviations are:

sym.	symmetric
antisym.	antisymmetric
str.	stretch
deform.	deformation
scis.	scissors
rock.	rocking
deg.	degenerate

In the case of free radicals, strong interactions may exist between the electronic and bending vibrational motions. Details can be found in References 3 and 4. The references should be consulted for information on the accuracy of the data and for data on other molecules not listed here.

All fundamental frequencies (more precisely, wavenumbers) are given in units of cm^{-1}.

XY_2 Molecules
Point groups $D_{\infty h}$(linear) and C_{2v}(bent)

Molecule	Structure	Sym. str.	Bend	Antisym. str.
CO_2	Linear	1333	667	2349
CS_2	Linear	658	397	1535
C_3	Linear	1224	63	2040
CNC	Linear		321	1453
NCN	Linear	1197	423	1476
BO_2	Linear	1056	447	1278
BS_2	Linear	510	120	1015
KrF_2	Linear	449	233	590
XeF_2	Linear	515	213	555
$XeCl_2$	Linear	316		481
H_2O	Bent	3657	1595	3756
D_2O	Bent	2671	1178	2788
F_2O	Bent	928	461	831
Cl_2O	Bent	639	296	686
O_3	Bent	1103	701	1042
H_2S	Bent	2615	1183	2626
D_2S	Bent	1896	855	1999
SF_2	Bent	838	357	813
SCl_2	Bent	525	208	535
SO_2	Bent	1151	518	1362
H_2Se	Bent	2345	1034	2358
D_2Se	Bent	1630	745	1696
NH_2	Bent	3219	1497	3301
NO_2	Bent	1318	750	1618
NF_2	Bent	1075	573	942
ClO_2	Bent	945	445	1111
CH_2	Bent		963	
CD_2	Bent		752	
CF_2	Bent	1225	667	1114
CCl_2	Bent	721	333	748
CBr_2	Bent	595	196	641
SiH_2	Bent	2032	990	2022
SiD_2	Bent	1472	729	1468
SiF_2	Bent	855	345	870

FUNDAMENTAL VIBRATIONAL FREQUENCIES OF SMALL MOLECULES (continued)

Molecule	Structure	Sym. str.	Bend	Antisym. str.
$SiCl_2$	Bent	515		505
$SiBr_2$	Bent	403		400
GeH_2	Bent	1887	920	1864
$GeCl_2$	Bent	399	159	374
SnF_2	Bent	593	197	571
$SnCl_2$	Bent	352	120	334
$SnBr_2$	Bent	244	80	231
PbF_2	Bent	531	165	507
$PbCl_2$	Bent	314	99	299
ClF_2	Bent	500		576

XYZ Molecules
Point Groups $C_{\infty v}$ (linear) and C_s(bent)

Molecule	Structure	XY str.	Bend	YZ str.
HCN	Linear	3311	712	2097
DCN	Linear	2630	569	1925
FCN	Linear	1077	451	2323
ClCN	Linear	744	378	2216
BrCN	Linear	575	342	2198
ICN	Linear	486	305	2188
CCN	Linear	1060	230	1917
CCO	Linear	1063	379	1967
HCO	Bent	2485	1081	1868
HCC	Linear	3612		1848
OCS	Linear	2062	520	859
NCO	Linear	1270	535	1921
NNO	Linear	2224	589	1285
HNB	Linear	3675		2035
HNC	Linear	3653		2032
HNSi	Linear	3583	523	1198
HBO	Linear		754	1817
FBO	Linear		500	2075
ClBO	Linear	676	404	1958
BrBO	Linear	535	374	1937
FNO	Bent	766	520	1844
ClNO	Bent	596	332	1800
BrNO	Bent	542	266	1799
HNF	Bent		1419	1000
HNO	Bent	2684	1501	1565
HPO	Bent	2095	983	1179
HOF	Bent	3537	886	1393
HOCl	Bent	3609	1242	725
HOO	Bent	3436	1392	1098
FOO	Bent	579	376	1490
ClOO	Bent	407	373	1443
BrOO	Bent			1487
HSO	Bent		1063	1009
NSF	Bent	1372	366	640
NSCl	Bent	1325	273	414
HCF	Bent		1407	1181
HCCl	Bent		1201	815
HSiF	Bent	1913	860	834
HSiCl	Bent		808	522
HSiBr	Bent	1548	774	408

Symmetric XY_3 Molecules
Point Groups D_{3h} (planar) and C_{3v} (pyramidal)

Molecule	Structure	Sym. str.	Sym. deform.	Deg. str.	Deg. deform.
NH_3	Pyram.	3337	950	3444	1627
ND_3	Pyram.	2420	748	2564	1191
PH_3	Pyram.	2323	992	2328	1118
AsH_3	Pyram.	2116	906	2123	1003
SbH_3	Pyram.	1891	782	1894	831
NF_3	Pyram.	1032	647	907	492
PF_3	Pyram.	892	487	860	344
AsF_3	Pyram.	741	337	702	262
PCl_3	Pyram.	504	252	482	198
PI_3	Pyram.	303	111	325	79
AsI_3	Pyram.	219	94	224	71
$AlCl_3$	Pyram.	375	183	595	150
SO_3	Planar	1065	498	1391	530
BF_3	Planar	888	691	1449	480
BH_3	Planar		1125	2808	1640
CH_3	Planar		606	3161	1396
CD_3	Planar		453	2369	1029
CF_3	Pyram.	1090	701	1260	510
SiF_3	Pyram.	830	427	937	290

Linear XYYX Molecules
Point Group $D_{\infty h}$

Molecule	Sym. XY str.	Antisym. XY str.	YY str.	Bend	Bend
C_2H_2	3374	3289	1974	612	730
C_2D_2	2701	2439	1762	505	537
C_2N_2	2330	2158	851	507	233

Planar X_2YZ Molecules
Point Group C_{2v}

Molecule	Sym.XY str.	YZ str.	YX_2 scis.	Antisym. XY str.	YX_2 rock	YX_2 wag
H_2CO	2783	1746	1500	2843	1249	1167
D_2CO	2056	1700	1106	2160	990	938
F_2CO	965	1928	584	1249	626	774
Cl_2CO	567	1827	285	849	440	580
O_2NF	1310	822	568	1792	560	742
O_2NCl	1286	793	370	1685	408	652

Tetrahedral XY_4 Molecules
Point Group T_d

Molecule	Sym. str.	Deg. deform.(e)	Deg. str.(f)	Deg. deform.(f)
CH_4	2917	1534	3019	1306
CD_4	2109	1092	2259	996
CF_4	909	435	1281	632
CCl_4	459	217	776	314

FUNDAMENTAL VIBRATIONAL FREQUENCIES OF SMALL MOLECULES (continued)

Molecule	Sym. str.	Deg. deform.(e)	Deg. str.(f)	Deg. deform.(f)
CBr_4	267	122	672	182
CI_4	178	90	555	125
SiH_4	2187	975	2191	914
SiD_4	1558	700	1597	681
SiF_4	800	268	1032	389
$SiCl_4$	424	150	621	221
GeH_4	2106	931	2114	819
GeD_4	1504	665	1522	596
$GeCl_4$	396	134	453	172
$SnCl_4$	366	104	403	134
$TiCl_4$	389	114	498	136
$ZrCl_4$	377	98	418	113
$HfCl_4$	382	102	390	112
RuO_4	885	322	921	336
OsO_4	965	333	960	329

REFERENCES

1. T. Shimanouchi, Tables of Molecular Vibrational Frequencies, Consolidated Volume I, Natl. Stand. Ref. Data Ser. Natl. Bur. Stand. (U.S.), 39, 1972.
2. T. Shimanouchi, Tables of Molecular Vibrational Frequencies, Consolidated Volume II, *J. Phys. Chem. Ref. Data*, 6, 993, 1977.
3. G. Herzberg, *Electronic Spectra and Electronic Structure of Polyatomic Molecules*, D. Van Nostrand Co., Princeton, 1966.
4. M. E. Jacox, Ground state vibrational energy levels of polyatomic transient molecules, *J. Phys. Chem. Ref. Data*, 13, 945, 1984.

SPECTROSCOPIC CONSTANTS OF DIATOMIC MOLECULES

This table lists the leading spectroscopic constants and equilibrium internuclear distance r_e in the ground electronic state for selected diatomic molecules. The constants are those describing the vibrational and rotational energy through the expressions:

$$E_{vib}/hc = \omega_e(v+1/2) - \omega_e x_e(v+1/2)^2 + \cdots$$

$$E_{rot}/hc = B_v J(J+1) - D_v[J(J+1)]^2 + \cdots$$

where

$$B_v = B_e - \alpha_e(v+1/2) + \cdots$$

$$D_v = D_e + \cdots$$

Here v and J are the vibrational and rotational quantum numbers, respectively, h is Planck's constant, and c is the speed of light. In this customary formulation the constants ω_e, B_e, etc. have dimensions of inverse length; in this table they are given in units of cm^{-1}.

Users should note that higher order terms in the above energy expressions are required for very precise calculations; constants for many of these terms can be found in the references. Also, if the ground electronic state is not $^1\Sigma$, additional terms are needed to account for the interaction between electronic and pure rotational angular momentum. For some molecules in the table the data have been analyzed in terms of the Dunham series expansion:

$$E/hc = \Sigma_{lm} Y_{lm}(v+1/2)^l J^m(J+1)^m$$

In such cases it has been assumed that $Y_{10} = \omega_e$, $Y_{01} = B_e$, etc., although in the highest approximations these identities are not precisely correct. Some of the values of r_e in the table have been corrected for breakdown of the Born-Oppenheimer approximation, which can affect the last decimal place. Because of differences in the method of data analysis and limitations in the model, care should be taken in comparing r_e values for different molecules to a precision beyond 0.001 Å.

Molecules are listed in alphabetical order by formula as written in the most common form. In most cases this form places the more electropositive element first, but there are exceptions such as OH, NH, CH, etc.

* Indicates a value for the interval between $v = 0$ and $v = 1$ states instead of a value of ω_e.

REFERENCES

1. Huber, K. P., and Herzberg, G., *Molecular Spectra and Molecular Structure IV. Constants of Diatomic Molecules*, Van Nostrand Reinhold, New York, 1979.
2. Lovas, F. J., and Tiemann, E., *J. Phys. Chem. Ref. Data*, 3, 609, 1974.
3. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series*, II/6 (1974), II/14a (1982), II/14b (1983), II/19a (1992), II/19d-1 (1995), *Molecular Constants*, Springer-Verlag, Heidelberg.

Molecule	State	ω_e cm^{-1}	$\omega_e x_e$ cm^{-1}	B_e cm^{-1}	α_e cm^{-1}	D_e $10^{-6}cm^{-1}$	r_e Å
$^{107}Ag^{79}Br$	$^1\Sigma^+$	249.57	0.63	0.064833	0.0002361	0.0175	2.39311
$^{107}Ag^{35}Cl$	$^1\Sigma^+$	343.49	1.17	0.12298388	0.00059541	0.06305	2.28079
$^{107}Ag^{19}F$	$^1\Sigma^+$	513.45	2.59	0.2657020	0.0019206	0.284	1.98318
$^{107}Ag^{1}H$	$^1\Sigma^+$	1759.9	34.06	6.449	0.201	344	1.618
$^{107}Ag^{2}H$	$^1\Sigma^+$	1250.70	17.17	3.2572	0.0722	85.9	1.6180
$^{107}Ag^{127}I$	$^1\Sigma^+$	206.50	0.46	0.04486821	0.0001414	0.00847	2.54463
$^{107}Ag^{16}O$	$^2\Pi_{1/2}$	490.2	3.1	0.3020	0.0025	0.45	2.003
$^{27}Al_2$	$^3\Sigma_g^-$	350.01	2.02	0.2054	0.0012	0.31	2.466
$^{27}Al^{79}Br$	$^1\Sigma^+$	378.0	1.28	0.15919713	0.00086045	0.11285	2.29481
$^{27}Al^{35}Cl$	$^1\Sigma^+$	481.30	1.95	0.24393012	0.00161113	0.2503	2.13011
$^{27}Al^{19}F$	$^1\Sigma^+$	802.3	4.77	0.5524798	0.0049841	1.0464	1.65437
$^{27}Al^{1}H$	$^1\Sigma^+$	1682.56	29.09	6.3907	0.1858	356.5	1.6478
$^{27}Al^{2}H$	$^1\Sigma^+$	1211.95	15.14	3.3186	0.0697	97	1.6463
$^{27}Al^{127}I$	$^1\Sigma^+$	316.1	1.0	0.11769985	0.00055859		2.53710
$^{27}Al^{16}O$	$^2\Sigma^+$	979.23	6.97	0.6414	0.0058	1.08	1.6179
$^{27}Al^{32}S$	$^2\Sigma^+$	617.1	3.33	0.2799	0.0018	0.22	2.029
$^{75}As_2$	$^1\Sigma_g^+$	429.55	1.12	0.10179	0.000333		2.1026
$^{75}As^{1}H$	$^3\Sigma^-$	2130*		7.3067	0.2117	327	1.52315
$^{75}As^{2}H$	$^3\Sigma^-$	1484*		3.6688		90	1.5306
$^{75}As^{14}N$	$^1\Sigma^+$	1068.54	5.41	0.54551	0.003366	0.53	1.6184
$^{75}As^{16}O$	$^2\Pi_{1/2}$	967.08	4.85	0.48482	0.003299	0.49	1.6236

SPECTROSCOPIC CONSTANTS OF DIATOMIC MOLECULES (continued)

Molecule	State	ω_e cm^{-1}	$\omega_e x_e$ cm^{-1}	B_e cm^{-1}	α_e cm^{-1}	D_e 10^{-6}cm^{-1}	r_e Å
$^{197}Au_2$	$^1\Sigma_g^+$	190.9	0.42	0.028013	0.0000723	0.00250	2.4719
$^{197}Au^1H$	$^1\Sigma^+$	2305.01	43.12	7.2401	0.2136	279	1.5239
$^{197}Au^2H$	$^1\Sigma^+$	1634.98	21.65	3.6415	0.07614	70.9	1.5238
$^{11}B_2$	$^3\Sigma_g^-$	1051.3	9.35	1.212	0.014		1.590
$^{11}B^{79}Br$	$^1\Sigma^+$	684.31	3.52	0.4894	0.0035	1.00	1.888
$^{11}B^{35}Cl$	$^1\Sigma^+$	840.29	5.49	0.684282	0.006812	1.84	1.71528
$^{11}B^{19}F$	$^1\Sigma^+$	1402.1	11.8	1.516950	0.019056	7.105	1.26267
$^{11}B^1H$	$^1\Sigma^+$	2366.9	49.40	12.021	0.412	1242	1.2324
$^{11}B^2H$	$^1\Sigma^+$	1703.3	28	6.54	0.17	400	1.2324
$^{11}B^{14}N$	$^3\Pi$	1514.6	12.3	1.666	0.025	8.1	1.281
$^{11}B^{16}O$	$^2\Sigma^+$	1885.69	11.81	1.7820	0.0166	6.32	1.2045
$^{11}B^{32}S$	$^2\Sigma^+$	1180.17	6.31	0.7949	0.0061	1.40	1.6092
$^{138}Ba^{79}Br$	$^2\Sigma^+$	193.77	0.41	0.0415082	0.0001219	0.00762	2.84449
$^{138}Ba^{35}Cl$	$^2\Sigma^+$	279.92	0.82	0.08396717	0.00033429	0.03022	2.68276
$^{138}Ba^{19}F$	$^2\Sigma^+$	468.9	1.79	0.2159	0.0012	0.175	2.163
$^{138}Ba^1H$	$^2\Sigma^+$	1168.31	14.50	3.38285	0.06599	112.67	2.23175
$^{138}Ba^2H$	$^2\Sigma^+$	829.77	7.32	1.7071	0.02363	28.77	2.2304
$^{138}Ba^{127}I$	$^2\Sigma^+$	152.14	0.27	0.02680587	0.00006634	0.00333	3.08476
$^{138}Ba^{16}O$	$^1\Sigma^+$	669.76	2.03	0.3126140	0.0013921	0.2724	1.93969
$^{138}Ba^{32}S$	$^1\Sigma^+$	379.42	0.88	0.10331	0.0003188	0.0306	2.5074
$^9Be^{19}F$	$^2\Sigma^+$	1247.36	9.12	1.4889	0.0176	8.28	1.3610
$^9Be^1H$	$^2\Sigma^+$	2060.78	36.31	10.3164	0.3030	1022.1	1.3426
$^9Be^2H$	$^2\Sigma^+$	1530.32	20.71	5.6872	0.1225	313.8	1.3419
$^9Be^{16}O$	$^1\Sigma^+$	1487.32	11.83	1.6510	0.0190	8.20	1.3309
$^9Be^{32}S$	$^1\Sigma^+$	997.94	6.14	0.79059	0.00664	2.00	1.7415
$^{209}Bi_2$	$^1\Sigma_g^+$	172.71	0.34	0.022781	0.000055	0.00150	2.6596
$^{209}Bi^1H$	$^3\Sigma^-$	1635.73	31.6	5.137	0.148	183	1.805
$^{209}Bi^2H$	$^3\Sigma^-$	1173.32	16.1	2.592	0.054	50.6	1.804
$^{79}Br_2$	$^1\Sigma_g^+$	325.32	1.08	0.082107	0.0003187	0.02092	2.2811
$^{79}Br^{35}Cl$	$^1\Sigma^+$	444.28	1.84	0.152470	0.000770	0.07183	2.13607
$^{79}Br^{19}F$	$^1\Sigma^+$	670.75	4.05	0.35584	0.00261	0.401	1.75894
$^{79}Br^{16}O$	$^2\Pi_{3/2}$	779	6.8	0.429598	0.003639	0.523	1.717
$^{12}C_2$	$^1\Sigma_g^+$	1854.71	13.34	1.8198	0.0177	6.92	1.2425
$^{12}C^{35}Cl$	$^2\Pi_{1/2}$	866.72*	6.2	0.6936	0.00672	1.9	1.6450
$^{12}C^{19}F$	$^2\Pi_{1/2}$	1308.1	11.10	1.4172	0.0184	6.5	1.2718
$^{12}C^1H$	$^2\Pi_{1/2}$	2858.5	63.0	14.457	0.534	1450	1.1199
$^{12}C^2H$	$^2\Pi_{1/2}$	2099.8	34.02	7.806	0.208	420	1.1190
$^{12}C^{14}N$	$^2\Sigma^+$	2068.59	13.09	1.8997830	0.0173717	6.4034	1.17181
$^{12}C^{16}O$	$^1\Sigma^+$	2169.81	13.29	1.93128075	0.01750390	6.1216	1.12823
$^{12}C^{31}P$	$^2\Sigma^+$	1239.67	6.86	0.7986	0.00597	1.33	1.562
$^{12}C^{32}S$	$^1\Sigma^+$	1285.15	6.50	0.8200434	0.0059182	1.336	1.53482
$^{12}C^{80}Se$	$^1\Sigma^+$	1035.36	4.86	0.5750	0.00379	0.71	1.67609
$^{40}Ca^{35}Cl$	$^2\Sigma^+$	367.53	1.31	0.1522302	0.0007990	0.1029	2.43676
$^{40}Ca^{19}F$	$^2\Sigma^+$	581.1	2.74	0.339	0.0026	0.45	1.967
$^{40}Ca^1H$	$^2\Sigma^+$	1298.34	19.10	4.2766	0.0970	183.7	2.0025
$^{40}Ca^2H$	$^2\Sigma^+$	910*		2.1769	0.035	47.9	2.002
$^{40}Ca^{127}I$	$^2\Sigma^+$	238.70	0.63	0.0693263	0.0002634	0.0234	2.82859
$^{40}Ca^{16}O$	$^1\Sigma^+$	732.03	4.83	0.444441	0.003282	0.6541	1.8221
$^{40}Ca^{32}S$	$^1\Sigma^+$	462.23	1.78	0.1766757	0.0008270	0.1032	2.31775
$^{114}Cd^1H$	$^2\Sigma^+$	1337.1*		5.323		314	1.781
$^{114}Cd^2H$	$^2\Sigma^+$			2.704		76	1.775
$^{35}Cl_2$	$^1\Sigma_g^+$	559.7	2.68	0.2440	0.0015	0.186	1.988
$^{35}Cl^{19}F$	$^1\Sigma^+$	786.15	6.16	0.516479	0.004358	0.88	1.62831
$^{35}Cl^{16}O$	$^2\Pi_{3/2}$	853.8	5.5	0.62345	0.0058	1.33	1.56963
$^{52}Cr^1H$	$^6\Sigma^+$	1581*	32	6.220	0.179	347	1.656
$^{52}Cr^2H$	$^6\Sigma^+$	1182*		3.14		88.8	1.664
$^{52}Cr^{16}O$	$^5\Pi$	898.4	6.8	0.5231	0.0070		1.615
$^{133}Cs_2$	$^1\Sigma_g^+$	42.02	0.08	0.0127	0.0000264	0.00464	4.47

Molecule	State	ω_e cm^{-1}	$\omega_e x_e$ cm^{-1}	B_e cm^{-1}	α_e cm^{-1}	D_e 10^{-6}cm^{-1}	r_e Å
$^{133}Cs^{79}Br$	$^1\Sigma^+$	149.66	0.37	0.03606925	0.00012401	0.00838	3.07225
$^{133}Cs^{35}Cl$	$^1\Sigma^+$	214.17	0.73	0.07209149	0.00033756	0.03268	2.90627
$^{133}Cs^{19}F$	$^1\Sigma^+$	352.56	1.62	0.18436969	0.0011756	0.20168	1.34535
$^{133}Cs^1H$	$^1\Sigma^+$	891.0	12.9	2.7099	0.0579	113	2.4938
$^{133}Cs^2H$	$^1\Sigma^+$	619.1*		1.354		20	2.505
$^{133}Cs^{127}I$	$^1\Sigma^+$	119.18	0.25	0.02362736	0.00006826	0.00371	3.31519
$^{133}Cs^{16}O$	$^2\Sigma^+$	357.5*		0.223073	0.001303	0.348	2.3007
$^{63}Cu_2$	$^1\Sigma_g^+$	264.55	1.02	0.10874	0.000614	0.0716	2.2197
$^{63}Cu^{79}Br$	$^1\Sigma^+$	314.8	0.96	0.10192625	0.00045214	0.04274	2.17344
$^{65}Cu^{35}Cl$	$^1\Sigma^+$	415.29	1.58	0.17628802	0.00099647	0.12706	2.05118
$^{63}Cu^{19}F$	$^1\Sigma^+$	622.7	3.95	0.3794029	0.0032298	0.563	1.74493
$^{63}Cu^1H$	$^1\Sigma^+$	1941.26	37.51	7.9441	0.2563	520	1.46263
$^{63}Cu^2H$	$^1\Sigma^+$	1384.14	18.97	4.0381	0.0917	136.2	1.4626
$^{63}Cu^{127}I$	$^1\Sigma^+$	264.5	0.60	0.07328742	0.00028390	0.02244	2.33832
$^{63}Cu^{16}O$	$^2\Pi_{3/2}$	640.17	4.43	0.44454	0.00456	0.85	1.7244
$^{63}Cu^{32}S$	$^2\Pi_{3/2}$	415.0	1.75	0.1891		0.18	2.051
$^{19}F_2$	$^1\Sigma_g^+$	916.64	11.24	0.89019	0.013847	3.3	1.41193
$^{56}Fe^{16}O$	$^5\Delta$	965*		0.650		0.72	1.444
$^{69}Ga^{81}Br$	$^1\Sigma^+$	263.0	0.81	0.081839	0.0003207	0.032	2.35248
$^{69}Ga^{35}Cl$	$^1\Sigma^+$	365.67	1.25	0.1499046	0.0007936	0.1008	2.20169
$^{69}Ga^{19}F$	$^1\Sigma^+$	622.2	3.2	0.3595161	0.0028642	0.50	1.77437
$^{69}Ga^1H$	$^1\Sigma^+$	1604.52	28.77	6.137	0.181	342	1.663
$^{69}Ga^2H$	$^1\Sigma^+$			3.083	0.06	84	1.663
$^{69}Ga^{127}I$	$^1\Sigma^+$	216.38	0.47	0.0569359	0.0001897	0.015770	2.57464
$^{69}Ga^{16}O$	$^2\Sigma$	767.5	6.24	0.4271		0.37	1.744
$^{74}Ge^{79}Br$	$^2\Pi_{1/2}$	295	0.7				
$^{74}Ge^{35}Cl$	$^2\Pi_{1/2}$	407.6	1.36				
$^{72}Ge^1H$	$^2\Pi_{1/2}$	1833.77	37	6.726	0.192	326	1.5880
$^{72}Ge^2H$	$^2\Pi_{1/2}$	1320.09	19	3.415	0.070	83.2	1.5874
$^{74}Ge^{16}O$	$^1\Sigma^+$	986.49	4.47	0.4856981	0.0030787	0.4709	1.62464
$^{74}Ge^{32}S$	$^1\Sigma^+$	575.8	1.80	0.18656576	0.00074910	0.07883	2.01209
$^{74}Ge^{80}Se$	$^1\Sigma^+$	408.7	1.36	0.09634051	0.00028904	0.02207	2.13463
$^{74}Ge^{130}Te$	$^1\Sigma^+$	323.9	0.75	0.06533821	0.00017246	0.012	2.34017
$^1H_2$	$^1\Sigma_g^+$	4401.21	121.34	60.853	3.062	47100	0.74144
$^2H_2$	$^1\Sigma_g^+$	3115.50	61.82	30.444	1.0786	11410	0.74152
$^3H_2$	$^1\Sigma_g^+$	2546.5	41.23	20.335	0.5887		0.74142
$^1H^{81}Br$	$^1\Sigma^+$	2648.97	45.22	8.46488	0.23328	345.8	1.41444
$^2H^{81}Br$	$^1\Sigma^+$	1884.75	22.72	4.245596	0.084	88.32	1.4145
$^1H^{35}Cl$	$^1\Sigma^+$	2990.95	52.82	10.59342	0.30718	531.94	1.27455
$^2H^{35}Cl$	$^1\Sigma^+$	2145.16	27.18	5.448796	0.113292	140	1.27458
$^1H^{19}F$	$^1\Sigma^+$	4138.32	89.88	20.9557	0.798	2151	0.91681
$^2H^{19}F$	$^1\Sigma^+$	2998.19	45.76	11.0102	0.3017	594	0.91694
$^1H^{127}I$	$^1\Sigma^+$	2309.01	39.64	6.4263650	0.1689	206.9	1.60916
$^{202}Hg^1H$	$^2\Sigma^+$	1203.24*		5.3888		395.3	1.7662
$^{202}Hg^2H$	$^2\Sigma^+$	896.12*		2.739		91	1.757
$^{127}I_2$	$^1\Sigma_g^+$	214.50	0.61	0.03737	0.000114	0.0043	2.666
$^{127}I^{79}Br$	$^1\Sigma^+$	268.64	0.81	0.0568325	0.0001969	0.0102	2.46899
$^{127}I^{35}Cl$	$^1\Sigma^+$	384.29	1.50	0.1141587	0.0005354	0.0403	2.32088
$^{127}I^{19}F$	$^1\Sigma^+$	610.24	3.12	0.2797111	0.0018738	0.2356	1.90976
$^{127}I^{16}O$	$^2\Pi_{3/2}$	681.5	4.3	0.34026	0.00270	0.36	1.8676
$^{115}In^{81}Br$	$^1\Sigma^+$	221.0	0.65	0.05489468	0.00018672	0.01350	2.54315
$^{115}In^{35}Cl$	$^1\Sigma^+$	317.39	1.03	0.1090583	0.0005177	0.0515	2.40117
$^{115}In^{19}F$	$^1\Sigma^+$	535.4	2.6	0.2623241	0.0018798	0.252	1.98540
$^{115}In^1H$	$^1\Sigma^+$	1476.0	25.61	4.995	0.143	223	1.8380
$^{115}In^2H$	$^1\Sigma^+$	1048.2	12.4	2.523	0.051	58	1.837
$^{115}In^{127}I$	$^1\Sigma^+$	177.08	0.34	0.03686702	0.00010411	0.00639	2.75364
$^{39}K_2$	$^1\Sigma_g^+$	92.02	0.28	0.056743	0.000165	0.0863	3.9051
$^{39}K^{79}Br$	$^1\Sigma^+$	213	0.80	0.08122109	0.00040481	0.04462	2.82078

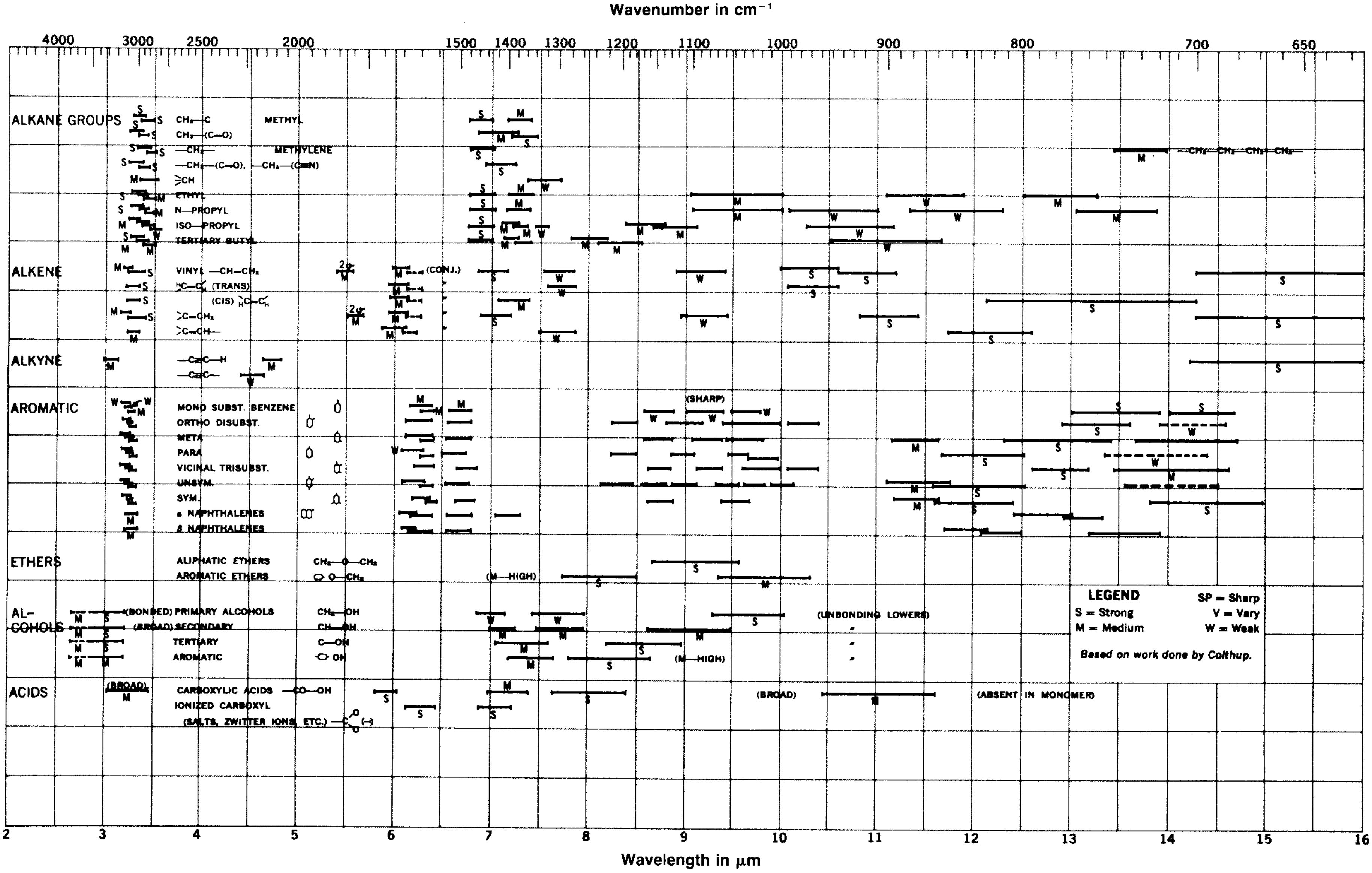
SPECTROSCOPIC CONSTANTS OF DIATOMIC MOLECULES (continued)

Molecule	State	ω_e cm^{-1}	$\omega_e x_e$ cm^{-1}	B_e cm^{-1}	α_e cm^{-1}	D_e 10^{-6}cm^{-1}	r_e Å
$^{39}K^{35}Cl$	$^1\Sigma^+$	281	1.30	0.1286348	0.0007899	0.1087	2.66665
$^{39}K^{19}F$	$^1\Sigma^+$	426.26	2.45	0.27993741	0.00233492	0.4829	2.17146
$^{39}K^1H$	$^1\Sigma^+$	983.6	14.3	3.416400	0.085313	163.55	2.243
$^{39}K^2H$	$^1\Sigma^+$	707	7.7	1.754	0.0318	50	2.240
$^{39}K^{127}I$	$^1\Sigma^+$	186.53	0.57	0.06087473	0.00026776	0.02593	3.04784
$^{139}La^{16}O$	$^2\Sigma^+$	812.8	2.22	0.35252001	0.00142365	0.2626	1.82591
$^7Li_2$	$^1\Sigma_g{}^+$	351.43	2.61	0.67264	0.00704	9.87	2.6729
$^7Li^{79}Br$	$^1\Sigma^+$	563.2	3.5	0.555399	0.005644	2.159	2.17043
$^7Li^{35}Cl$	$^1\Sigma^+$	642.95	4.47	0.7065225	0.0080102	3.409	2.02067
$^7Li^{19}F$	$^1\Sigma^+$	910.57	8.21	1.3452583	0.0202887	11.745	1.56386
$^7Li^1H$	$^1\Sigma^+$	1405.65	23.20	7.51373	0.21665	862	1.59490
$^7Li^2H$	$^1\Sigma^+$	1054.80	12.94	4.23310	0.09155	276	1.5941
$^7Li^{127}I$	$^1\Sigma^+$	496.85	2.85	0.4431766	0.0040862	1.4104	2.39192
$^7Li^{16}O$	$^2\Pi$	814.62	7.78	1.212830	0.017899	0.1079	1.68822
$^{24}Mg_2$	$^1\Sigma_g{}^+$	51.12	1.64	0.09287	0.00378	1.22	3.891
$^{24}Mg^{35}Cl$	$^2\Sigma^+$	462.12*	2.1	0.2456154	0.0016204	0.2723	2.19639
$^{24}Mg^{19}F$	$^2\Sigma^+$	711.69*	4.9	0.51922	0.00470	1.080	1.7500
$^{24}Mg^1H$	$^2\Sigma^+$	1495.20	31.89	5.8257	0.1859	344	1.7297
$^{24}Mg^2H$	$^2\Sigma^+$	1077.9	16.1	3.0306	0.06289	92	1.7302
$^{24}Mg^{16}O$	$^1\Sigma^+$	784.78	5.26	0.57470436	0.00532377	1.2328	1.74838
$^{55}Mn^1H$	$^7\Sigma$	1548.0	28.8	5.6841	0.1570	303.9	1.7311
$^{55}Mn^2H$	$^7\Sigma$	1103	13.9	2.8957	0.051	79.5	1.7310
$^{14}N_2$	$^1\Sigma_g{}^+$	2358.57	14.32	1.99824	0.017318	5.76	1.09769
$^{14}N^{79}Br$	$^3\Sigma^-$	691.75	4.72	0.444	0.0040		1.79
$^{14}N^{35}Cl$	$^3\Sigma^-$	827.96	5.30	0.649770	0.006414	1.598	1.61071
$^{14}N^{19}F$	$^3\Sigma^-$	1141.37	8.99	1.2057	0.01492	5.39	1.3170
$^{14}N^1H$	$^3\Sigma^-$	3282.3	78.4	16.6993	0.6490	1709.7	1.0362
$^{14}N^2H$	$^3\Sigma^-$	2398	42	8.7913	0.2531	490.4	1.0361
$^{14}N^{16}O$	$^2\Pi_{1/2}$	1904.20	14.07	1.67195	0.0171	0.5	1.15077
$^{14}N^{32}S$	$^2\Pi_{1/2}$	1218.7	7.28	0.769602	0.0064	1.2	1.4940
$^{23}Na_2$	$^1\Sigma_g{}^+$	159.13	0.72	0.154707	0.008736	0.581	3.0789
$^{23}Na^{79}Br$	$^1\Sigma^+$	302	1.5	0.1512533	0.0009410	0.1554	2.50204
$^{23}Na^{35}Cl$	$^1\Sigma^+$	366	2.05	0.2180631	0.0016248	0.3120	2.36080
$^{23}Na^{19}F$	$^1\Sigma^+$	535.66	3.57	0.4369011	0.0045580	1.163	1.92595
$^{23}Na^1H$	$^1\Sigma^+$	1172.2	19.72	4.9033634	0.1370919	343.40	1.88654
$^{23}Na^2H$	$^1\Sigma^+$	826.1*		2.557089	0.051600	93.46	1.88654
$^{23}Na^{127}I$	$^1\Sigma^+$	258	1.1	0.1178056	0.0006478	0.0973	2.71145
$^{23}Na^{16}O$	$^2\Pi$	492.3		0.424630	0.004506	1.2638	2.05155
$^{93}Nb^{16}O$	$^4\Sigma^-$	989.0	3.8	0.4321	0.0021	0.22	1.691
$^{58}Ni^1H$	$^2\Delta_{5/2}$	1926.6	38	7.700	0.23	481	1.476
$^{58}Ni^2H$	$^2\Delta_{5/2}$	1390.1	19	3.992	0.092	130	1.465
$^{16}O_2$	$^3\Sigma_g{}^-$	1580.19	11.98	1.44563	0.0159	4.839	1.20752
$^{16}O^1H$	$^2\Pi_{3/2}$	3737.76	84.88	18.911	0.7242	1938	0.96966
$^{16}O^2H$	$^2\Pi_{3/2}$	2720.24	44.05	10.021	0.276	537.4	0.9698
$^{31}P_2$	$^1\Sigma_g{}^+$	780.77	2.84	0.30362	0.00149	0.188	1.8934
$^{31}P^{35}Cl$	$^3\Sigma^-$	551.38	2.23	0.2528748	0.0015119	0.2124	2.01461
$^{31}P^{19}F$	$^3\Sigma^-$	846.75	4.49	0.5665	0.00456		1.58938
$^{31}P^1H$	$^3\Sigma^-$	2365.2	44.5	8.5371	0.2514	436	1.42140
$^{31}P^2H$	$^3\Sigma^-$	1699.2	23.0	4.4081	0.0928	116	1.4220
$^{31}P^{14}N$	$^1\Sigma^+$	1337.24	6.98	0.7864854	0.0055364	1.091	1.49087
$^{31}P^{16}O$	$^2\Pi_{1/2}$	1233.34	6.56	0.7337	0.0055	1.3	1.4759
$^{208}Pb_2$		110.5	0.35				
$^{208}Pb^{79}Br$	$^2\Pi_{1/2}$	207.5	0.50				
$^{208}Pb^{35}Cl$	$^2\Pi_{1/2}$	303.9	0.88				
$^{208}Pb^{19}F$	$^2\Pi_{1/2}$	502.73	2.28	0.22875	0.001473	0.183	2.0575
$^{208}Pb^1H$	$^2\Pi_{1/2}$	1564.1	29.75	4.971	0.144	201	1.839
$^{208}Pb^{16}O$	$^1\Sigma^+$	720.96	3.52	0.30730373	0.00190977	0.2138	1.92181
$^{208}Pb^{32}S$	$^1\Sigma^+$	429.17	1.26	0.11632307	0.00043510	0.03418	2.28678

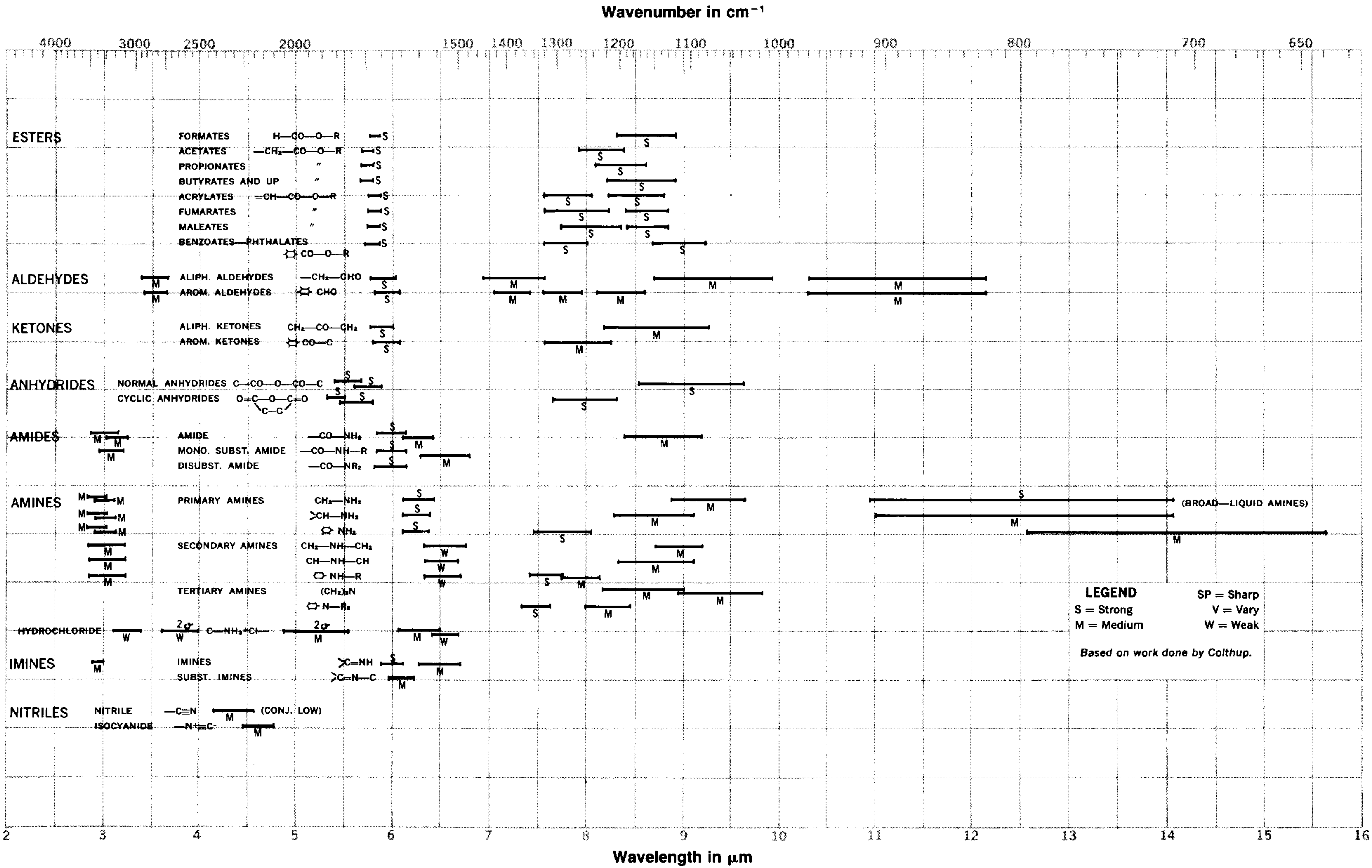
Molecule	State	ω_e cm^{-1}	$\omega_e x_e$ cm^{-1}	B_e cm^{-1}	α_e cm^{-1}	D_e 10^{-6}cm^{-1}	r_e Å
$^{208}Pb^{80}Se$	$^1\Sigma^+$	277.6	0.51	0.05059953	0.00012993	0.0070	2.40218
$^{208}Pb^{130}Te$	$^1\Sigma^+$	212.0	0.43	0.03130774	0.00006743	0.0027	2.59492
$^{195}Pt^{12}C$	$^1\Sigma^+$	1051.13	4.86	0.53044	0.003273	0.546	1.6767
$^{195}Pt^1H$	$^2\Delta_{5/2}$	2294.68*	46	7.1963	0.1996	261	1.52852
$^{195}Pt^2H$	$^2\Delta_{5/2}$	1644.3*	23	3.640	0.071	66	1.524
$^{85}Rb^{79}Br$	$^1\Sigma^+$	169.46	0.46	0.04752798	0.00018596	0.01496	2.94474
$^{85}Rb^{35}Cl$	$^1\Sigma^+$	228	0.92	0.0876404	0.0004537	0.04947	2.78673
$^{85}Rb^{19}F$	$^1\Sigma^+$	376	1.9	0.2106640	0.0015228	0.2684	2.27033
$^{85}Rb^1H$	$^1\Sigma^+$	936.9	14.21	3.020	0.072	123	2.367
$^{85}Rb^{127}I$	$^1\Sigma^+$	138.51	0.33	0.03283293	0.00010946	0.00738	3.17688
$^{85}Rb^{16}O$	$^2\Sigma^+$	388.4*		0.246481	0.002174	0.397	2.25420
$^{32}S_2$	$^3\Sigma_g^-$	725.65	2.84	0.2955	0.001570	0.19	1.8892
$^{32}S^{19}F$	$^2\Pi_{3/2}$			0.552174			1.60058
$^{32}S^1H$	$^2\Pi_{3/2}$	2711.6	59.9	9.5995	0.2785	480.6	1.34066
$^{32}S^2H$	$^2\Pi_{3/2}$	1885	31	4.95130	0.10308	130	1.34049
$^{32}S^{16}O$	$^3\Sigma^-$	1149.2	5.6	0.7208171	0.005737	1.134	1.48109
$^{121}Sb^{35}Cl$	$^3\Sigma^-$	374.7	0.6				
$^{121}Sb^{19}F$	$^3\Sigma^-$	605.0	2.6	0.2792	0.0020	0.23	1.918
$^{121}Sb^1H$	$^3\Sigma^-$			5.684		240	1.723
$^{121}Sb^2H$	$^3\Sigma^-$			2.8782		45	1.7194
$^{121}Sb^{14}N$	$^1\Sigma^+$	942.0	5.6				
$^{121}Sb^{16}O$	$^2\Pi_{1/2}$	816	4.2	0.3580	0.0022	0.270	1.826
$^{45}Sc^{19}F$	$^1\Sigma^+$	735.6	3.8	0.3950	0.00266		1.788
$^{80}Se_2$	$^3\Sigma_g^-$	385.30	0.96	0.08992	0.000288	0.024	2.166
$^{80}Se^1H$	$^2\Pi_{3/2}$	2400*		8.02	0.23	330	1.48
$^{80}Se^2H$	$^2\Pi_{3/2}$	1708*		3.94			1.48
$^{80}Se^{16}O$	$^3\Sigma^-$	914.69	4.52	0.4655	0.00323	0.5	1.648
$^{28}Si_2$	$^3\Sigma_g^-$	510.98	2.02	0.2390	0.0014	0.21	2.246
$^{28}Si^{35}Cl$	$^2\Pi_{1/2}$	535.60	2.17	0.2561	0.0016	0.25	2.058
$^{28}Si^{19}F$	$^2\Pi_{1/2}$	857.19	4.73	0.5812	0.00494	1.07	1.6011
$^{28}Si^1H$	$^2\Pi_{1/2}$	2041.80	35.51	7.4996	0.2190	397	1.5201
$^{28}Si^2H$	$^2\Pi_{1/2}$	1469.32	18.23	3.8840	0.0781	105.4	1.5199
$^{28}Si^{14}N$	$^2\Sigma^+$	1151.4	6.47	0.7311	0.00565	1.2	1.572
$^{28}Si^{16}O$	$^1\Sigma^+$	1241.54	5.97	0.7267521	0.0050379	0.9923	1.50975
$^{28}Si^{32}S$	$^1\Sigma^+$	749.64	2.58	0.30352788	0.00147308	0.201	1.92926
$^{28}Si^{80}Se$	$^1\Sigma^+$	580.0	1.78	0.1920117	0.0007767	0.0842	2.05832
$^{120}Sn^{79}Br$	$^2\Pi_{1/2}$	247.2	0.6				
$^{120}Sn^{35}Cl$	$^2\Pi_{1/2}$	351.1	1.06	0.1117	0.0004		2.361
$^{118}Sn^{19}F$	$^2\Pi_{1/2}$	577.6	2.69	0.2727	0.0014	0.26	1.944
$^{120}Sn^1H$	$^2\Pi_{1/2}$			5.31488		207.5	1.78146
$^{120}Sn^2H$	$^2\Pi_{1/2}$	1188.0*		2.6950	0.049	53.4	1.7770
$^{120}Sn^{127}I$	$^2\Pi_{1/2}$	199.0	0.6				
$^{120}Sn^{16}O$	$^1\Sigma^+$	822.13	3.72	0.35571998	0.00214432	0.26638	1.83251
$^{120}Sn^{32}S$	$^1\Sigma^+$	487.26	1.36	0.13686139	0.00050563	0.0424	2.20898
$^{120}Sn^{80}Se$	$^1\Sigma^+$	331.2	0.74	0.0649978	0.0001705	0.011	2.32557
$^{120}Sn^{130}Te$	$^1\Sigma^+$	259.5	0.50	0.04247917	0.00009543	0.0055	2.52280
$^{88}Sr^{79}Br$	$^2\Sigma^+$	216.60	0.52	0.0541847	0.0001827	0.01356	2.73522
$^{88}Sr^{35}Cl$	$^2\Sigma^+$	302.3	0.95				
$^{88}Sr^{19}F$	$^2\Sigma^+$	502.4	2.3	0.2505346	0.0015513	0.2498	2.07537
$^{88}Sr^1H$	$^2\Sigma^+$	1206.2	17.0	3.6751	0.0814	135	2.1456
$^{88}Sr^2H$	$^2\Sigma^+$	841	8.6	1.8609	0.0292	34.7	2.1449
$^{88}Sr^{127}I$	$^2\Sigma^+$	173.77	0.35	0.0367097	0.0001060	0.00655	2.94364
$^{88}Sr^{16}O$	$^1\Sigma^+$	653.5	3.96	0.33798	0.00219	0.36	1.91983
$^{181}Ta^{16}O$	$^2\Delta_{3/2}$	1028.69	3.51	0.40284	0.00182	0.2450	1.68746
$^{130}Te_2$	$^3\Sigma_g^-$	247.07	0.51	0.039681	0.000106	0.0044	2.5574
$^{130}Te^1H$	$^2\Pi_{3/2}$			5.56			1.74
$^{130}Te^{16}O$	0^+	797.11	4.00	0.3554	0.00237	0.27	1.825
$^{232}Th^{16}O$	$^1\Sigma^+$	895.77	2.39	0.332644	0.001302	0.1833	1.84032

Molecule	State	ω_e cm^{-1}	$\omega_e x_e$ cm^{-1}	B_e cm^{-1}	α_e cm^{-1}	D_e $10^{-6}cm^{-1}$	r_e Å
$^{48}Ti^{16}O$	$^3\Delta_1$	1009.02	4.50	0.53541	0.00301	0.603	1.6202
$^{205}Tl^{81}Br$	$^1\Sigma^+$	192.10	0.39	0.0423899	0.0001276	0.0083	1.61817
$^{205}Tl^{35}Cl$	$^1\Sigma^+$	284.71	0.86	0.09139702	0.00039784	0.0377	2.48483
$^{205}Tl^{19}F$	$^1\Sigma^+$	476.86	2.24	0.22315014	0.00150380	0.1955	2.08439
$^{205}Tl^{1}H$	$^1\Sigma^+$	1390.7	22.7	4.806	0.154	254	1.870
$^{205}Tl^{2}H$	$^1\Sigma^+$	987.7	12.04	2.419	0.057	60	1.869
$^{205}Tl^{127}I$	$^1\Sigma^+$	150*		0.0271676	0.0000664	0.0036	2.81361
$^{51}V^{16}O$	$^4\Sigma^-$	1011.3	4.86	0.54825	0.00352	0.6	1.5893
$^{89}Y^{35}Cl$	$^1\Sigma$	380.7	1.3	0.1160	0.0003	0.09	2.41
$^{89}Y^{19}F$	$^1\Sigma^+$	631.29	2.50	0.29042	0.00163	0.237	1.9257
$^{89}Y^{16}O$	$^2\Sigma^+$	861.0	2.9	0.3881	0.0018	0.32	1.790
$^{174}Yb^{1}H$	$^2\Sigma^+$	1249.54	21.06	3.9931	0.0957	161.8	2.0526
$^{174}Yb^{2}H$	$^2\Sigma^+$	886.6	10.57	2.01162	0.03425	41.60	2.0516
$^{64}Zn^{35}Cl$	$^2\Sigma$	390.5	1.6				
$^{64}Zn^{19}F$	$^2\Sigma$	628	3.5				
$^{64}Zn^{1}H$	$^2\Sigma^+$	1607.6	55.14	6.6794	0.2500	466	1.5949
$^{64}Zn^{2}H$	$^2\Sigma^+$	1072	28	3.350		124	1.6054
$^{64}Zn^{127}I$	$^2\Sigma$	223.4	0.6				
$^{90}Zr^{16}O$	$^1\Sigma^+$	969.8	4.9	0.42263	0.0023	0.319	1.7116

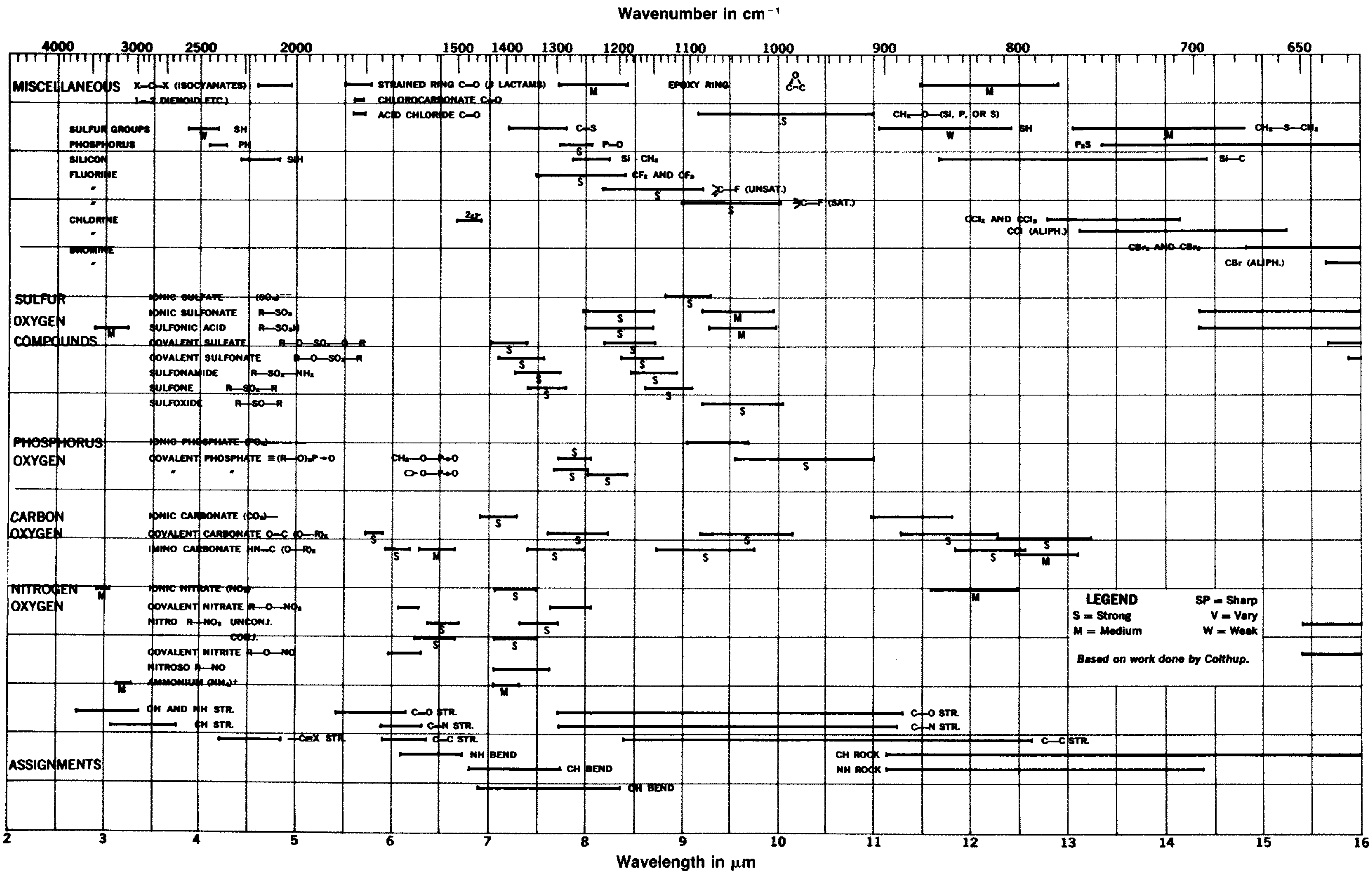
INFRARED CORRELATION CHARTS



INFRARED CORRELATION CHARTS (continued)

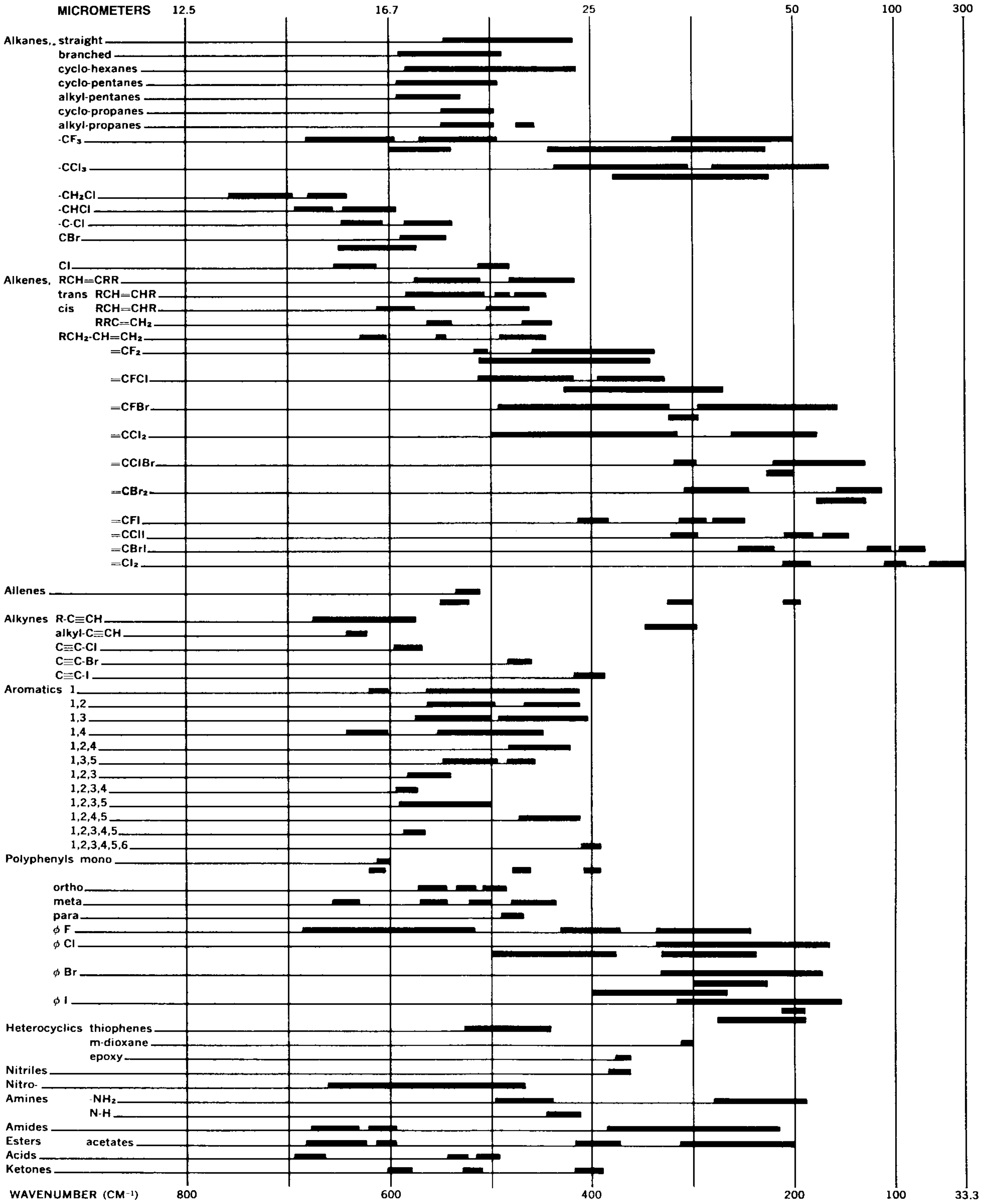


INFRARED CORRELATION CHARTS (continued)

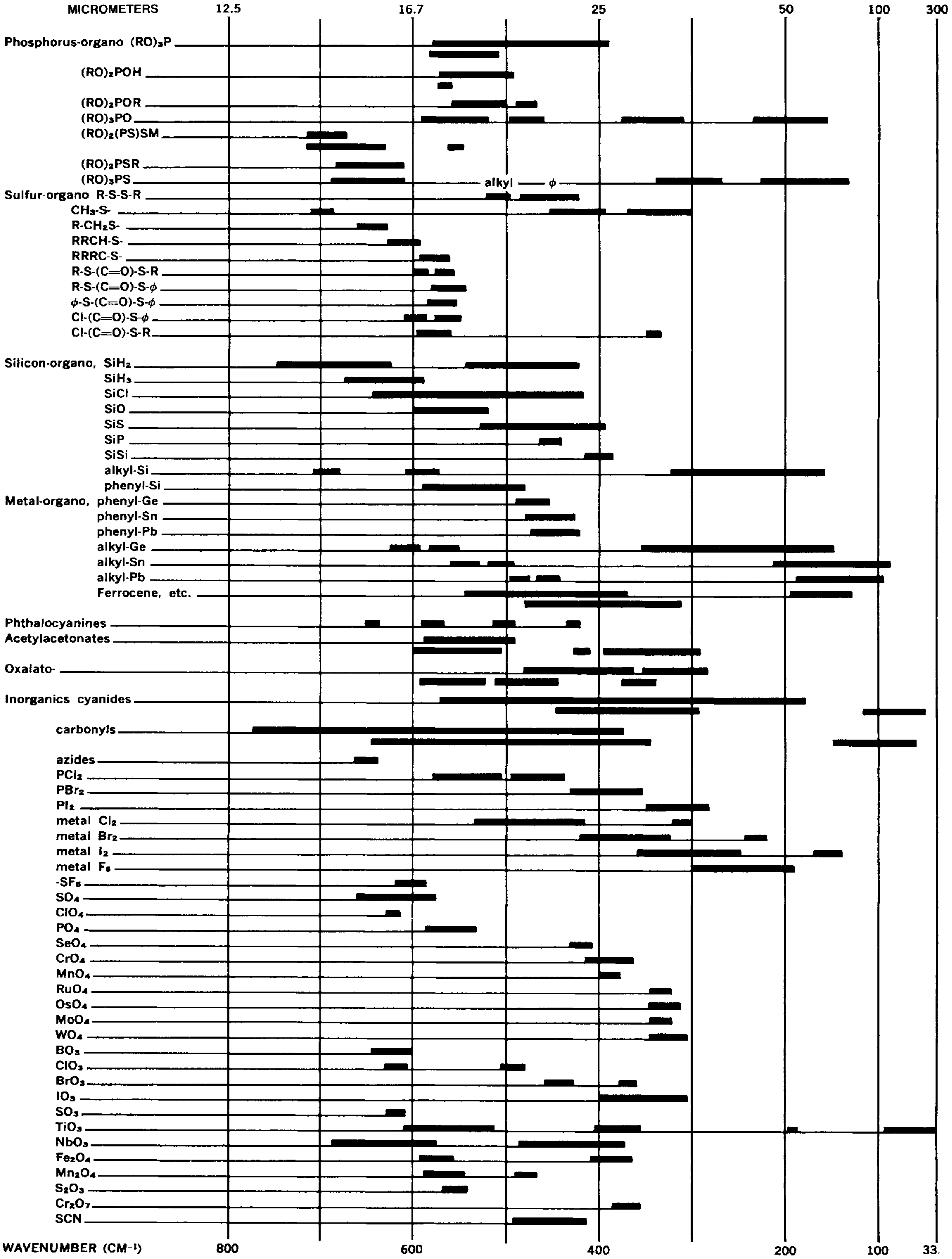


INFRARED CORRELATION CHARTS (continued)

Far Infrared Region



INFRARED CORRELATION CHARTS (continued)



NUCLEAR SPINS, MOMENTS, AND OTHER DATA RELATED TO NMR SPECTROSCOPY

This table presents the following data relevant to nuclear magnetic resonance spectroscopy:

Z: Atomic number
Isotope: Element symbol and mass number
Abundance: Natural abundance of the isotope in percent. An * indicates a radioactive nuclide; if no value is given, the nuclide is not present in nature or its abundance is highly variable.
I: Nuclear spin
ν: Resonant frequency in megahertz for an applied field H_o of 1 tesla (in cgs units, 10 kilogauss)
Relative sensitivity: Sensitivity relative to ^{1}H (=1) assuming an equal number of nuclei and constant temperature. Values were calculated from the expressions:

For constant H_o: $0.0076508(\mu/\mu_N)^3(I + 1)/I^2$

For constant ν: $0.23871(\mu/\mu_N)\ (I + 1)$

μ: Nuclear magnetic moment in units of the nuclear magneton μ_N
Q: Nuclear quadrupole moment in units of femtometers squared (1 fm^2 = 10^{-2} barn)

The table includes all stable nuclides of non-zero spin for which spin and magnetic moment values have been measured, as well as selected radioactive nuclides of current or potential interest. At least one isotope is included for each element through *Z* = 95 for which data are available. See Reference 2 for a complete listing of spins and moments.

The assistance of P. Pyykkö in providing recent data on nuclear quadrupole moments is gratefully acknowledged.

REFERENCES

1. Raghavan, P., "Table of Nuclear Moments", *At. Data Nuc. Data Tables,* 42, 189, 1989.
2. Holden, N. E., "Table of the Isotopes", in Lide, D. R., Ed., *CRC Handbook of Chemistry and Physics,* 74th Ed., CRC Press, Boca Raton, FL, 1993.
3. Pyykkö, P., *Z. Naturforsch.,* 47a, 189, 1992.

		Abundance		ν/MHz	Relative sensitivity			
Z	**Isotope**	**%**	**I**	**for H_o = 1 T**	**Const. H_o**	**Const. ν**	**μ/μ$_N$**	***Q*/fm^2**
1	^{1}n	*	1/2	29.1639	0.32139	0.6850	-1.91304275	
1	^{1}H	99.985	1/2	42.5764	1.00000	1.0000	+2.7928474	
1	^{2}H	0.015	1	6.53573	0.00965	0.4093	+0.8574382	+0.2860
1	^{3}H	*	1/2	45.4137	1.21354	1.0666	+2.9789625	
2	^{3}He	0.0001	1/2	32.4352	0.44212	0.7618	-2.1276248	
3	^{6}Li	7.5	1	6.2660	0.00850	0.3925	+0.8220467	-0.082
3	^{7}Li	92.5	3/2	16.5478	0.29355	1.9433	+3.256427	-4.01
4	^{9}Be	100	3/2	5.986	0.01389	0.7029	-1.1779	+5.288
5	^{10}B	19.9	3	4.5751	0.01985	1.7193	+1.800645	+8.459
5	^{11}B	80.1	3/2	13.6626	0.16522	1.6045	+2.688649	+4.059
6	^{13}C	1.10	1/2	10.7081	0.01591	0.2515	+0.7024118	
7	^{14}N	99.634	1	3.0776	0.00101	0.1928	+0.4037610	+2.02
7	^{15}N	0.366	1/2	4.3172	0.00104	0.1014	-0.2831888	
8	^{17}O	0.038	5/2	5.7741	0.02910	1.5822	-1.89379	-2.558
9	^{19}F	100	1/2	40.0765	0.83400	0.9413	+2.628868	
10	^{21}Ne	0.27	3/2	3.3630	0.00246	0.3949	-0.661797	+10.155
11	^{23}Na	100	3/2	11.2686	0.09270	1.3233	+2.217522	+10.89
12	^{25}Mg	10.00	5/2	2.6082	0.00268	0.7147	-0.85545	+19.94
13	^{27}Al	100	5/2	11.1028	0.20689	3.0424	+3.641507	+14.03
14	^{29}Si	4.67	1/2	8.4653	0.00786	0.1988	-0.55529	
15	^{31}P	100	1/2	17.2510	0.06652	0.4052	+1.13160	
16	^{33}S	0.75	3/2	3.2716	0.00227	0.3842	+0.6438212	-6.78
17	^{35}Cl	75.77	3/2	4.1764	0.00472	0.4905	+0.8218743	-8.165
17	^{37}Cl	24.23	3/2	3.4764	0.00272	0.4083	+0.6841236	-6.435
18	^{37}Ar	*	3/2	5.818	0.01276	0.6833	+1.145	
18	^{39}Ar	*	7/2	2.8	0.00617	1.3964	-1.3	
19	^{39}K	93.2581	3/2	1.9893	0.00051	0.2336	+0.3914662	+6.01
19	^{40}K	0.0117	4	2.4737	0.00523	1.5493	-1.298100	-7.49
19	^{41}K	6.7302	3/2	1.0919	0.00008	0.1282	+0.2148701	+7.33

Z	Isotope	Abundance %	I	ν/MHz for H_o = 1 T	Relative sensitivity Const. H_o	Const. ν	μ/μ$_N$	*Q*/fm^2
20	^{43}Ca	0.135	7/2	2.8688	0.00642	1.4150	-1.31726	-4.08
21	^{45}Sc	100	7/2	10.3588	0.30244	5.1093	+4.756487	-22
22	^{47}Ti	7.3	5/2	2.4040	0.00210	0.6587	-0.78848	+29
22	^{49}Ti	5.5	7/2	2.4047	0.00378	1.1861	-1.10417	+24
23	^{50}V	0.250	6	4.2504	0.05571	5.5904	+3.345689	+21
23	^{51}V	99.750	7/2	11.2130	0.38360	5.5306	+5.1487057	-5.2
24	^{53}Cr	9.501	3/2	2.4114	0.00091	0.2832	-0.47454	-15
25	^{55}Mn	100	5/2	10.5760	0.17881	2.8980	+3.46872	+33
26	^{57}Fe	2.1	1/2	1.3815	0.00003	0.0324	+0.0906230	
27	^{59}Co	100	7/2	10.077	0.27841	4.9702	+4.627	+42
28	^{61}Ni	1.140	3/2	3.8113	0.00359	0.4476	-0.75002	+16.2
29	^{63}Cu	69.17	3/2	11.2979	0.09342	1.3268	+2.22329	-22.0
29	^{65}Cu	30.83	3/2	12.1027	0.11484	1.4213	+2.38167	-20.4
30	^{67}Zn	4.1	5/2	2.6693	0.00287	0.7314	+0.875479	+15.0
31	^{69}Ga	60.108	3/2	10.2475	0.06971	1.2034	+2.01659	+17.0
31	^{71}Ga	39.892	3/2	13.0204	0.14300	1.5291	+2.56227	+10.0
32	^{73}Ge	7.73	9/2	1.4897	0.00141	1.1546	-0.8794677	-17.3
33	^{75}As	100	3/2	7.3148	0.02536	0.8590	+1.439475	+31.4
34	^{77}Se	7.63	1/2	8.1566	0.00703	0.1916	+0.535042	
35	^{79}Br	50.69	3/2	10.7039	0.07945	1.2570	+2.106400	+33.1
35	^{81}Br	49.31	3/2	11.5381	0.09951	1.3550	+2.270562	+27.6
36	^{83}Kr	11.5	9/2	1.6442	0.00190	1.2744	-0.970669	+25.3
37	^{85}Rb	72.165	5/2	4.1253	0.01061	1.1304	+1.35303	+27.4
37	^{87}Rb	27.835	3/2	13.9807	0.17703	1.6418	+2.75124	+13.2
38	^{87}Sr	7.00	9/2	1.8524	0.00272	1.4358	-1.093603	+33.5
39	^{89}Y	100	1/2	2.0949	0.00012	0.0492	-0.1374154	
40	^{91}Zr	11.22	5/2	3.9747	0.00949	1.0891	-1.30362	-20.6
41	^{93}Nb	100	9/2	10.4520	0.48821	8.1011	+6.1705	-32
42	^{95}Mo	15.92	5/2	2.7874	0.00327	0.7638	-0.9142	-2.2
42	^{97}Mo	9.55	5/2	2.8462	0.00349	0.7799	-0.9335	+25.5
43	^{99}Tc	*	9/2	9.63	0.38174	7.4633	+5.6847	-12.9
44	^{99}Ru	12.7	5/2	1.9553	0.00113	0.5358	-0.6413	+7.9
44	^{101}Ru	17.0	5/2	2.192	0.00159	0.6005	-0.7188	+45.7
45	^{103}Rh	100	1/2	1.3476	0.00003	0.0317	-0.08840	
46	^{105}Pd	22.33	5/2	1.957	0.00113	0.5364	-0.642	+66.0
47	^{107}Ag	51.839	1/2	1.7330	0.00007	0.0407	-0.1136796	
47	^{109}Ag	48.161	1/2	1.9924	0.00010	0.0468	-0.1306906	
48	^{111}Cd	12.80	1/2	9.0689	0.00966	0.2130	-0.5948861	
48	^{113}Cd	12.22	1/2	9.4868	0.01106	0.2228	-0.6223009	
49	^{113}In	4.3	9/2	9.3652	0.35121	7.2588	+5.5289	+79.9
49	^{115}In	95.7	9/2	9.3854	0.35348	7.2744	+5.5408	+81
50	^{115}Sn	0.34	1/2	14.0074	0.03561	0.3290	-0.91883	
50	^{117}Sn	7.68	1/2	15.2606	0.04605	0.3584	-1.00104	
50	^{119}Sn	8.59	1/2	15.9656	0.05273	0.3750	-1.04728	
51	^{121}Sb	57.36	5/2	10.2549	0.16302	2.8100	+3.3634	-36
51	^{123}Sb	42.64	7/2	5.5530	0.04659	2.7389	+2.5498	-49
52	^{123}Te	0.908	1/2	11.2346	0.01837	0.2639	-0.7369478	
52	^{125}Te	7.139	1/2	13.5451	0.03220	0.3181	-0.8885051	
53	^{127}I	100	5/2	8.5776	0.09540	2.3504	+2.813273	-78.9
54	^{129}Xe	26.4	1/2	11.8601	0.02162	0.2786	-0.7779763	
54	^{131}Xe	21.2	3/2	3.5158	0.00282	0.4129	+0.6918619	-12.0
55	^{133}Cs	100	7/2	5.6232	0.04838	2.7735	+2.582025	-0.37
56	^{135}Ba	6.592	3/2	4.2581	0.00500	0.5001	+0.837943	+16.0
56	^{137}Ba	11.23	3/2	4.7633	0.00700	0.5594	+0.937365	+24.5
57	^{138}La	* 0.0902	5	5.6614	0.09404	5.3188	+3.713646	+45
57	^{139}La	99.9098	7/2	6.0610	0.06058	2.9895	+2.7830455	+20
58	^{137}Ce	*	3/2	4.62	0.00641	0.5431	0.91	

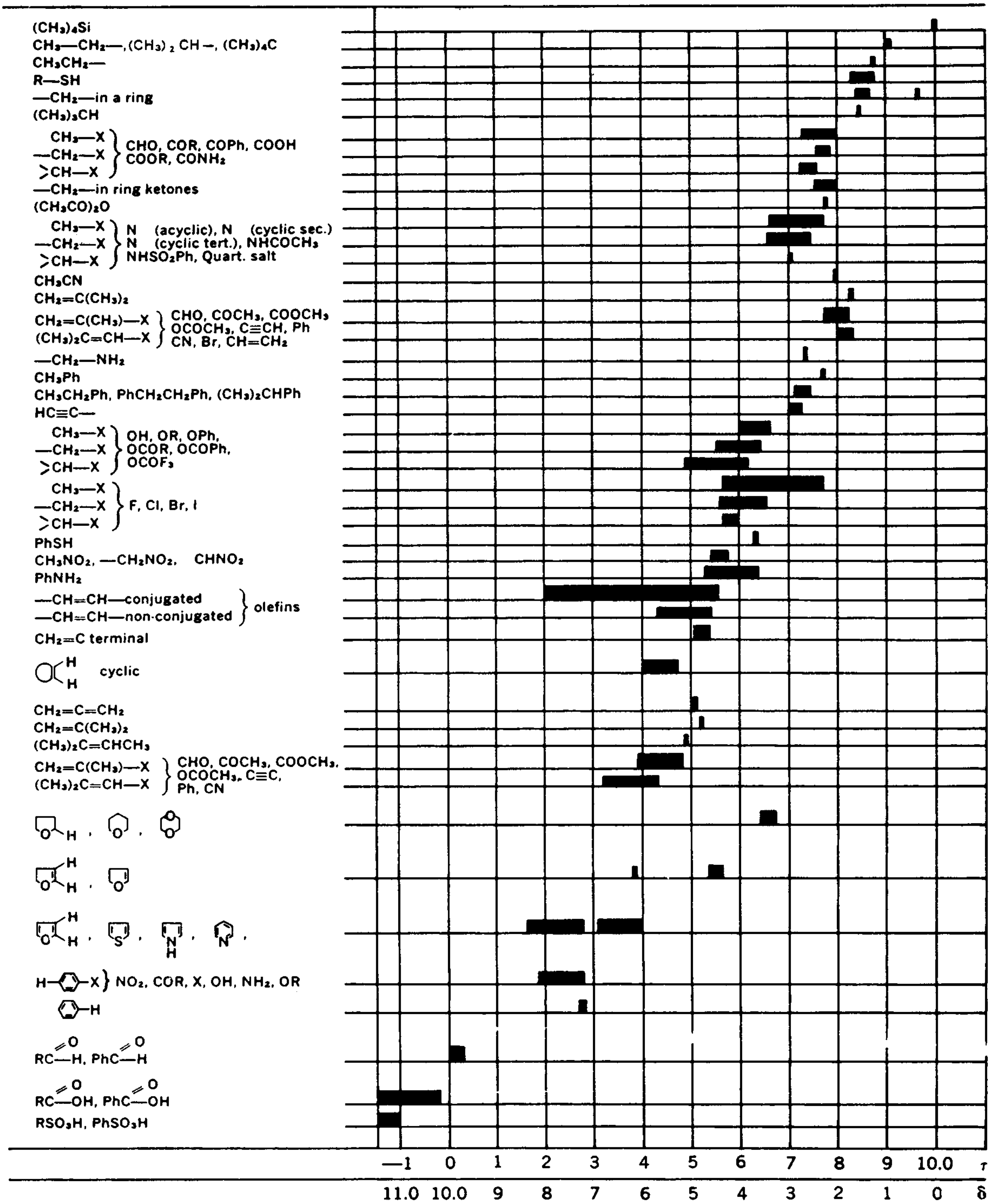
Z	**Isotope**	**Abundance %**	**I**	**ν/MHz for H_o = 1 T**	**Relative sensitivity Const. H_o**	**Const. ν**	**μ/μ$_N$**	**Q/fm^2**
58	^{139}Ce	*	3/2	4.62	0.00641	0.5431	0.91	
58	^{141}Ce	*	7/2	2.37	0.00364	1.1708	1.09	
59	^{141}Pr	100	5/2	13.0355	0.33483	3.5720	+4.2754	-5.9
60	^{143}Nd	12.18	7/2	2.319	0.00339	1.1440	-1.065	-63
60	^{145}Nd	8.30	7/2	1.429	0.00079	0.7047	-0.656	-33
61	^{143}Pm	*	5/2	11.6	0.23510	3.1748	3.8	
61	^{147}Pm	*	7/2	5.7	0.04940	2.7928	+2.6	+70
62	^{147}Sm	15.0	7/2	1.7747	0.00152	0.8753	-0.8149	-26
62	^{149}Sm	13.8	7/2	1.4631	0.00085	0.7216	-0.6718	+9.4
63	^{151}Eu	47.8	5/2	10.5854	0.17929	2.9006	+3.4718	+90.3
63	^{153}Eu	52.2	5/2	4.6744	0.01544	1.2809	+1.5331	+241
64	^{155}Gd	14.80	3/2	1.317	0.00015	0.1546	-0.2591	+127
64	^{157}Gd	15.65	3/2	1.727	0.00033	0.2028	-0.3399	+135
65	^{159}Tb	100	3/2	10.23	0.06945	1.2019	+2.014	+143.2
66	^{161}Dy	18.9	5/2	1.4653	0.00048	0.4015	-0.4806	+247
66	^{163}Dy	24.9	5/2	2.0507	0.00130	0.5619	+0.6726	+265
67	^{165}Ho	100	7/2	9.0881	0.20423	4.4825	+4.173	+358
68	^{167}Er	22.95	7/2	1.2281	0.00050	0.6057	-0.5639	+357
69	^{169}Tm	100	1/2	3.531	0.00057	0.0829	-0.2316	
70	^{171}Yb	14.3	1/2	7.5259	0.00552	0.1768	+0.49367	
70	^{173}Yb	16.12	5/2	2.0730	0.00135	0.5680	-0.67989	+280
71	^{175}Lu	97.41	7/2	4.8624	0.03128	2.3983	+2.2327	+349
71	^{176}Lu	* 2.59	7	3.451	0.03975	6.0516	+3.169	+497
72	^{177}Hf	18.606	7/2	1.7281	0.00140	0.8524	+0.7935	+336
72	^{179}Hf	13.629	9/2	1.0856	0.00055	0.8414	-0.6409	+379
73	^{180}Ta	0.012	9	4.04	0.10251	11.3862	4.77	
73	^{181}Ta	99.988	7/2	5.1625	0.03744	2.5463	+2.3705	+317
74	^{183}W	14.3	1/2	1.7956	0.00008	0.0422	+0.1177847	
75	^{185}Re	37.40	5/2	9.717	0.13870	2.6627	+3.1871	+218
75	^{187}Re	*62.60	5/2	9.817	0.14300	2.6900	+3.2197	+207
76	^{187}Os	1.6	1/2	0.9856	0.00001	0.0231	+0.06465189	
76	^{189}Os	16.1	3/2	3.3535	0.00244	0.3938	+0.659933	+85.6
77	^{191}Ir	37.3	3/2	0.766	0.00003	0.0899	+0.1507	+81.6
77	^{193}Ir	62.7	3/2	0.832	0.00004	0.0977	+0.1637	+75.1
78	^{195}Pt	33.8	1/2	9.2920	0.01039	0.2182	+0.60952	
79	^{197}Au	100	3/2	0.7406	0.00003	0.0870	+0.145746	+54.7
80	^{199}Hg	16.87	1/2	7.7121	0.00594	0.1811	+0.5058855	
80	^{201}Hg	13.18	3/2	2.8468	0.00149	0.3343	-0.5602257	+38.6
81	^{203}Tl	29.524	1/2	24.7310	0.19598	0.5809	+1.6222579	
81	^{205}Tl	70.476	1/2	24.9742	0.20182	0.5866	+1.6382146	
82	^{207}Pb	22.1	1/2	9.0338	0.00955	0.2122	+0.59258	
83	^{209}Bi	100	9/2	6.9628	0.14433	5.3967	+4.1106	-50
84	^{209}Po	*	1/2	11.7	0.02096	0.2757	+0.77	
86	^{211}Rn	*	1/2	9.16	0.00997	0.2152	+0.601	
87	^{223}Fr	*	3/2	5.94	0.01362	0.6982	+1.17	+117
88	^{223}Ra	*	3/2	1.3746	0.00017	0.1614	+0.2705	+119
88	^{225}Ra	*	1/2	11.187	0.01814	0.2627	-0.7338	
89	^{227}Ac	*	3/2	5.6	0.01131	0.6564	+1.1	+170
90	^{229}Th	*	5/2	1.40	0.00042	0.3843	+0.46	+430
91	^{231}Pa	*	3/2	10.2	0.06903	1.1995	2.01	-172
92	^{235}U	* 0.7200	7/2	0.83	0.00015	0.4082	-0.38	+493.6
93	^{237}Np	*	5/2	9.57	0.13264	2.6234	+3.14	+388.6
94	^{239}Pu	*	1/2	3.09	0.00038	0.0727	+0.203	
95	^{243}Am	*	5/2	4.91	0.01788	1.3451	+1.61	+421

PROTON NMR CHEMICAL SHIFTS FOR CHARACTERISTIC ORGANIC STRUCTURES

The chart below summarizes the range of chemical shifts for protons in several classes or organic compounds and substituent groups. The chemical shifts δ are given in parts per million relative to tetramethylsilane.

REFERENCE

Mohacsi, E., *J. Chem. Edu.*, 41, 38, 1964 (with permission).



^{13}C-NMR ABSORPTIONS OF MAJOR FUNCTIONAL GROUPS

The table below lists the range of ^{13}C chemical shifts δ in parts per million relative to tetramethylsilane, in descending order, for various functional groups. Examples of simple compounds for each family are given to illustrate the correlations. The shifts for the carbons of interest, which are italicized, are given in parentheses; when two or more values appear, they refer to the sequence of italicized carbon atoms from left to right in the formula.

REFERENCES

1. Yoder, C. H. and Schaeffer, C. D., Jr., *Introduction to Multinuclear NMR: Theory and Application*, Benjamin/ Cummings, Menlo Part, CA, 1987.
2. Silverstein, R. M., Bassler, G. C., and Morrill, T. C., *Spectrometric Identification of Organic Compounds*, John Wiley & Sons, New York, 1981.
3. Brown, D. W., A Short Set of ^{13}C NMR Correlation Tables, *J. Chem. Educ.*, 62, 209, 1985.

δ (ppm)	**Group**	**Family**	**Example (δ of italicized carbon)**	
220-165	>C=O	Ketones	$\mathrm{(CH_3)_2\mathit{C}O}$	(206.0)
			$\mathrm{(CH_3)_2CH\mathit{C}OCH_3}$	(212.1)
		Aldehydes	$\mathrm{CH_3\mathit{C}HO}$	(199.7)
		α,β-Unsaturated	$\mathrm{CH_3CH{=}CH\mathit{C}HO}$	(192.4)
		carbonyls	$\mathrm{CH_2{=}CH\mathit{C}OCH_3}$	(169.9)
		Carboxylic acids	$\mathrm{H\mathit{C}O_2H}$	(166.0)
			$\mathrm{CH_3\mathit{C}O_2H}$	(178.1)
		Amides	$\mathrm{H\mathit{C}ONH_2}$	(165.0)
			$\mathrm{CH_3\mathit{C}ONH_2}$	(172.7)
		Esters	$\mathrm{CH_3\mathit{C}O_2CH_2CH_3}$	(170.3)
			$\mathrm{CH_2{=}CH\mathit{C}O_2CH_3}$	(165.5)
140-120	>C=C<	Aromatic	$\mathrm{\mathit{C}_6H_6}$	(128.5)
		Alkenes	$\mathrm{\mathit{C}H_2{=}CH_2}$	(123.2)
			$\mathrm{\mathit{C}H_2{=}\mathit{C}HCH_3}$	(115.9, 136.2)
			$\mathrm{\mathit{C}H_2{=}\mathit{C}HCH_2Cl}$	(117.5, 133.7)
			$\mathrm{CH_3CH{=}\mathit{C}HCH_2CH_3}$	(132.7)
125-115	-CN	Nitriles	$\mathrm{CH_3\text{-}\mathit{C}N}$	(117.7)
80-70	-CC-	Alkynes	$\mathrm{H\mathit{C}CH}$	(71.9)
			$\mathrm{CH_3\mathit{C}CH_3}$	(73.9)
70-45	-C-O	Esters	$\mathrm{\mathit{C}H_3OO\mathit{C}H_2CH_3}$	(57.6, 67.9)
		Alcohols	$\mathrm{HO\mathit{C}H_3}$	(49.0)
			$\mathrm{HO\mathit{C}H_2CH_3}$	(57.0)
40-20	$\mathrm{\text{-}C\text{-}NH_2}$	Amines	$\mathrm{\mathit{C}H_3NH_2}$	(26.9)
			$\mathrm{CH_3\mathit{C}H_2NH_2}$	(35.9)
30-15	$\mathrm{\text{-}S\text{-}CH_3}$	Sulfides (thioethers)	$\mathrm{C_6H_5\text{-}S\text{-}\mathit{C}H_3}$	15.6
30-(-2.3)	-C-H	Alkanes, cycloalkanes	$\mathrm{\mathit{C}H_4}$	(-2.3)
			$\mathrm{\mathit{C}H_3CH_3}$	(5.7)
			$\mathrm{\mathit{C}H_3\mathit{C}H_2CH_3}$	(15.8, 16.3)
			$\mathrm{\mathit{C}H_3\mathit{C}H_2CH_2CH_3}$	(13.4, 25.2)
			$\mathrm{\mathit{C}H_3\mathit{C}H_2\mathit{C}H_2CH_2CH_3}$	(13.9, 22.8, 34.7)
		Cyclohexane		(26.9)

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BOND LENGTHS IN ORGANOMETALLIC COMPOUNDS

This table summarizes the average values of interatomic distances of representative metal-ligand bonds. Sigma bonds between *d*- and *f*-block metals and the elements C, N, O, P, S, and As are included. The values are extracted from a much larger list in Reference 1. The tabulated values are the unweighted means of reported measurements on compounds in each category. If four or more measurements are available, the standard deviation is given in parentheses. All values are in Ångstrom units (10^{-10} m).

The first part of the table covers metal-carbon bonds in different ligand categories, while the second part covers metal bonds to other elements. R stands for any alkyl group; Me for a CH_3 group; C_6R_5 indicates an aryl group; and C(=O)R an acyl group. Metals are listed in atomic number order.

REFERENCE

1. Orpen, A. G., Brammer, L., Allen, F.H., Kennard, O., Watson, D. G., and Taylor, R., *J. Chem. Soc. Dalton Trans*., 1989, S1-S83.

M	M-CH_3	M-CH_2R	M-CR=CR_2	M-C_6R_5	M-C(=O)R
Ti		2.167	2.215(0.042)	2.148	
V				2.114(0.012)	
Cr	2.168		2.035(0.009)	2.075(0.019)	
Mn	2.095(0.030)	2.176(0.024)	2.007	2.064(0.021)	2.044
Fe	2.074	2.091(0.030)	1.991(0.039)	2.031(0.062)	1.997(0.033)
Co	2.014(0.023)	2.039(0.032)	1.934(0.019)	1.974	1.990
Ni	2.029	1.964	1.892(0.017)	1.917(0.038)	1.850(0.059)
Cu				2.020	
Zn		1.964			
Zr	2.292(0.049)		2.257		
Nb	2.336	1.319			
Mo	2.254(0.065)	2.250(0.061)	2.204(0.049)	2.193(0.054)	2.109
Ru	2.179(0.045)	2.036(0.010)	2.063	2.092(0.057)	2.091
Rh	2.092(0.027)	2.100	2.040(0.054)	2.011(0.026)	1.995(0.031)
Pd		2.028	2.000(0.024)	1.981(0.032)	1.982(0.029)
Hf	2.275(0.049)		2.205		
Ta	2.217(0.035)	2.225(0.056)		2.199(0.073)	
W	2.189(0.039)	2.175	2.224		
Re	2.173(0.051)	2.290		2.027	2.190(0.027)
Os		2.221	2.052	2.090(0.032)	2.161
Ir	2.175		2.071(0.044)	2.070(0.038)	2.019
Pt	2.083(0.045)	2.062(0.031)	2.024(0.037)	2.049(0.046)	1.991(0.025)
Au	2.066(0.045)		2.042	2.059(0.024)	
Hg	2.072(0.026)	2.125		2.086(0.040)	
Th	2.567				

M	M-NH_3	M-OH_2	M-PMe_3	M-SR	M-AsR_3
Ti		2.066(0.052)		2.369	2.686
V		2.129(0.131)	2.510(0.010)	2.378(0.007)	
Cr	2.069(0.008)	1.997(0.070)	2.389(0.069)	2.362	2.460(0.040)
Mn		2.189(0.040)	2.455(0.164)	2.366(0.054)	2.400(0.013)
Fe		2.085(0.066)	2.246(0.042)	2.271(0.028)	2.352(0.043)
Co	1.965(0.021)	2.085(0.064)	2.217(0.043)	2.254(0.025)	2.323(0.021)
Ni	2.074(0.093)	2.079(0.038)	2.204(0.031)	2.187(0.007)	2.333(0.035)
Cu	1.987(0.017)	2.186(0.215)			2.367(0.016)
Zn	2.044	2.090(0.061)		2.295	
Y		2.398(0.068)			
Zr			2.692		
Nb		2.248(0.137)			2.741(0.008)
Mo	2.217	2.201(0.094)	2.462(0.046)	2.401(0.050)	2.582(0.036)
Ru	2.126(0.024)	2.074(0.051)	2.307(0.050)		2.446(0.031)
Rh	2.114(0.018)	2.190(0.096)	2.266(0.036)		2.416(0.039)
Pd	2.032	2.200	2.287(0.018)		2.386(0.052)
Ag		2.350			
Cd		2.318(0.065)		2.444	

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M	M-NH_3	M-OH_2	M-PMe_3	M-SR	M-AsR_3
La		2.556(0.062)			
Ce		2.565(0.063)			
Pr		2.518(0.038)			
Nd		2.533(0.058)			
Sm		2.459(0.050)			
Eu		2.441(0.055)			
Gd		2.443(0.074)			
Tb		2.455			
Dy		2.409(0.074)			
Ho		2.407(0.069)			
Er		2.404(0.083)			
Yb		2.353(0.066)			
Lu		2.404(0.116)			
Ta			2.589(0.044)		
W		2.115(0.065)	2.485(0.039)		
Re	2.253	2.199(0.091)	2.369(0.065)		2.575(0.006)
Os	2.136	2.166	2.328(0.029)		
Ir	2.050(0.021)		2.323(0.028)	2.461	
Pt			2.295(0.036)	2.320(0.015)	2.366(0.058)
Au		2.157		2.293	
Hg		2.690(0.083)		2.402(0.065)	
Th		2.483(0.032)			
U		2.455(0.047)			

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LINE SPECTRA OF THE ELEMENTS

Joseph Reader and Charles H. Corliss

The original tables from which this table was derived were prepared under the auspices of the Committee on Line Spectra of the Elements of the National Academy of Sciences-National Research Council. The table contains the outstanding spectral lines of neutral (I) and singly ionized (II) atoms of the elements from hydrogen through plutonium (Z = 1-94); selected strong lines from doubly ionized (III), triply ionized (IV), and quadruply ionized (V) atoms are also included. Listed are lines that appear in emission from the vacuum ultraviolet to the far infrared. These lines were selected from much larger lists in such a way as to include the stronger observed lines in each spectral region. A more extensive list may be found in Reference 1.

The data were compiled by the following contributors.

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All wavelengths are given in Angstrom units (10^{-10} m). Below 2000 Å, the wavelengths are in vacuum; above 2000 Å, the wavelengths are in air. Wavelengths given to three decimal places have an uncertainty of less than 0.001 Å and are therefore suitable for calibration purposes. In the air region, the elements used most commonly for calibration are Ne, Ar, Kr, Fe, Th, and Hg; in the vacuum region, the most common are C, N, O, Si, Cu.

All data refer to natural isotopic abundance of the elements except that Kr I and Kr II lines below 11,000 A given to three decimal places are for ^{86}Kr. Also, Hg I lines given to three decimal places are for ^{198}Hg; these are frequently used for calibration.

A large number of the lines for neutral and singly ionized atoms were extracted from the National Bureau of Standards (NBS) *Tables of Spectral-Line Intensities* (Reference 2). The intensities of these lines represent quantitative estimates of relative line strengths that take account of varying detection sensitivity at different wavelengths. They are on a linear scale. For nearly all of the other lines the intensities represent qualitative estimates of the relative strengths of lines not greatly separated in wavelength. Because different observers frequently use different scales for their intensity estimates, these intensities are useful only as a rough indication of the appearance of a spectrum. In some cases the intensity scale is not intended to be linear. In the first and second spectra the intensities of the lines of the singly ionized atom (II) relative to those of the neutral atom (I) should be used with caution, inasmuch as the concentration of ions in a light source depends greatly on the excitation conditions.

The default order of the table is alphabetical by element name (not symbol); for each element the lines are then listed by wavelength. The table can be sorted on wavelength to produce a finding list for identifying unknown lines. References to the sources of data for each element are given below.

GENERAL REFERENCES

1. Reader, J., Corliss, C. H., Wiese, W. L., and Martin, G. A., Tables of Line Spectra of the Elements, Part 1. Wavelengths and Intensities, Nat. Stand. Ref. Data Sys.- Nat. Bur. Standards (U.S.), No. 68, 1980.
2. Meggers, W. F., Corliss, C. H., and Scribner, B. F., Tables of Spectral Line Intensities, Part 1. Arranged by Elements, Nat. Bur. Stand. (U.S.), Monograph 145, 1975.
3. Fuhr, J. R., Martin, W. C., Musgrove, A., Sugar, J., and Wiese, W. L., "NIST Atomic Spectroscopic Database" ver. 1.1, January 1996. NIST Physical Reference Data, National Institute of Standards and Technology, Gaithersburg, MD. Available at the WWW address: http://physics.nist.gov/PhysRefData/contents.html

SOURCES OF DATA FOR EACH ELEMENT

Numbers following the element name refer to the references below.

Actinium: 193
Aluminum: 6,8,81,89,127,144,146,227,228,282
Americium: 92
Antimony: 164,167,194,386,406
Argon: 190,203,204,219,367,368,372,373,374,375,414,421
Arsenic: 163,168,197,244,280
Astatine: 188
Barium: 1,78,111,252,259,277,279

Berkelium: 53,339
Beryllium: 15,44,73,102,115,134,135,171,175,198,335
Bismuth: 1,357,358,359,360,361
Boron: 66,69,74,94,104,171,221,222
Bromine: 42,122,124,139,142,240,243,246,248,249,250,316
Cadmium: 44,285,296,353,399
Calcium: 16,25,70,150,270
Californium: 52,331
Carbon: 22,66,211
Cerium: 1,136,166,261,305
Cesium: 78,82,154,155,200,201,259,263,325
Chlorine: 11,28,30,31,85,233,238,239
Chromium: 1,379,380,412
Cobalt: 1,100,125,159,236,276,291
Copper: 199,273,290,295,324
Curium: 51,332
Dysprosium: 1
Einsteinium: 333
Erbium: 1,301
Europium: 1,312
Fluorine: 68,169,224,225,226
Francium: 408
Gadolinium: 1,46,137,151,152
Gallium: 2,19,62,132,140,141,143,195,281
Germanium: 5,119,293,340,341,342
Gold: 38,72,234,393,395
Hafnium: 1,369,404,410,425
Helium: 16,94,173,183,317
Holmium: 1
Hydrogen: 214
Indium: 1,132,348,349,350,351,352,353,435,436
Iodine: 20,21,58,84,124,153,161,176,184
Iridium: 1
Iron: 56,63,71,101,105,138,174,278,381,382
Krypton: 61,121,123,147,208,232,366,390,409,417,421
Lanthanum: 1,78,79,220,309
Lead: 54,64,106,256,274,297,283,329,330
Lithium: 3,15,17,18,37,44,112,284,321,335
Lutetium: 1,148,310,401
Magnesium: 4,7,49,83,103,128,129,177,217,269,315,335
Manganese: 1,126,385,405,433
Mercury (198): 43,50,69,145,229,242
Mercury (Natural): 34,45,90,117,133,189,235,304,327,328,343
Molybdenum: 1,383,420
Neodymium: 1
Neon: 56,58,69,118,150,230,364,365,371,388,389,400,402,413,430

Neptunium: 93
Nickel: 1,294,415,416,422
Niobium: 1,392,407,431
Nitrogen: 66,107,108,212,213,318
Osmium: 1
Oxygen: 23,24,36,66,69,209,210,215
Palladium: 1,287,424
Phosphorus: 179,180,182,336
Platinum: 1,288
Plutonium: 91
Polonium: 47,48
Potassium: 32,59,60,75,76,86,150,160,172,268,314,322
Praseodymium: 1,149,306,308,337,338
Promethium: 196,260
Protactinium: 96
Radium: 253,254
Radon: 251
Rhenium: 1
Rhodium: 1,396
Rubidium: 12,109,130,241,257,258,262,264
Ruthenium: 1,423
Samarium: 1
Scandium: 1,88,150,298,323
Selenium: 9,80,181,216,245,247,275
Silicon: 87,170,237,292,319,320
Silver: 13,99,255,286,289,363,387,398
Sodium: 178,205,206,207,268,299,334
Strontium: 1,109,110,218,231,265,279,313
Sulfur: 29,144,202,209,210,266
Tantalum: 1,411,426
Technetium: 35
Tellurium: 1,344,345,346,347
Terbium: 1,302
Thallium: 1,195,348,354,355,356
Thorium: 1,97,98,156,157,165,434
Thulium: 1,307
Tin: 187,191,399,423
Titanium: 1,378,427,428
Tungsten: 1
Uranium: 1,303
Vanadium: 1,394,397,432
Xenon: 33,116,118,120,232,384,391,429
Ytterbium: 1,40,192,311
Yttrium: 1,77,265,419
Zinc: 39,55,113,131,185,186,370,376,377
Zirconium: 1,362,403,418

REFERENCES

1. Meggers, W. F., Corliss, C. H., and Scribner, B. F., *Natl. Bur. Stand. (U.S.) Monogr.*, 145, Washington, DC., 1975.
2. Aksenov, V. P. and Ryabtsev, A. N., *Opt. Spectrosc.*, 37, 860, 1970.
3. Andersen, N., Bickel, W. S., Carriveau, G. W., Jensen, K., and Veje, E., *Phys. Scr.*, 4, 113, 1971.
4. Andersson, E. and Johannesson, G. A., *Phys. Scr.*, 3, 203, 1971.
5. Andrew, K. L. and Meissner, K. W., *J. Opt. Soc. Am.*, 49, 146, 1959.
6. Artru, M. C. and Brillet, W. U. L., *J. Opt. Soc. Am.*, 64, 1063, 1974.
7. Artru, M. C. and Kaufman, V., *J. Opt. Soc. Am.*, 62, 949, 1972.
8. Artru, M. C. and Kaufman, V., *J. Opt. Soc. Am.*, 65, 594, 1975.
9. Badami, J. S. and Rao, K. R., *Proc. R. Soc. London*, 140(A), 387, 1933.
10. Baird, K. M. and Smith, D. S., *J. Opt. Soc. Am.*, 48, 300, 1958.
11. Bashkin, S. and Martinson, I., *J. Opt. Soc. Am.*, 61, 1686, 1971.
12. Beacham, J. R., Ph.D. thesis, Purdue University, 1970.
13. Benschop, H., Joshi, Y. N., and van Kleef, T. A. M., *Can. J. Phys.*, 53, 700, 1975.
14. Berry, H. G., Bromander, J., and Buchta, R., *Phys. Scr.*, 1, 181, 1970.
15. Berry, H. G., Bromander, J., Martinson, I., and Buchta, R., *Phys. Scr.*, 3, 63, 1971.
16. Berry, H. G., Desesquelles, J., and Dufay, M., *Phys. Rev. Sect. A.*, 6, 600, 1972.
17. Berry, H. G., Desesquelles, J., and Dufay, M., *Nucl. Instrum. Methods*, 110, 43, 1973.
18. Berry, H. G., Pinnington, E. H., and Subtil, J. L., *J. Opt. Soc. Am.*, 62, 767, 1972.
19. Bidelman, W. P. and Corliss, C. H., *Astrophys. J.*, 135, 968, 1962.
20. Bloch, L. and Bloch, E., *Ann. Phys.* (Paris), 10(11), 141, 1929.
21. Bloch, L., Bloch, E., and Felici, N., *J. Phys. Radium*, 8, 355, 1937.
22. Bockasten, K., *Ark. Fys.*, 9, 457, 1955.
23. Bockasten, K., Hallin, R., Johansson, K. B., and Tsui, P., *Phys. Lett.* (Netherlands), 8, 181, 1964.
24. Bockasten, K. and Johansson, K. B., *Ark. Fys.*, 38, 563, 1969.
25. Borgstrom, A., *Ark. Fys.*, 38, 243, 1968.
26. Borgstrom, A., *Phys. Scr.*, 3, 157, 1971.
27. Bowen, I. S., *Phys. Rev.*, 29, 231, 1927.
28. Bowen, I. S., *Phys. Rev.*, 31, 34, 1928.
29. Bowen, I. S., *Phys. Rev.*, 39, 8, 1932.
30. Bowen, I. S., *Phys. Rev.*, 45, 401, 1934.
31. Bowen, I. S., *Phys. Rev.*, 46, 377, 1934.
32. Bowen, I. S., *Phys. Rev.*, 46, 791, 1934.
33. Boyce, J. C., *Phys. Rev.*, 49, 730, 1936.
34. Boyce, J. C. and Robinson, H. A., *J. Opt. Soc. Am.*, 26, 133, 1936.
35. Bozman, W. R., Meggers, W. F., and Corliss, C. H., *J. Res. Natl. Bur. Stand. Sect. A*, 71, 547, 1967.
36. Bromander, J., *Ark. Fys.*, 40, 257, 1969.
37. Bromander, J. and Buchta, R., *Phys. Scr.*, 1, 184, 1970.
38. Brown, C. M. and Ginter, M. L., *J. Opt. Soc. Am.*, 68, 243, 1978.
39. Brown, C. M., Tilford, S. G., and Ginter, M. L., *J. Opt. Soc. Am.*, 65, 1404, 1975.

40. Bryant, B. W., *Johns Hopkins Spectroscopic Report* No. 21, 1961.
41. Buchet, J. P., Buchet-Poulizac, M. C., Berry, H. G., and Drake, G. W. F., *Phys. Rev. Sect. A*, 7, 922, 1973.
42. Budhiraja, C. J. and Joshi, Y. N., *Can. J. Phys.*, 49, 391, 1971.
43. Burns, K. and Adams, K. B., *J. Opt. Soc. Am.*, 42, 56, 1952.
44. Burns, K. and Adams, K. B., *J. Opt. Soc. Am.*, 46, 94, 1956.
45. Burns, K., Adams, K. B., and Longwell, J., *J. Opt. Soc. Am.*, 40, 339, 1950.
46. Callahan, W. R., Ph.D. thesis, Johns Hopkins University, 1962.
47. Charles, G. W., *J. Opt. Soc. Am.*, 56, 1292, 1966.
48. Charles, G. W., Hunt, D. J., Pish, G., and Timma, D. L., *J. Opt. Soc. Am.*, 45, 869, 1955.
49. Codling, K., *Proc. Phys. Soc.*, 77, 797, 1961.
50. Comite Consulatif Pour La Definition du Metre, *J. Phys. Chem. Ref. Data*, 3, 852, 1974.
51. Conway, J. G., Blaise, J., and Verges, J., *Spectrochim. Acta Part B*, 31, 31, 1976.
52. Conway, J. G., Worden, E. F., Blaise, J., and Verges, J., *Spectrochim. Acta Part B*, 32, 97, 1977.
53. Conway, J. G., Worden, E. F., Blaise, J., Camus, P., and Verges, J., *Spectrochim. Acta Part B*, 32, 101, 1977.
54. Crooker, A. M., *Can. J. Res. Sect. A,* 14, 115, 1936.
55. Crooker, A. M. and Dick, K. A., *Can. J. Phys.*, 46, 1241, 1968.
56. Crosswhite, H. M., *J. Res. Natl. Bur. Stand. Sect. A*, 79, 17, 1975.
58. Crosswhite, H. M. and Dieke, G. H., *American Institute of Physics Handbook*, Section 7, 1972.
59. de Bruin, T. L., *Z. Phys.*, 38, 94, 1926.
60. de Bruin, T. L., *Z. Phys.*, 53, 658, 1929.
61. de Bruin, T. L., Humphreys, C. J., and Meggers, W. F., *J. Res. Natl. Bur. Stand.*, 11, 409, 1933.
62. Dick, K. A., *J. Opt. Soc. Am.*, 64, 702, 1973.
63. Dobbie, J. C., *Ann. Solar Phys. Observ.* (Cambridge), 5, 1, 1938.
64. Earls, L. T. and Sawyer, R. A., *Phys. Rev.*, 47, 115, 1935.
65. Edlen, B., *Z. Phys.*, 85, 85, 1933.
66. Edlen, B., *Nova Acta Reglae Soc. Sci. Ups.*, (IV) 9, No. 6, 1934.
67. Edlen, B., *Z. Phys.*, 93, 726, 1935.
68. Edlen, B., *Z. Phys.*, 94, 47, 1935.
69. Edlen, B., *Rep. Prog. Phys.*, 26, 181, 1963.
70. Edlen, B. and Risberg, P., *Ark. Fys.*, 10, 553, 1956.
71. Edlen, B. and Swings, P., *Astrophys. J.*, 95, 532, 1942.
72. Ehrhardt, J. C. and Davis, S. P., *J. Opt. Soc. Am.*, 61, 1342, 1971.
73. Eidelsberg, M., *J. Phys. B*, 5, 1031, 1972.
74. Eidelsberg, M., *J. Phys. B*, 7, 1476, 1974.
75. Ekberg, J. O. and Svensson, L. A., *Phys. Scr.*, 2, 283, 1970.
76. Ekefors, E., *Z. Phys.*, 71, 53, 1931.
77. Epstein, G. L. and Reader, J., *J. Opt. Soc. Am.*, 65, 310, 1975.
78. Epstein, G. L. and Reader, J., *J. Opt. Soc. Am.*, 66, 590, 1976.
79. Epstein, G. L. and Reader, J., unpublished.
80. Eriksson, K. B. S., *Phys. Lett. A.*, 41, 97, 1972.
81. Eriksson, K. B. S. and Isberg, H. B. S., *Ark. Fys.*, 23, 527, 1963.

82. Eriksson, K. B. S. and Wenaker, I., *Phys. Scr.*, 1, 21, 1970.
83. Esteva, J. M. and Mehlman, G., *Astrophys. J.*, 193, 747, 1974.
84. Even-Zohar, M. and Fraenkel, B. S., *J. Phys. B*, 5, 1596, 1972.
85. Fawcett, B. C., *J. Phys. B*, 3, 1732, 1970.
86. Fawcett, B. C., Culham Laboratory Report ARU-R4, 1971.
87. Ferner, E., *Ark. Mat. Astron. Fys.*, 28(A), 4, 1941.
88. Fischer, R. A., Knopf, W. C., and Kinney, F. E., *Astrophys. J.*, 130, 683, 1959.
89. Fowler, A., *Report on Series in Line Spectra*, Fleetway Press, London, 1922.
90. Fowles, G. R., *J. Opt. Soc. Am.*, 44, 760, 1954.
91. Fred, M., *Argonne Natl. Lab.*, unpublished, 1977.
92. Fred, M. and Tomkins, F. S., *J. Opt. Soc. Am.*, 47, 1076, 1957.
93. Fred, M., Tomkins, F. S., Blaise, J. E., Camus, P., and Verges, J., Argonne National Laboratory Report No. 76-68, 1976.
94. Garcia, J. D. and Mack, J. E., *J. Opt. Soc. Am.*, 55, 654, 1965.
96. Giacchetti, A., *Argonne Natl. Lab.*, unpublished, 1975.
97. Giacchetti, A., Blaise, J., Corliss, C. H., and Zalubas, R., *J. Res. Natl. Bur. Stand. Sect. A*, 78, 247, 1974.
98. Giacchetti, A., Stanley, R. W., and Zalubas, R., *J. Opt. Soc. Am.*, 69, 474, 1970.
99. Gilbert, W. P., *Phys. Rev.*, 47, 847, 1935.
100. Gilroy, H. T., *Phys. Rev.*, 38, 2217, 1931.
101. Glad, S., *Ark. Fys.*, 10, 291, 1956.
102. Goldsmith, S., *J. Phys. B*, 2, 1075, 1969.
103. Goorvitch, D., Mehlmam-Balloffet, G., and Valero, F. P. J., *J. Opt. Soc. Am.*, 60, 1458, 1970.
104. Goorvitch, D. and Valero, F. P. J., *Astrophys. J.*, 171, 643, 1972.
105. Green, L. C., *Phys. Rev.*, 55, 1209, 1939.
106. Gutman, F., *Diss. Abstr. Int. B*, 31, 363, 1970.
107. Hallin, R., *Ark. Fys.*, 31, 511, 1966.
108. Hallin, R., *Ark. Fys.*, 32, 201, 1966.
109. Hansen, J. E. and Persson, W., *J. Opt. Soc. Am.*, 64, 696, 1974.
110. Hansen, J. E. and Persson, W., *Phys. Scr.*, 13, 166, 1976.
111. Hellintin, P., *Phys. Scr.*, 13, 155, 1976.
112. Herzberg, G. and Moore, H. R., *Can. J. Phys.*, 37, 1293, 1959.
113. Hetzler, C. W., Boreman, R. W., and Burns, K., *Phys. Rev.*, 48, 656, 1935.
114. Holmstrom, J. E. and Johansson, L., *Ark. Fys.*, 40, 133, 1969.
115. Hontzeas, S., Martinson, I., Erman, P., and Buchta, R., *Nucl. Instrum. Methods*, 110, 51, 1973.
116. Humphreys, C. J., *J. Res. Natl. Bur. Stand.*, 22, 19, 1939.
117. Humphreys, C. J., *J. Opt. Soc. Am.*, 43, 1027, 1953.
118. Humphreys, C. J., *J. Phys. Chem. Ref. Data*, 2, 519, 1973.
119. Humphreys, C. J. and Andrew, K. L., *J. Opt. Soc. Am.*, 54, 1134, 1964.
120. Humphreys, C. J. and Meggers, W. F., *J. Res. Natl. Bur. Stand.*, 10, 139, 1933.
121. Humphreys, C. J. and Paul, E., Jr., *J. Opt. Soc. Am.*, 60, 200, 1970.
122. Humphreys, C. J. and Paul, E., Jr., *J. Opt. Soc. Am.*, 62, 432, 1972.
123. Humphreys, C. J., Paul, E., Jr., Cowan, R. D., and Andrew, K. L., *J. Opt. Soc. Am.*, 57, 855, 1967.

124. Humphreys, C. J., Paul, E., Jr., and Minnhagen, L., *J. Opt. Soc. Am.*, 61, 110, 1971.
125. Iglesias, L., Inst. of Optics, Madrid, unpublished, 1977.
126. Iglesias, L. and Velasco, R., *Publ. Inst. Opt. Madrid*, No. 23, 1964.
127. Isberg, B., *Ark. Fys.*, 35, 551, 1967.
128. Johannesson, G. A., Lundstrom, T., and Minnhagen, L., *Phys. Scr.*, 6, 129, 1972.
129. Johannesson, G. A. and Lundstrom, T., *Phys. Scr.*, 8, 53, 1973.
130. Johansson, I. *Ark. Fys.*, 20, 135, 1961.
131. Johansson, I. and Contreras, R., *Ark. Fys.*, 37, 513, 1968.
132. Johansson, I. and Litzen, U., *Ark. Fys.*, 34, 573, 1967.
133. Johansson, I. and Svensson, K. F., *Ark. Fys.*, 16, 353, 1960.
134. Johansson, L., *Ark. Fys.*, 20, 489, 1961.
135. Johansson, L., *Ark. Fys.*, 23, 119, 1963.
136. Johansson, S. and Litzen, U., *Phys. Scr.*, 6, 139, 1972.
137. Johansson, S. and Litzen, U., *Phys. Scr.*, 8, 43, 1973.
138. Johansson, S. and Litzen, U., *Phys. Scr.*, 10, 121, 1974.
139. Joshi, Y. N., St. Francis Xavier Univ., Nova Scotia, unpublished.
140. Joshi, Y. N., Bhatia, K. S., and Jones, W. E., *Sci. Light Tokyo*, 21, 113, 1972.
141. Joshi, Y. N., Bhatia, K. S., and Jones, W. E., *Spectrochim. Acta Part B*, 28, 149, 1973.
142. Joshi, Y. N. and Budhiraja, C. J., *Can. J. Phys.*, 49, 670, 1971.
143. Joshi, Y. N. and van Kleef, T. A. M., *Can. J. Phys.*, 52, 1891, 1974.
144. Kaufman, V., *Natl. Bur. Stand.*, unpublished.
145. Kaufman, V., *J, Opt. Soc. Am.*, 52, 866, 1962.
146. Kaufman, V., Artru, M. C., and Brillet, W. U. L., *J. Opt. Soc. Am.*, 64, 197, 1974.
147. Kaufman, V. and Humphreys, C. J., *J. Opt. Soc. Am.*, 59, 1614, 1969.
148. Kaufman, V. and Sugar, J., *J. Opt. Soc. Am.*, 61, 1693, 1971.
149. Kaufman, V. and Sugar, J., *J. Res. Natl. Bur. Stand. Sect. A*, 71, 583, 1967.
150. Kelly, R. L. and Palumbo, L. J., *Naval Research Laboratory Report 7599*, Washington, DC., 1973.
151. Kielkopf, J. F., *Univ. of Louisville*, unpublished. 1975.
152. Kielkopf, J. F., *Univ. of Louisville*, unpublished, 1976.
153. Kiess, C. C. and Corliss, C. H., *J. Res. Natl. Bur. Stand. Sect. A*, 63, 1, 1959.
154. Kleiman, H., *J. Opt. Soc. Am.*, 52, 441, 1962.
155. Eriksson, K. B., Johansson, I., and Norlen, G., *Ark. Fys.*, 28, 233, 1964.
156. Klinkenberg, P. F. A., *Physica*, 15, 774, 1949.
157. Klinkenberg, P. F. A., *Physica*, 16, 618, 1950.
158. Krishnamurty, S. G., *Proc. Phys. Soc. London*, 48, 277, 1936.
159. Kruger, P. G. and Gilroy, H. T., *Phys. Rev.*, 48, 720, 1935.
160. Kruger, P. G. and Pattin, H. S., *Phys. Rev.*, 52, 621, 1937.
161. Lacroute, P., *Ann. Phys.* (Paris), 3, 5, 1935.
162. Lang, R. J., *Phys. Rev.*, 30, 762, 1927.
163. Lang, R. J., *Phys. Rev.*, 32, 737, 1928.
164. Lang, R. J., *Phys. Rev.*, 35, 445, 1930.
165. Lang, R. J., *Can. J. Res. Sect. A*, 14, 43, 1936.
166. Lang, R. J., *Can. J. Res. Sect. A*, 14, 127, 1936.
167. Lang, R. J. and Vestine, E. H., *Phys. Rev.*, 42, 233, 1932.
168. Li, H. and Andrew, K. L., *J. Opt. Soc. Am.*, 61, 96, 1971.

169. Liden, K., *Ark. Fys*., 1, 229, 1949.
170. Litzen, U., *Ark. Fys*., 28, 239, 1965.
171. Litzen, U., *Phys. Scr.*, 1, 251, 1970.
172. Litzen, U., *Phys. Scr.*, 1, 253, 1970.
173. Litzen, U., *Phys. Scr.*, 2, 103, 1970.
174. Litzen, U. and Verges, I., *Phys. Scr*., 13, 240, 1976.
175. Lofstrand, B., *Phys. Scr.*, 8, 57, 1973.
176. Luc-Koenig, E., Morillon, C., and Verges, J., *Phys. Scr*., 12, 199, 1975.
177. Lundstrom, T., *Phys. Scr.*, 7, 62, 1973.
178. Lundstrom, T. and Minnhagen, L., *Phys. Scr*., 5, 243, 1972.
179. Magnusson, C. E. and Zetterberg, P. O., *Phys. Scr.*, 10, 177, 1974.
180. Magnusson, C. E., and Zetterberg, P. O., *Phys. Scr*., 15, 237, 1977.
181. Martin, D. C., *Phys. Rev*., 48. 938, 1935.
182. Svendenius, N., *Phys. Scr*., 22, 240, 1980.
183. Martin, W. C., *J. Res. Natl. Bur. Stand. Sect. A*, 64, 19, 1960.
184. Martin, W. C. and Corliss, C. H., *J. Res. Natl. Bur. Stand. Sect. A,* 64, 443, 1960.
185. Martin, W. C. and Kaufman, V., *J. Res. Natl. Bur. Stand. Sect. A*, 74, 11, 1970.
186. Martin, W. C. and Kaufman, V., *J. Opt. Soc. Am*., 60, 1096, 1970.
187. McCormick, W. W. and Sawyer, R. A., *Phys. Rev.*, 54, 71, 1938.
188. McLaughlin, R., *J. Opt. Soc. Am.*, 54, 965, 1964.
189. McLennan, J. C., McLay, A. B., and Crawford, M. F., *Proc. R. Soc. London Ser. A*, 134, 41, 1931.
190. Meissner, K. W., *Z. Phys.*, 39, 172, 1926.
191. Meggers, W. F., *J. Res. Natl. Bur. Stand*., 24, 153, 1940.
192. Meggers, W. F. and Corliss, C. H., *J. Res. Natl. Bur. Stand. Sect. A*, 70, 63, 1966.
193. Meggers, W. F., Fred, M., and Tomkins, F. S., *J. Res. Natl. Bur. Stand*., 58, 297, 1957.
194. Meggers, W. F. and Humphreys, C. J., *J. Res. Natl. Bur. Stand*., 28, 463, 1942.
195. Meggers, W. F. and Murphy, R. J., *J. Res. Natl. Bur. Stand*., 48, 334, 1952.
196. Meggers, W. F., Scribner, B. F., and Bozman, W. R., *J. Res. Natl. Bur. Stand*., 46, 85, 1951.
197. Meggers, W. F., Shenstone, A. G., and Moore, C. E., *J. Res. Natl. Bur. Stand.*, 45, 346, 1950.
198. Mehlman, G. and Esteva, J. M., *Astrophys. J*., 188, 191, 1974.
199. Meinders, E., *Physica*, 84(C), 117, 1976.
200. Sansonetti, C. J., Dissertation, Purdue University, 1981.
201. Sansonetti, C. J., *Natl. Bur. Stand. (U.S.)*, unpublished.
202. Millikan, R. A. and Bowen, I. S., *Phys. Rev.*, 25, 600, 1925.
203. Minnhagen, L., *J. Opt. Soc. Am*., 61, 1257, 1925.
204. Minnhagen, L., *J. Opt. Soc. Am*., 63, 1185, 1973.
205. Minnhagen, L., *Phys. Scr*., 11, 38, 1975.
206. Minnhagen, L., *J. Opt. Soc. Am*., 66, 659, 1976.
207. Minnhagen, L. and Nietsche, H., *Phys. Scr*., 5, 237, 1972.
208. Minnhagen. L., Strihed, H., and Petersson, B., *Ark. Fys*., 39, 471, 1969.
209. Moore, C. E., *Natl. Bur. Stand. (U.S.) Circ*., 488, 1950.
210. Moore, C. E., *Revised Multiplet Table*, Princeton University Observatory No. 20, 1945.

211. Moore, C. E., National Standard Reference Data Series - National Bureau of Standards 3, Sect. 3, 1970.
212. Moore, C. E., National Standard Reference Data Series - National Bureau of Standards 3, Sect. 4, 1971.
213. Moore, C. E., National Standard Reference Data Series - National Bureau of Standards 3, Sect. 5, 1975.
214. Moore, C. E., National Standard Reference Data Series - National Bureau of Standards 3, Sect. 6, 1972.
215. Moore, C. E., National Standard Reference Data Series - National Bureau of Standards 3, Sect. 7, 1975.
216. Morillon, C. and Verges, J., *Phys. Scr.*, 10, 227, 1974.
217. Newsom, G. H., *Astrophys. J.*, 166, 243, 1971.
218. Newsom, G. H., O'Connor, S., and Learner, R. C. M., *J. Phys. B*, 6, 2162, 1973.
219. Norlen, G., *Phys. Scr.*, 8, 249, 1973.
220. Odabasi, H., *J. Opt. Soc. Am.*, 57, 1459, 1967.
221. Olme, A., *Ark. Fys.*, 40, 35, 1969.
222. Olme, A., *Phys. Scr.*, 1, 256, 1970.
223. Johansson, S., and Litzen, U., *J. Opt. Soc. Am.*, 61, 1427, 1971.
224. Palenius, H. P., *Ark. Fys.*, 39, 15, 1969.
225. Palenius, H. P., *Phys. Scr.*, 1, 113, 1970.
226. Palenius, H. P., *Univ. of Lund, Sweden*, unpublished.
227. Paschen, F., *Ann. Phys.*, Series 5, 12, 509, 1932.
228. Paschen, F. and Ritschl, R., *Ann. Phys.*, Series 5, 18, 867, 1933.
229. Peck, E. R., Khanna, B. N., and Anderholm, N. C., *J. Opt. Soc. Am.*, 52, 53, 1962.
230. Persson, W., *Phys. Scr.*, 3, 133, 1971.
231. Persson, W. and Valind, S., *Phys. Scr.*, 5, 187, 1972.
232. Petersson, B., *Ark. Fys.*, 27, 317, 1964.
233. Phillips, L. W. and Parker, W. L., *Phys. Rev.*, 60, 301, 1941.
234. Platt, J. R. and Sawyer, R. A., Phys. Rev., 60, 866, 1941.
235. Plyer, E. K., Blaine, L. R., and Tidwell, E., *J. Res. Natl. Bur. Stand.*, 55, 279, 1955.
236. Poppe, R., van Kleef, T. A. M., and Raassen, A. J. J., *Physica*, 77, 165, 1974.
237. Radziemski, L. J., Jr. and Andrew, K. L., *J. Opt. Soc. Am.*, 55, 474, 1965.
238. Radziemski, L. J., Jr. and Kaufman, V., *J. Opt. Soc. Am.*, 59, 424, 1969.
239. Radziemski, L. J., Jr. and Kaufman, V., *J. Opt. Soc. Am.*, 64, 366, 1974.
240. Ramanadham, R. and Rao, K. R., *Indian J. Phys.*, 18, 317, 1944.
241. Ramb, R., *Ann. Phys.*, 10, 311, 1931.
242. Rank, D. H., Bennett, J. M., and Bennett, H. E., *J. Opt. Soc. Am.*, 40, 477, 1950.
243. Rao, A. S. and Krishnamurty, S. G., *Proc. Phys. Soc. London*, 46, 531, 1943.
244. Rao, K. R., *Proc. R. Soc. London, Ser. A*, 134, 604, 1932.
245. Rao, K. R. and Badami, J. S., *Proc. R. Soc. London Ser. A*, 131, 154, 1931.
246. Rao, K. R. and Krishnamurty, S. G., *Proc. R. Soc. London Ser. A*, 161, 38, 1937.
247. Rao, K. R. and Murti, S. G. K., *Proc. R. Soc. London Ser. A*, 145, 681, 1934.
248. Rao, Y. B., *Indian J. Phys.*, 32, 497, 1958.
249. Rao, Y. B., *Indian J. Phys.*, 33, 546, 1959.
250. Rao, Y. B., *Indian J. Phys.*, 35, 386, 1961.
251. Rasmussen, E., *Z. Phys.*, 80, 726, 1933.

252. Rasmussen, E., *Z. Phys*., 83, 404, 1933.
253. Rasmussen, E., *Z. Phys*., 86, 24, 1934.
254. Rasmussen, E., *Z. Phys*., 87, 607, 1934.
255. Rasmussen, E., *Phys. Rev*., 57, 840, 1940.
256. Rau, A. S. and Narayan, A. L., *Z. Phys*., 59, 687, 1930.
257. Reader, J., *J. Opt. Soc. Am*., 65, 286, 1975.
258. Reader, J., *J. Opt. Soc. Am.*, 65, 988, 1975.
259. Reader, J., *J. Opt Soc. Am*., 73, 349, 1983.
260. Reader, J. and Davis, S., *J. Res. Natl. Bur. Stand. Sect. A*, 71, 587, 1967, and unpublished.
261. Reader, J. and Ekberg, J. O., *J. Opt. Soc. Am*., 62, 464, 1972.
262. Reader, J. and Epstein, G. L., *J. Opt. Soc. Am*., 62, 1467, 1972.
263. Reader, J. and Epstein, G. L., *J. Opt. Soc. Am.*, 65, 638, 1975.
264. Reader, J. and Epstein, G. L., *Natl. Bur. Stand*., unpublished.
265. Reader, J., Epstein, G. L., and Ekberg, J. O., *J. Opt. Soc. Am*., 62, 273, 1972.
266. Kaufman, V., *Phys. Scr*., 26, 439, 1982.
267. Ricard, R., Givord, M., and George, F., *C. R. Acad. Sci. Paris*, 205, 1229, 1937.
268. Risberg, P., *Ark. Fys.*, 10, 583, 1956.
269. Risberg, G., *Ark. Fys*., 28, 381, 1965.
270. Risberg, G., *Ark. Fys.*, 37, 231, 1968.
271. Robinson, H. A., *Phys. Rev.*, 49, 297, 1936.
272. Robinson, H. A., *Phys. Rev.*, 50, 99, 1936.
273. Ross, C. B., Jr., Doctoral dissertation, Purdue University, 1969.
274. Ross, C. B., Wood, D. R., and Scholl, P. S., *J. Opt. Soc. Am*., 66, 36, 1976.
275. Ruedy, J. E. and Gibbs, R. C., *Phys. Rev*., 46, 880, 1934.
276. Russell, H. N., King, R. B., and Moore, C. E., *Phys. Rev*., 58, 407, 1940.
277. Russell, H. N. and Moore, C. E., *J. Res. Natl. Bur. Stand.*, 55, 299, 1955.
278. Russell, H. N., Moore, C. E., and Weeks, D. W., *Trans. Am. Philos. Soc.*, 34(2), 111, 1944.
279. Saunders, F., Schneider, E., and Buckingham, E., *Proc. Natl. Acad. Sci.*, 20, 291, 1934.
280. Sawyer, R. A. and Humphreys, C. J., *Phys. Rev*., 32, 583, 1928.
281. Sawyer, R. A. and Lang, R. J., *Phys. Rev.*, 34, 712, 1929.
282. Sawyer, R. A. and Paschen, F., *Ann. Phys.*, 84(4),1, 1927.
283. Scholl, P. S., M.S. thesis, Wright State Univ., 1975.
284. Schurmann, D., *Z. Phys*., 17, 4, 1975.
285. Seguier, J., *C. R. Acad. Sci. Paris*, 256, 1703, 1963.
286. Shenstone, A. G., *Phys. Rev*., 31, 317, 1928.
287. Shenstone, A. G., *Phys. Rev.*, 32, 30, 1928.
288. Shenstone, A. G., *Trans. R. Soc. London*, 237(A), 57, 1938.
289. Shenstone, A. G., *Phys. Rev*., 57, 894, 1940.
290. Shenstone, A. G. *Philos. Trans. R. Soc. London Ser. A*, 241, 297, 1948.
291. Shenstone, A. G., *Can. J. Phys*., 38, 677, 1960.
292. Shenstone, A. G., *Proc. R. Soc. London*, 261(A), 153, 1961.
293. Shenstone, A. G., *Proc. R. Soc. London*, 276(A), 293, 1963.
294. Shenstone, A. G., *J. Res. Natl. Bur. Stand. Sect. A*, 74, 801, 1970.
295. Shenstone, A. G., *J. Res. Natl. Bur. Stand. Sect. A*, 79, 497, 1975.
296. Shenstone, A. G. and Pittenger, J. T., *J. Opt. Soc. Am*., 39, 219, 1949.
297. Smith, S., *Phys. Rev*., 36, 1, 1930.

298. Smitt, R., *Phys. Scr.*, 8, 292, 1973.
299. Soderqvist, J., *Ark. Mat. Astronom. Fys.*, 32(A), 1, 1946.
300. Sommer, L. A., *Ann. Phys.*, 75, 163, 1924.
301. Spector, N., *J. Opt. Soc. Am.*, 63, 358, 1973.
302. Spector, N. and Sugar, J., *J. Opt. Soc. Am.*, 66, 436, 1976.
303. Steinhaus, D. W., Radziemski, L. J., Jr., and Blaise, J., *Los Alamos Sci. Lab.*, unpublished, 1975.
304. Subbaraya, T. S., *Z. Phys.*, 78, 541, 1932.
305. Sugar, J., *J. Opt. Soc. Am.*, 55, 33, 1965.
306. Sugar, J., *J. Res. Natl. Bur. Stand. Sect. A*, 73, 333, 1969.
307. Sugar, J., *J. Opt. Soc. Am.*, 60, 454, 1970.
308. Sugar, J., *J. Res. Natl. Bur. Stand. Sect. A,* 78, 555, 1974.
309. Sugar, J. and Kaufman, V., *J. Opt. Soc. Am.*, 55, 1283, 1965.
310. Sugar, J. and Kaufman, V., *J. Opt. Soc. Am.*, 62, 562, 1972.
311. Sugar, J., Kaufman, V., and Spector, N., *J. Res. Natl. Bur. Stand., Sect. A*, 83, 233, 1978.
312. Sugar, J. and Spector, N., *J. Opt. Soc. Am.*, 64, 1484, 1974.
313. Sullivan, F. J. *Univ. Pittsburgh Bull.*, 35, 1, 1938.
314. Svensson, L. A. and Ekberg, J. O., *Ark. Fys.*, 37, 65, 1968.
315. Swensson, J. W. and Risberg, G., *Ark. Fys.*, 31, 237, 1966.
316. Tech, J. L., *J. Res. Natl. Bur. Stand. Sect. A*, 67, 505, 1963.
317. Tech, J. L. and Ward, J. F., *Phys. Rev. Lett.*, 27, 367, 1971.
318. Tilford, S. G., *J. Opt. Soc. Am.*, 53, 1051, 1963.
319. Toresson, Y. G., *Ark. Fys.*, 17, 179, 1960.
320. Toresson, Y. G., *Ark. Fys.*, 18, 389, 1960.
321. Toresson, Y. G. and Edlen, B., *Ark. Fys.*, 23, 117, 1963.
322. Tsien, W. Z., *Chin. J. Phys.*, Peiping, 3, 117, 1939.
323. van Deurzen, C. H. H., Conway, J., and Davis, S. P., *J. Opt. Soc. Am.*, 63, 158, 1973.
324. van Kleef, T. A. M., Raassen, A. J. J., and Joshi, Y. N., *Physica*, 84(C), 401, 1976.
325. Sansonetti, C. J., Andrew, K. L., and Verges, J., *J. Opt. Soc. Am.*, 71, 423, 1981.
326. Wheatley, M. A. and Sawyer, R. A., *Phys. Rev.*, 61, 591, 1942.
327. Wilkinson, P. G., *J. Opt. Soc. Am.*, 45, 862, 1955.
328. Wilkinson, P. G. and Andrew, K. L., *J. Opt. Soc. Am.*, 53, 710, 1963.
329. Wood, D. and Andrew, K. L., *J. Opt. Soc. Am.*, 58, 818, 1968.
330. Wood, D. R., Ron, C. B., Scholl, P. S., and Hoke, M., *J. Opt. Soc. Am.*, 64, 1159, 1974.
331. Worden, E. F. and Conway, J. G., *Lawrence Livermore Lab.*, unpublished, 1977.
332. Worden, E. F., Hulet, E. K., Gutmacher, R. G., Conway, J. G., *At. Data Nucl. Data Tables*, 18, 459, 1976.
333. Worden, E. F., Lougheed, R. W., Gutmacher, R. G., and Conway, J. G., *J. Opt. Soc. Am.*, 64, 77, 1974.
334. Wu, C. M., Ph.D. thesis, University of British Columbia, 1971.
335. Zaidel, A. N., Prokofev, V. K., Raiskii, S. M., Slavnyi, V. A., and Schreider, E. Y., *Tables of Spectral Lines*, 3rd ed., Plenum, New York, 1970.
336. Zetterberg, P. O. and Magnusson, C. E., *Phys. Scr.*, 15, 189, 1977.
337. Sugar, J., *J. Opt. Soc. Am.*, 55, 1058, 1965.
338. Sugar, J., *J. Opt. Soc. Am.*, 61, 727, 1971.
339. Worden, E. F., and Conway, J. G., *At. Data Nucl. Data Tables*, 22, 329, 1978.

340. Kaufman, V. and Edlen, B., *J. Phys. Chem. Ref. Data*, 3, 825, 1974.
341. Lang, R. J., *Phys. Rev.*, 34, 697, 1929.
342. Ryabtsev, A. N., *Opt. Spectros.*, 39, 455, 1975.
343. Foster, E. W., *Proc. R. Soc. London*, 200(A), 429, 1950.
344. Morillon, C. and Verges, J., *Phys. Scr.*, 12, 129, 1975.
345. Ruedy, J. E., *Phys. Rev.*, 41, 588, 1932.
346. McLennan, J. C., McLay, A. B., and McLeod, J. H., *Philos. Mag.*, 4 ,486, 1927.
347. Handrup, M. B. and Mack, J. E., *Physica*, 30, 1245, 1964.
348. Clearman, H. E., *J. Opt. Soc. Am.*, 42, 373, 1952.
349. Paschen, F., *Ann. Physik*, 424, 148, 1938.
350. Paschen, F. and Campbell, J. S., *Ann. Phys.*, 31(5), 29, 1938.
351. Nodwell, R., *Univ. of British Columbia, Vancouver*, unpublished, 1955.
352. Gibbs, R. C. and White, H. E., *Phys. Rev.*, 31, 776, 1928.
353. Green, M., *Phys. Rev.*, 60, 117, 1941.
354. Ellis, C. B. and Sawyer, R. A., *Phys. Rev.*, 49, 145, 1936.
355. McLennan, J. C., McLay, A. B., and Crawford, M. F., *Proc. R. Soc. London Ser. A*, 125, 50, 1929.
356. Mack, J. E. and Fromer, M., *Phys. Rev.*, 48, 346, 1935.
357. Humphreys, C. J. and Paul, E., U.S. Nav. Ord. Lab., Navord Rep. 4589, 25, 1956.
358. Walters, F. M., *Sci. Pap. Bur. Stand.*, 17, 161, 1921.
359. Crawford, M. F. and McLay, A. B., *Proc. R. Soc. London Ser. A*, 143, 540, 1934.
360. McLay, A. D. and Crawford, M. F., Phys. Rev., 44, 986, 1933.
361. Schoepfle, G. K., *Phys. Rev.*, 47, 232, 1935.
362. Acquista, N., and Reader, J., *J. Opt. Soc. Am.*, 70, 789, 1980.
363. Benschop, H., Joshi, Y. N., and van Kleef, T. A. M., *Can. J. Phys.*, 53, 498, 1975.
364. Bockasten, K., Hallin, R., and Hughes, T. P., *Proc. Phys. Soc.*, 81, 522, 1963.
365. Boyce, J. C., *Phys. Rev.*, 46, 378, 1934.
366. Boyce, J. C., *Phys. Rev.*, 47, 718, 1935.
367. Boyce, J. C., *Phys. Rev.*, 48, 396, 1935.
368. Boyce, J. C., *Phys. Rev.*, 49, 351, 1936.
369. Corliss, C. H. and Meggers, W. F., *J. Res. Natl. Bur. Stand.*, 61, 269, 1958.
370. Crooker, A. M. and Dick, K. A., *Can. J. Phys.*, 42, 766, 1964.
371. De Bruin, T. L., *Z. Physik*, 77, 505, 1932.
372. De Bruin, T. L., *Proc. Roy. Acad. Amsterdam*, 36, 727, 1933.
373. De Bruin, T. L., *Zeeman Verhandelingen*, (The Hague), 1935, p. 415.
374. De Bruin, T. L., *Physica*, 3, 809, 1936.
375. De Bruin, T. L., *Proc. Roy. Acad. Amsterdam*, 40, 339, 1937.
376. Dick, K. A., *Can. J. Phys.*, 46, 1291, 1968.
377. Dick, K. A., unpublished, 1978.
378. Edlen, B. and Swensson, J. W., *Phys. Scr.*, 12, 21, 1975.
379. Ekberg, J. O., *Phys. Scr.*, 7, 55, 1973.
380. Ekberg, J. O., *Phys. Scr.*, 7, 59, 1973.
381. Ekberg, J. O., *Phys. Scr.*, 12, 42, 1975.
382. Ekberg, J. O. and Edlen, B., *Phys. Scr.*, 18, 107, 1978.
383. Eliason, A. Y., *Phys. Rev.*, 43, 745, 1933.

384. Gallardo, M., Massone, C. A., Tagliaferri, A. A., Garavaglia, M., and Persson, W., *Phys. Scr*., 19, 538, 1979.
385. Garcia-Riquelme, O., *Optica Pura Y Aplicada*, 1, 53, 1968.
386. Gibbs, R. C., Vieweg, A. M., and Gartlein, C. W., *Phys. Rev*., 34, 406, 1929.
387. Gilbert, W. P., *Phys. Rev*., 48, 338, 1935.
388. Goldsmith, S. and Kaufman, A. S., *Proc. Phys. Soc*., 81, 544, 1963.
389. Hermansdorfer, H., *J. Opt. Soc. Am*., 62, 1149, 1972.
390. Humphreys, C. J., *Phys. Rev*., 47, 712, 1935.
391. Humphreys, C. J., *J. Res. Natl. Bur. Stand*., 16, 639, 1936.
392. Iglesias, L., *J. Opt. Soc. Am*., 45, 856, 1955.
393. Iglesias, L., *J. Res. Natl. Bur. Stand*., 64A, 481, 1960.
394. Iglesias, L., *Anales Fisica Y Quimica*, 58A, 191, 1962.
395. Iglesias, L., *J. Res. Natl. Bur. Stand*., 70A, 465, 1966.
396. Iglesias, L., *Can. J. Phys*., 44, 895, 1966.
397. Iglesias, L., *J. Res. Natl. Bur. Stand*., 72A, 295, 1968.
398. Joshi, Y. N., *Can. Spectrosc*., 15, 96, 1970.
399. Joshi, Y. N. and van Kleef, T. A. M., *Can. J. Phys*., 55, 714, 1977.
400. Kaufman, A. S., Hughes, T. P., and Williams, R. V., *Proc. Phys. Soc*., 76, 17, 1960.
401. Kaufman, V. and Sugar, J., *J. Opt. Soc. Am*., 68, 1529, 1978.
402. Keussler, V., *Z. Physik*, 85, 1, 1933.
403. Kiess, C. C., *J. Res. Natl. Bur. Stand*., 56, 167, 1956.
404. Klinkenberg, P. F. A., van Kleef, T. A. M., and Noorman, P. E., *Physica*, 27, 1177, 1961.
405. Kovalev, V. I., Romanos, A. A., and Ryabtsev, A. N., *Opt. Spectrosc*., 43, 10, 1977.
406. Lang, R. J., *Proc. Natl. Acad. Sci.*, 13, 341, 1927.
407. Lang, R. J., *Zeeman Verhandelingen*, (The Hague), 44, 1935.
408. Liberman, S., et al., *C. R. Acad. Sci*. (Paris), 286, 253, 1978.
409. Livingston, A. E., *J. Phys*., B9, L215, 1976.
410. Meijer, F. G., *Physica*, 72, 431, 1974.
411. Meijer, F. G. and Metsch, B. C., *Physica*, 94C, 259, 1978.
412. Moore, F. L., thesis, Princeton, 1949.
413. Paul, F. W. and Polster, H. D., *Phys. Rev*., 59, 424, 1941.
414. Phillips, L. W. and Parker, W. L., *Phys. Rev*., 60, 301, 1941.
415. Poppe, R., *Physica*, 81C, 351, 1976.
416. Raassen, A. J. J., van Kleef, T. A. M., and Metsch, B. C., *Physica*, 84C, 133, 1976.
417. Rao, A. B. and Krishnamurty, S. G., *Proc. Phys. Soc. (London)*, 51, 772, 1939.
418. Reader, J. and Acquista, N., *J. Opt. Soc. Am*., 69, 239, 1979.
419. Reader, J. and Epstein, G. L., *J. Opt. Soc. Am*., 62, 619, 1972.
420. Rico, F. R., *Anales, Real Soc. Esp. Fis. Quim*., 61, 103, 1965.
421. Schonheit, E., *Optik*, 23, 409, 1966.
422. Shenstone, A. G., *J. Opt. Soc. Am*., 44, 749, 1954.
423. Shenstone, A. G., unpublished, 1958.
424. Shenstone, A. G., *J. Res. Natl. Bur. Stand*., 67A, 87, 1963.
425. Sugar, J. and Kaufman, V., *J. Opt. Soc. Am*., 64, 1656, 1974.
426. Sugar, J. and Kaufman, V., *Phys. Rev*., C12, 1336, 1975.
427. Svensson, L. A., *Phys. Scr*., 13, 235, 1976.
428. Swensson, J. W. and Edlen, B., *Phys. Scr*., 9, 335, 1974.

429. Tagliaferri, A. A., Gallego Lluesma, E., Garavaglia, M., Gallardo, M., and Massone, C. A., *Optica Pura Y Aplica*, 7, 89.
430. Tilford, S. G. and Giddings, L. E., *Astrophys. J.*, 141, 1222, 1965.
431. Trawick, M. W., *Phys. Rev.*, 46, 63, 1934.
432. Van Deurzen, C. H. H., *J. Opt. Soc. Am.*, 67, 476, 1977.
433. Yarosewick, S. L. and Moore, F. L., *J. Opt. Soc. Am.*, 57, 1381, 1967.
434. Zalubas, R., unpublished, 1979.
435. Bhatia, K. S., Jones, W. E., and Crooker, A. M., *Can. J. Phys.*, 50, 2421, 1972.
436. van Kleef, T. A. M. and Joshi, Y. N., *Phys. Scr.*, 24, 557, 1981.

NIST ATOMIC TRANSITION PROBABILITY TABLES

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These tables substantially update and enlarge our earlier tables in this *Handbook*. The new tables contain critically evaluated atomic transition probabilities for about 9000 selected lines of all elements for which reliable data are available on an absolute scale. The material is largely for neutral and singly ionized spectra, but also includes a number of prominent lines of more highly charged ions of important elements.

Many of the data are obtained from comprehensive compilations of the Data Center on Atomic Transition Probabilities at the National Institute of Standards and Technology (formerly the National Bureau of Standards). Specifically, data have been taken from three recent comprehensive critical compilations on C, N and O,[1] on Sc through Mn,[2] and Fe through Ni.[3] Material from earlier compilations for the elements H through Ne[4] and Na through Ca[5] was supplemented by more recent material taken directly from the original literature. For the highly charged ions, some of the data were derived from studies of the systematic behavior of transition probabilities.[6-8] Most of the original literature is cited in the above tables and in recent bibliographies[9,10]; for lack of space, individual literature references are not cited here.

The wavelength range for the neutral species is normally the visible spectrum or shorter wavelengths; only the very prominent near infrared lines are included. For the higher ions, most of the strong lines are located in the far UV. The tabulation is limited to electric dipole — including intercombination — lines and comprises essentially the fairly strong transitions with estimated uncertainties of 50% or less. With the exception of hydrogen, helium, and the alkalis, most transitions are between states with low principal quantum numbers.

The transition probability, A, is given in units of 10^8 s^{-1} and is listed to as many digits as is consistent with the indicated accuracy. The power of 10 is indicated by the E notation (i.e., E-02 means 10^{-2}). Generally, the estimated uncertainties of the A-values are ±25 to 50% for two-digit numbers, ±10 to 25% for three-digit numbers and ±1% or better for four- and five-digit numbers.

Each transition is identified by the wavelength, λ, in angstroms; and the statistical weights, g_i and g_k, of the lower (i) and upper (k) states [the product $g_k A$ (or $g_i f$) is needed for many applications]. Whenever the wavelengths of individual lines within a multiplet are extremely close, only an average wavelength for the multiplet as well as the multiplet A-value are given, and this is indicated by an asterisk (*) to the left of the wavelength. This also has been done when the transition probability for an entire multiplet has been taken from the literature and values for individual lines cannot be determined because of insufficient knowledge of the coupling of electrons. The wavelength data have been taken either from recent compilations or from the original literature cited in bibliographies published by the Atomic Energy Levels Data Center[11,12] at the National Institute of Standards and Technology. Wavelength values are consistent with those given in the table "Line Spectra of the Elements", which appears elsewhere in this *Handbook*.

The transition probabilities for hydrogen and hydrogen-like ions are known precisely. Because of the hydrogen degeneracy, a "transition" is actually the sum of all fine-structure transitions between the principal quantum numbers listed in the transition column; therefore, the special hydrogen table which appears below gives weighted average A-values.

In addition to the transition probability A, the atomic oscillator strength f and the line strength S are often used in the literature. The conversion factors between these quantities are (for electric-dipole transitions):

$$g_i f = 1.499 \times 10^{-8}\ \lambda^2\ g_k A = 303.8\ \lambda^{-1}\ S$$

where λ is in angstroms, A is in 10^8 s^{-1}, and S is in atomic units, which are
$a_0^2 e^2 = 7.188 \times 10^{-59}$ m^2 C^2.

After the special table for hydrogen, the tables for other elements appear in alphabetical sequence by element name (not symbol). Within each element, the tables are ordered by increasing ionization stage (e.g., Al I, Al II, etc.).

REFERENCES

1. Wiese, W.L., Fuhr, J.R., and Deters, T.M., *Atomic Transition Probabilities of Carbon, Nitrogen and Oxygen, J. Phys. Chem. Ref. Data, Monograph 7*, 1996.
2. Martin, G.A., Fuhr, J.R., and Wiese, W.L., *Atomic Transition Probabilities—Scandium through Manganese*, *J. Phys. Chem. Ref. Data, 17, Suppl.* 3, 1988.
3. Fuhr, J.R., Martin, G.A., and Wiese, W.L., *Atomic Transition Probabilities—Iron through Nickel, J. Phys. Chem. Ref. Data, 17, Suppl.* 4, 1988.
4. Wiese, W.L., Smith, M.W., and Glennon, B.M., *Atomic Transition Probabilities (H through Ne—A Critical Data Compilation),* National Standard Reference Data Series, National Bureau of Standards 4, Vol. I, U.S. Government Printing Office, Washington, D.C., 1966.
5. Wiese, W.L., Smith, M.W., and Miles, B.M., *Atomic Transition Probabilities (Na through Ca—A Critical Data Compilation),* National Standard Reference Data Series, National Bureau of Standards 22, Vol. II, U. S. Government Printing Office, Washington, D.C., 1969.
6. Wiese, W.L. and Weiss, A.W., *Phys. Rev.*, 175, 50, 1968.
7. Smith, M.W. and Wiese,M.L., *Astrophys. J., Suppl. Ser.*, 23, No. 196, 103, 1971.
8. Martin, G.A., and Wiese,W.L., *J. Phys. Chem. Ref. Data,* 5, 537, 1976.
9. Fuhr, J.R., Miller, B.J., and Martin, G.A., *Bibliography on Atomic Transition Probabilities (1914 through October 1997),* National Bureau of Standards Special Publication 505, 1978; Miller, B.J., Fuhr, J.R., and Martin, G.A., *Bibliography on Atomic Transition Probabilities (November 1977 through February 1980),* National Bureau of Standards Special Publication 505, Supplement 1, 1980.
10. Wiese, W.L., Reports on Astronomy, *Trans. Int. Astron. Union*, 18A, 116—123, 1982; 19A, 122—138, 1985.; 20A, 117—123, 1988, Reidel, D., Ed., Kluwer, Dordrecht, Holland.
11. Moore, C.E., *Bibliography on the Analyses of Optical Atomic Spectra,* National Bureau of Standards Special Publication 306—Section 1, 1968; Sections 2—4, 1969.

12. Hagan, L. and Martin, W.C., *Bibliography on Atomic Energy Levels and Spectra (July 1968 through June 1971)*, National Bureau of Standards Special Publication 363, 1972; Hagan, L., *Bibliography on Atomic Energy Levels and Spectra (July 1971 through June 1975)*, National Bureau of Standards Special Publication 363, Supplement 1, 1977; Zalubas, R. and Albright, A., *Bibliography on Atomic Energy Levels and Spectra (July 1975 through June 1979)*, National Bureau of Standards Special Publication 363, Supplement 2, 1980; Musgrove, A. and Zalubas, R., *Bibliography on Atomic Energy Levels and Spectra (July 1979 through December 1983)*, National Bureau of Standards Special Publication 363, Supplement 3, 1985.
13. Younger, S.M. and Weiss, A., *J. Res. Natl. Bur. Stand.*, 79A, 629, 1975.

Transition Probabilities for Allowed Lines of Hydrogen

λ	Weights		A
Å	g_i	g_k	10^8 s^{-1}
Hydrogen			
H I			
912.768	2	1800	5.167E-06
912.839	2	1682	6.122E-06
912.918	2	1568	7.297E-06
913.006	2	1458	8.753E-06
913.104	2	1352	1.057E-05
913.215	2	1250	1.286E-05
913.339	2	1152	1.578E-05
913.480	2	1058	1.952E-05
913.641	2	968	2.438E-05
913.826	2	882	3.077E-05
914.039	2	800	3.928E-05
914.286	2	722	5.077E-05
914.576	2	648	6.654E-05
914.919	2	578	8.858E-05
915.329	2	512	1.200E-04
915.824	2	450	1.657E-04
916.429	2	392	2.341E-04
917.181	2	338	3.393E-04
918.129	2	288	5.066E-04
919.351	2	242	7.834E-04
920.963	2	200	1.263E-03
923.150	2	162	2.143E-03
926.226	2	128	3.869E-03
930.748	2	98	7.568E-03
937.803	2	72	1.644E-02
949.743	2	50	4.125E-02
972.537	2	32	1.278E-01
1025.72	2	18	5.575E-01
1215.67	2	8	4.699E+00
3662.26	8	1800	2.847E-06
3663.40	8	1682	3.374E-06
3664.68	8	1568	4.022E-06
3666.10	8	1458	4.826E-06
3667.68	8	1352	5.830E-06
3669.46	8	1250	7.096E-06
3671.48	8	1152	8.707E-06
3673.76	8	1058	1.078E-05
3676.36	8	968	1.347E-05
3679.35	8	882	1.700E-05
3682.81	8	800	2.172E-05
3686.83	8	722	2.809E-05
3691.55	8	648	3.685E-05
3697.15	8	578	4.910E-05
3703.85	8	512	6.658E-05
3711.97	8	450	9.210E-05
3721.94	8	392	1.303E-04
3734.37	8	338	1.893E-04
3750.15	8	288	2.834E-04
3770.63	8	242	4.397E-04
3797.90	8	200	7.122E-04
3835.38	8	162	1.216E-03
3889.05	8	128	2.215E-03
3970.07	8	98	4.389E-03
4101.73	8	72	9.732E-03
4340.46	8	50	2.530E-02
4861.32	8	32	8.419E-02
6562.80	8	18	4.410E-01
8392.40	18	800	1.517E-05
8413.32	18	722	1.964E-05
8437.96	18	648	2.580E-05
8467.26	18	578	3.444E-05
8502.49	18	512	4.680E-05
8545.39	18	450	6.490E-05
8598.40	18	392	9.211E-05
8665.02	18	338	1.343E-04
8750.48	18	288	2.021E-04
8862.79	18	242	3.156E-04
9014.91	18	200	5.156E-04
9229.02	18	162	8.905E-04
9545.97	18	128	1.651E-03
10049.4	18	98	3.358E-03
10938.1	18	72	7.783E-03
12818.1	18	50	2.201E-02
16407.2	32	288	1.620E-04
16806.5	32	242	2.556E-04
17362.1	32	200	4.235E-04
18174.1	32	162	7.459E-04
18751.0	18	32	8.986E-02
19445.6	32	128	1.424E-03
21655.3	32	98	3.041E-03
26251.5	32	72	7.711E-03
27575	50	288	1.402E-04
28722	50	242	2.246E-04
30384	50	200	3.800E-04
32961	50	162	6.908E-04
37395	50	128	1.388E-03
40511.5	32	50	2.699E-02
43753	72	288	1.288E-04
46525	50	98	3.253E-03
46712	72	242	2.110E-04
51273	72	200	3.688E-04
59066	72	162	7.065E-04
74578	50	72	1.025E-02
75004	72	128	1.561E-03
123680	72	98	4.561E-03

For hydrogen-like ions of nuclear charge *Z*, the following scaling laws hold:

$$A_Z = Z^4 A_{\mathrm{Hydrogen}};\ f_Z = f_H;\ S_Z = Z^{-2} S_H$$

$$\text{(For wavelengths, } \lambda_Z = Z^{-2}\lambda_H\text{)}$$

For very highly charged hydrogen-like ions, starting at about *Z*>25, relativistic corrections[13] must be applied.

Transition Probabilities for Other Elements

λ Å	Weights g_i	g_k	*A* 10^8 s^{-1}
Aluminum			
Al I			
2263.5	2	4	6.6E-01
2269.1	4	6	7.9E-01
2269.2	4	4	1.3E-01
2367.1	2	4	7.2E-01
2373.1	4	6	8.6E-01
2373.4	4	4	1.4E-01
2568.0	2	4	2.3E-01
2575.1	4	6	2.8E-01
2575.4	4	4	4.4E-02
2652.5	2	2	1.33E-01
2660.4	4	2	2.64E-01
3082.2	2	4	6.3E-01
3092.7	4	6	7.4E-01
3092.8	4	4	1.2E-01
3944.0	2	2	4.93E-01
3961.5	4	2	9.8E-01
6696.0	2	4	1.69E-02
6698.7	2	2	1.69E-02
7835.3	4	6	5.7E-02
7836.1	6	8	6.2E-02
Al II			
1047.9	1	3	3.6E-01
1048.6	3	5	4.8E-01
1539.8	3	5	8.8E+00
1670.8	1	3	1.46E+01
1719.4	1	3	6.79E+00
1764.0	5	5	9.8E+00
1772.8	1	3	9.5E+00
1777.0	5	7	1.7E+01
*1819.0	15	15	5.6E+00
1855.9	1	3	8.32E-01
1858.0	3	3	2.48E+00
1862.3	5	3	4.12E+00
1931.0	3	1	1.08E+01
1990.5	3	5	1.47E+01
2816.2	3	1	3.83E+00
4663.1	5	3	5.3E-01
6226.2	1	3	6.2E-01
6231.8	3	5	8.4E-01
6243.4	5	7	1.1E+00
6335.7	5	3	1.4E-01
6823.4	3	3	3.4E-01
6837.1	5	3	5.7E-01
6920.3	3	1	9.6E-01
7042.1	3	5	5.9E-01
7056.7	3	3	5.8E-01
7471.4	5	7	9.4E-01
Al III			
*560.36	2	6	4.0E-01
695.83	2	4	7.4E-01
696.22	2	2	7.2E-01
*1352.8	10	14	4.40E+00
1379.7	2	2	4.59E+00
1384.1	4	2	9.1E+00
1605.8	2	4	1.22E+01
1611.8	4	4	2.42E+00
1611.9	4	6	1.45E+01
1854.7	2	4	5.40E+00
1862.8	2	2	5.33E+00
*1935.9	10	14	1.22E+01
3601.6	6	4	1.34E+00
3601.9	4	4	1.49E-01
3612.4	4	2	1.5E+00
Al X			
39.925	1	3	2.22E+03
51.979	1	3	4.8E+03
55.227	1	3	5.2E+03
55.272	3	5	7.2E+03
55.376	5	7	9.5E+03
59.107	3	5	4.6E+03
332.78	1	3	5.6E+01
394.83	3	1	8.3E+01
395.36	3	5	1.2E+01
397.76	1	3	1.7E+01
400.43	3	3	1.3E+01
401.12	5	5	3.6E+01
403.55	3	1	4.9E+01
406.31	5	3	1.9E+01
670.06	3	5	9.8E+00
2535	1	3	3.8E-01
Al XI			
*36.675	2	6	1.5E+03
39.091	2	4	2.6E+03
39.180	4	6	3.1E+03
39.530	2	2	1.8E+02
39.623	4	2	3.7E+02
48.298	2	4	3.09E+03
48.338	2	2	3.08E+03
52.299	2	4	8.1E+03
52.446	4	6	9.6E+03
52.458	4	4	1.6E+03
54.217	2	2	4.8E+02
54.388	4	2	9.6E+02
*99.083	2	6	2.2E+02
103.6	2	4	4.2E+02
103.8	4	6	5.0E+02
*141.6	2	6	4.07E+02
150.31	2	4	8.5E+02
150.61	4	6	9.9E+02
157.0	2	2	1.3E+02
157.4	4	2	2.6E+02
*205.0	2	6	6.3E+01
*308.6	2	6	9.9E+01
*341.3	6	2	1.3E+02
550.05	2	4	8.55E+00
568.12	2	2	7.73E+00
1997	2	4	1.07E+00
2069	2	2	9.7E-01
*4761	2	6	2.55E-01
5172	2	4	3.95E-02
5551	4	6	3.85E-02
5687	4	4	6.0E-03
Argon			
Ar I			
1048.22	1	3	5.36E+00
1066.66	1	3	1.29E+00
3406.18	3	1	3.9E-03
3461.08	3	5	6.7E-04
3554.30	5	5	2.7E-03
3563.29	1	3	1.2E-03
3567.66	5	7	1.1E-03
3572.30	3	1	5.1E-03
3606.52	3	1	7.6E-03
3632.68	3	5	6.6E-04
3634.46	3	3	1.3E-03
3643.12	3	5	2.4E-04
3649.83	3	1	8.0E-03
3659.53	3	3	4.4E-04
3670.67	3	5	3.1E-04
3675.23	3	3	4.9E-04
3770.37	1	3	7.0E-04
3834.68	3	1	7.5E-03
3894.66	3	3	5.7E-04
3947.50	5	5	5.6E-04
3948.98	5	3	4.55E-03
4044.42	3	5	3.33E-03
4045.96	3	3	4.1E-04
4054.53	3	3	2.7E-04
4158.59	5	5	1.40E-02
4164.18	5	3	2.88E-03
4181.88	1	3	5.61E-03
4190.71	5	5	2.80E-03
4191.03	1	3	5.39E-03
4198.32	3	1	2.57E-02
4200.67	5	7	9.67E-03
4251.18	5	3	1.11E-03
4259.36	3	1	3.98E-02
4266.29	3	5	3.12E-03
4272.17	3	3	7.97E-03
4300.10	3	5	3.77E-03
4333.56	3	5	5.68E-03
4335.34	3	3	3.87E-03
4345.17	3	3	2.97E-03
4363.79	3	3	1.2E-04
4424.00	1	3	7.3E-05
4510.73	3	1	1.18E-02
4522.32	1	3	8.98E-04
4544.75	3	3	8.3E-04
4554.32	3	5	3.8E-04
4584.96	3	5	1.6E-03
4586.61	3	3	2.3E-03
4587.21	3	1	4.9E-03
4589.29	3	5	6.2E-05
4596.10	3	3	9.47E-04

λ Å	Weights g_i	g_k	*A* 10^8 s^{-1}	λ Å	Weights g_i	g_k	*A* 10^8 s^{-1}	λ Å	Weights g_i	g_k	*A* 10^8 s^{-1}
4628.44	3	5	3.83E-04	5473.46	5	3	2.0E-03	6025.15	5	3	9.0E-03
4642.15	3	5	9.6E-04	5490.12	5	5	8.5E-04	6043.22	5	7	1.47E-02
4647.49	3	3	1.2E-03	5492.09	3	1	5.6E-03	6052.73	3	5	1.9E-03
4702.32	3	3	1.09E-03	5495.87	7	9	1.69E-02	6064.76	5	7	5.8E-04
4746.82	3	1	3.6E-03	5506.11	5	7	3.6E-03	6081.25	3	3	7.5E-04
4752.94	3	3	4.5E-03	5524.96	7	7	1.7E-03	6085.86	3	3	9.0E-05
4768.68	3	5	8.6E-03	5528.97	1	3	1.2E-03	6090.79	1	3	3.0E-03
4798.74	7	9	8.8E-04	5534.49	5	3	2.7E-03	6098.81	3	3	5.2E-03
4835.97	7	9	9.3E-04	5540.87	7	5	4.1E-04	6101.16	3	3	3.3E-03
4836.70	3	5	1.02E-03	5552.77	3	3	7.9E-04	6104.58	3	1	3.4E-03
4876.26	3	5	7.8E-03	5558.70	3	5	1.42E-02	6105.64	3	5	1.21E-02
4886.29	7	9	1.2E-03	5559.66	3	5	2.2E-03	6113.46	3	5	4.7E-04
4887.95	3	3	1.3E-02	5572.54	5	7	6.6E-03	6119.66	3	3	5.1E-04
4894.69	3	1	1.8E-02	5574.22	3	5	4.6E-04	6121.86	3	5	1.3E-04
4921.04	5	7	5.9E-04	5581.87	7	5	5.6E-04	6127.42	5	3	1.1E-03
4937.72	7	5	3.6E-04	5588.72	5	5	1.5E-03	6128.73	3	5	8.6E-04
4956.75	7	9	1.8E-03	5597.48	5	7	4.2E-03	6145.44	5	7	7.6E-03
4989.95	5	7	1.1E-03	5606.73	3	3	2.20E-02	6155.24	5	3	5.1E-03
5032.03	7	5	8.2E-04	5618.01	3	3	2.1E-03	6165.12	5	5	9.89E-04
5048.81	3	5	4.6E-03	5620.92	3	1	3.6E-03	6170.17	5	5	5.0E-03
5054.18	3	3	4.5E-03	5623.78	5	5	1.4E-03	6173.10	3	5	6.7E-03
5056.53	3	1	5.7E-03	5635.58	3	5	9.6E-04	6179.41	5	3	6.6E-04
5060.08	7	9	3.7E-03	5637.33	1	3	9.1E-04	6212.50	5	7	3.9E-03
5070.99	5	3	2.6E-03	5639.12	1	3	2.1E-03	6215.94	5	5	5.7E-03
5073.08	3	5	5.9E-04	5641.39	3	5	8.7E-04	6230.93	5	5	1.2E-04
5078.03	7	7	4.7E-04	5648.69	5	3	1.2E-03	6243.40	3	1	1.3E-03
5087.09	5	7	1.6E-03	5650.70	3	1	3.20E-02	6244.73	3	5	2.0E-04
5104.74	3	5	8.7E-04	5659.13	5	5	2.6E-03	6248.41	3	5	6.8E-04
5118.21	5	7	2.7E-03	5681.90	5	7	2.0E-03	6278.65	5	7	2.0E-04
5127.80	5	5	3.3E-04	5683.73	5	5	2.0E-03	6296.87	3	5	9.0E-03
5151.39	3	1	2.39E-02	5700.87	5	7	5.9E-03	6307.66	5	5	6.0E-03
5152.30	3	5	1.1E-03	5712.51	1	3	8.7E-04	6309.14	3	3	7.6E-04
5162.29	3	3	1.90E-02	5739.52	3	5	8.7E-03	6364.89	3	1	5.6E-03
5177.54	7	5	2.4E-03	5772.11	5	7	2.0E-03	6369.58	5	3	4.2E-03
5192.72	7	7	1.2E-04	5773.99	5	5	1.1E-03	6384.72	3	3	4.21E-03
5194.02	3	1	7.8E-03	5783.54	3	5	8.1E-04	6416.31	3	5	1.16E-02
5210.49	7	7	1.1E-03	5789.48	5	5	4.6E-04	6431.56	5	3	5.1E-04
5214.77	5	3	2.1E-03	5790.40	5	3	3.4E-04	6466.55	1	3	1.5E-03
5216.28	5	3	1.3E-03	5802.08	5	3	4.2E-03	6481.14	1	3	9.4E-04
5221.27	7	9	8.8E-03	5843.77	3	5	3.3E-04	6513.85	3	3	5.4E-04
5241.09	5	5	1.3E-03	5882.62	3	1	1.23E-02	6538.11	7	7	1.1E-03
5246.24	5	7	1.2E-03	5888.58	7	5	1.29E-02	6596.12	7	5	2.3E-04
5249.20	5	5	7.9E-04	5916.58	5	3	5.9E-04	6598.68	5	5	3.6E-04
5252.79	5	7	5.4E-03	5927.11	7	7	3.7E-04	6604.02	7	5	2.8E-03
5254.47	3	5	3.6E-03	5928.81	5	3	1.1E-02	6604.85	5	7	1.3E-04
5286.07	5	7	9.6E-04	5940.86	1	3	1.2E-03	6632.09	3	3	5.3E-04
5290.00	5	3	9.0E-04	5942.67	5	5	1.8E-03	6656.88	3	3	3.1E-04
5309.52	5	5	1.2E-03	5943.89	7	5	3.6E-04	6660.68	3	1	7.8E-03
5317.73	5	7	2.6E-03	5949.26	3	3	1.5E-03	6664.05	5	5	1.5E-03
5373.50	3	5	2.7E-03	5964.48	1	3	7.7E-04	6677.28	3	1	2.36E-03
5393.27	5	5	9.6E-04	5968.32	3	3	1.8E-03	6684.73	3	5	3.9E-04
5410.48	5	7	2.0E-03	5971.60	3	1	1.1E-02	6698.47	3	3	2.5E-04
5421.35	7	5	6.0E-03	5981.90	5	7	1.2E-04	6698.88	5	3	1.6E-03
5439.99	3	3	1.9E-03	5987.30	7	7	1.2E-03	6719.22	1	3	2.4E-03
5442.24	7	7	9.3E-04	5988.13	3	5	6.1E-04	6722.88	5	7	3.2E-04
5451.65	3	5	4.7E-03	5994.66	3	5	2.6E-04	6752.84	3	5	1.93E-02
5457.42	5	3	3.6E-03	5999.00	5	5	1.4E-03	6754.37	3	3	2.1E-03
5459.65	7	7	3.8E-04	6005.73	5	3	1.4E-03	6756.10	5	5	3.6E-03
5467.16	5	5	7.6E-04	6013.68	7	5	1.4E-03	6766.61	5	3	4.0E-03

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
6779.93	1	3	1.21E-03
6818.29	3	1	2.0E-03
6827.25	5	3	2.4E-03
6851.88	3	5	6.7E-04
6871.29	3	3	2.78E-02
6879.59	3	5	1.8E-03
6887.10	5	7	1.3E-03
6888.17	3	5	2.5E-03
6925.01	3	3	1.2E-03
6937.67	3	1	3.08E-02
6951.46	5	5	2.2E-03
6960.23	5	5	2.4E-03
6965.43	5	3	6.39E-02
6992.17	3	1	7.5E-03
7030.25	7	5	2.67E-02
7067.22	5	5	3.80E-02
7068.73	5	3	2.0E-02
7086.70	1	3	1.5E-03
7107.48	5	5	4.5E-03
7125.83	3	3	6.0E-03
7147.04	5	3	6.25E-03
7158.83	3	1	2.1E-02
7162.57	1	3	5.8E-04
7206.98	5	3	2.48E-02
7229.93	5	5	6.6E-04
7265.17	3	3	1.7E-03
7270.66	7	7	1.1E-03
7272.93	3	3	1.83E-02
7285.44	5	3	1.2E-03
7311.72	3	3	1.7E-02
7316.01	3	3	9.6E-03
7350.78	3	1	1.2E-02
7353.32	5	7	9.6E-03
7372.12	7	9	1.9E-02
7383.98	3	5	8.47E-02
7392.97	5	3	7.2E-03
7412.33	3	5	3.9E-03
7422.26	3	5	6.6E-04
7425.29	5	7	3.1E-03
7435.33	5	5	9.0E-03
7436.25	7	5	2.7E-03
7471.17	3	3	2.2E-04
7484.24	3	5	3.4E-03
7503.84	3	1	4.45E-01
7510.42	5	5	4.5E-03
7514.65	3	1	4.02E-01
7618.33	3	5	2.9E-03
7628.86	3	5	2.9E-03
7635.11	5	5	2.45E-01
7670.04	5	3	2.8E-03
7704.81	5	7	6.3E-04
7723.76	5	3	5.18E-02
7724.21	1	3	1.17E-01
7798.55	3	5	8.7E-04
7868.20	1	3	3.50E-03
7891.08	5	5	9.5E-03
7916.45	3	3	1.2E-03
7948.18	1	3	1.86E-01
8006.16	3	5	4.90E-02
8014.79	5	5	9.28E-02
8037.23	1	3	3.59E-03
8046.13	3	1	1.12E-02
8053.31	5	3	8.6E-03
8066.60	5	5	1.4E-03
8103.69	3	3	2.5E-01
8115.31	5	7	3.31E-01
8264.52	3	3	1.53E-01
8384.73	5	7	2.4E-03
8408.21	3	5	2.23E-01
8424.65	3	5	2.15E-01
8490.30	3	5	9.6E-04
8521.44	3	3	1.39E-01
8605.78	5	5	1.04E-02
8620.46	1	3	9.2E-03
8667.94	1	3	2.43E-02
8761.69	3	5	9.5E-03
8784.61	3	1	2.4E-03
8799.08	5	3	4.6E-03
8962.19	3	3	1.6E-03
9075.42	3	1	1.2E-02
9122.97	5	3	1.89E-01
9194.64	3	3	1.76E-02
9224.50	3	5	5.03E-02
9291.53	3	1	3.26E-02
9354.22	3	3	1.06E-02
9657.78	3	3	5.43E-02
9784.50	3	5	1.47E-02
10470.05	1	3	9.8E-03
10478.0	3	3	2.44E-02
10950.7	5	3	3.96E-03
11078.9	5	5	8.3E-03
11393.7	3	1	2.22E-02
11441.8	5	3	1.39E-02
11467.5	3	5	3.69E-03
11488.11	3	3	1.9E-03
11668.7	5	5	3.76E-02
11719.5	5	3	9.52E-03
12026.6	1	3	4.2E-03
12112.2	7	7	3.1E-02
12139.8	3	3	4.5E-02
12343.7	5	7	2.0E-02
12402.9	3	3	1.1E-01
12439.2	3	5	4.9E-02
12456.1	5	3	8.9E-02
12487.6	7	5	1.1E-01
12554.4	7	5	1.2E-03
12702.4	3	3	7.1E-02
12733.6	5	5	1.1E-02
12746.3	3	3	2.0E-02
12802.7	5	5	5.7E-02
12933.3	3	1	1.0E-01
12956.6	3	3	7.4E-02
13008.5	5	3	8.9E-02
13214.7	3	1	8.1E-02
13273.1	5	7	1.5E-01
13313.4	3	5	1.3E-01
13504.0	5	7	1.1E-01
13599.2	5	5	2.2E-02
13622.4	3	5	7.3E-02
13678.5	3	5	6.2E-02
14093.6	1	3	4.3E-02
14739.1	5	7	8.8E-04
15046.4	1	3	5.2E-02
15172.3	1	3	1.3E-02
15329.6	5	5	1.2E-03
15555.5	5	7	9.8E-05
15734.9	5	3	2.9E-04
15816.8	5	3	8.7E-04
15989.3	1	3	1.9E-02
16122.7	5	3	3.9E-04
16180.0	5	5	1.2E-03
16264.1	3	3	3.0E-04
16520.1	3	5	2.6E-03
16739.8	3	5	3.1E-03
16940.4	5	5	2.5E-02
20317.0	1	3	1.6E-03
20616.5	5	5	3.9E-03
20812.0	5	7	7.6E-04
21332.2	3	3	3.2E-04
21534.9	3	5	1.1E-03
22039.2	3	1	1.2E-03
22077.4	5	3	1.4E-03
23133.4	3	3	1.7E-03
23844.8	9	7	1.1E-02
23967.5	3	1	3.6E-03

Ar II

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
2317.7	6	4	1.4E-01
2891.6	4	2	1.82E-01
2942.9	4	4	5.3E-01
2979.1	2	2	4.16E-01
3033.5	2	4	9.9E-02
3139.0	6	6	5.2E-01
3169.7	4	6	4.9E-01
3181.0	6	4	3.7E-01
3212.5	4	4	5.2E-02
3221.6	6	6	1.8E-02
3226.0	4	4	2.1E-02
3243.7	4	2	1.06E+00
3249.8	2	4	6.3E-01
3263.6	2	4	1.55E-01
3281.7	2	2	4.2E-01
3430.4	6	8	6.2E-02
3454.1	6	4	3.14E-01
3466.3	8	6	3.0E-02
3476.7	6	6	1.25E+00
3491.2	4	4	1.79E+00
3491.5	6	8	2.31E+00
3509.8	2	2	2.55E+00
3514.4	4	6	1.36E+00
3520.0	6	6	5.2E-01
3521.3	8	8	2.27E-01
3535.3	2	4	5.7E-01
3548.5	4	4	8.7E-01
3550.0	6	6	2.6E-02
3556.9	2	2	5.0E-02
3559.5	6	8	2.88E+00

λ	Weights		A
Å	g_i	g_k	10^8 s^{-1}
3565.0	2	4	5.5E-01
3576.6	6	8	2.75E+00
3581.6	2	4	1.76E+00
3582.4	4	6	2.53E+00
3588.4	8	10	3.03E+00
3605.9	4	6	4.4E-02
3656.0	6	6	7.6E-02
3682.5	4	2	1.7E-02
3709.9	4	4	4.7E-02
3717.2	6	8	5.2E-02
3729.3	6	4	4.80E-01
3746.9	4	6	2.1E-02
3763.5	8	6	1.78E-01
3766.1	4	4	7.4E-02
3777.5	2	2	1.1E-02
3780.8	8	8	7.7E-01
3786.4	8	6	1.5E-02
3799.4	6	4	1.7E-01
3808.6	6	6	1.0E-02
3826.8	6	6	2.81E-01
3841.5	4	2	2.69E-01
3844.7	6	8	4.8E-02
3845.4	6	4	1.6E-02
3850.6	4	4	3.87E-01
3868.5	4	6	1.4E+00
3872.1	4	4	1.5E-01
3875.3	4	2	8.2E-02
3880.3	2	2	2.32E-01
3891.4	2	2	4.3E-02
3892.0	6	4	6.3E-02
3900.6	4	6	7.2E-02
3911.6	2	4	7.7E-02
3914.8	4	4	3.7E-02
3928.6	2	4	2.44E-01
3931.2	2	4	2.0E-02
3932.5	4	4	9.3E-01
3944.3	8	6	4.1E-02
3952.7	4	4	2.08E-01
3958.4	6	4	3.8E-02
3968.4	6	6	4.8E-02
3979.4	4	2	9.8E-01
3988.2	6	6	4.1E-02
3992.1	4	6	1.6E-02
4013.9	8	8	1.05E-01
4031.4	4	2	7.5E-02
4035.5	4	6	4.4E-02
4038.8	6	8	1.2E-02
4042.9	4	4	4.06E-01
4045.7	4	4	1.6E-02
4052.9	2	4	6.7E-01
4065.1	4	4	1.1E-02
4072.0	6	6	5.8E-01
4079.6	6	4	1.19E-01
4082.4	6	6	2.9E-02
4112.8	4	4	1.1E-02
4128.6	8	6	1.4E-02
4131.7	4	2	8.5E-01
4178.4	6	4	1.2E-02
4202.0	2	4	2.1E-02
4228.2	4	6	1.31E-01
4237.2	4	4	1.12E-01
4266.5	6	6	1.64E-01
4277.5	6	4	8.0E-01
4282.9	4	2	1.32E-01
4300.6	6	6	5.7E-02
4331.2	4	4	5.74E-01
4332.0	4	2	1.92E-01
4348.1	6	8	1.17E+00
4352.2	2	2	2.12E-01
4362.1	4	6	5.5E-02
4370.8	4	4	6.6E-01
4371.3	6	4	2.21E-01
4376.0	4	2	2.05E-01
4379.7	2	2	1.00E+00
4383.8	4	4	1.1E-02
4400.1	4	4	1.60E-01
4401.0	8	6	3.04E-01
4412.9	6	8	6.1E-02
4420.9	2	4	3.1E-02
4426.0	4	6	8.17E-01
4430.2	2	4	5.69E-01
4431.0	6	6	1.09E-01
4460.6	4	6	1.5E-02
4474.8	4	2	2.90E-01
4481.8	6	6	4.55E-01
4491.0	6	4	4.6E-02
4530.5	6	4	2.1E-02
4545.1	4	4	4.71E-01
4579.4	2	2	8.0E-01
4589.9	4	6	6.64E-01
4598.8	4	4	6.7E-02
4609.6	6	8	7.89E-01
4637.2	6	6	7.1E-02
4657.9	4	2	8.92E-01
4726.9	4	4	5.88E-01
4732.1	6	4	6.7E-02
4735.9	6	4	5.80E-01
4764.9	2	4	6.4E-01
4806.0	6	6	7.80E-01
4847.8	4	2	8.49E-01
4879.9	4	6	8.23E-01
4889.0	2	2	1.9E-01
4904.8	6	8	3.7E-02
4933.2	4	4	1.44E-01
4965.1	2	4	3.94E-01
4972.2	2	2	9.7E-02
5009.3	4	6	1.51E-01
5017.2	4	6	2.07E-01
5017.6	4	4	1.1E-02
5062.0	2	4	2.23E-01
5141.8	6	8	8.1E-02
5145.3	4	6	1.06E-01
5176.2	6	6	1.7E-02
6103.5	2	2	1.7E-02
6114.9	10	8	2.00E-01
6138.7	6	4	1.2E-02
6172.3	8	6	2.00E-01
6243.1	8	6	3.0E-02
6483.1	4	2	1.06E-01
6638.2	6	4	1.37E-01
6639.7	4	2	1.69E-01
6643.7	10	8	1.47E-01
6666.4	2	2	8.8E-02
6684.3	8	6	1.07E-01
6756.6	4	4	2.0E-02
6863.5	6	6	2.5E-02
7233.5	2	4	3.7E-02
7380.4	4	4	5.6E-02
7589.3	6	4	1.07E-01
Ar III			
769.15	5	3	6.0E+00
871.10	5	3	1.59E+00
875.53	3	1	3.74E+00
878.73	5	5	2.79E+00
879.62	3	3	9.2E-01
883.18	1	3	1.22E+00
887.40	3	5	9.0E-01
3024.1	5	7	2.6E+00
3027.2	5	5	6.4E-01
3054.8	3	5	1.9E+00
3064.8	3	3	1.0E+00
3078.2	1	3	1.4E+00
3285.9	5	7	2.0E+00
3301.9	5	5	2.0E+00
3311.3	5	3	2.0E+00
3336.1	7	9	2.0E+00
3344.7	5	7	1.8E+00
3352.1	7	7	2.2E-01
3358.5	3	5	1.6E+00
3361.3	5	5	3.0E-01
3472.6	5	7	2.0E-01
3480.6	7	7	1.6E+00
3499.7	3	3	1.3E+00
3500.6	3	5	2.6E-01
3502.7	5	3	4.3E-01
3503.6	5	5	1.2E+00
3511.7	7	5	2.6E-01
Ar IV			
840.03	4	2	2.73E+00
843.77	4	4	2.70E+00
850.60	4	6	2.63E+00
Ar VI			
292.15	2	2	6.9E+01
294.05	4	2	1.36E+02
Ar VII			
*250.41	9	3	2.78E+02
*477.54	9	15	9.92E+01
585.75	1	3	7.83E+01
*637.30	9	9	6.7E+01
Ar VIII			
158.92	2	4	1.1E+02
159.18	2	2	1.11E+02

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
229.44	2	2	1.12E+02
230.88	4	2	2.21E+02
337.09	4	4	1.2E+01
337.26	6	4	1.0E+02
338.22	4	2	1.1E+02
519.43	2	4	6.3E+01
526.46	4	6	7.2E+01
526.87	4	4	1.2E+01
700.24	2	4	2.55E+01
713.81	2	2	2.4E+01
Ar IX			
48.739	1	3	1.69E+03
Ar XIII			
162.96	5	3	3.4E+02
*163.08	9	3	5.3E+02
184.90	5	5	1.66E+02
186.38	1	3	8.8E+01
*207.89	9	9	9.5E+01
*245.10	9	15	3.7E+01
Ar XIV			
180.29	2	4	4.5E+01
183.41	2	2	1.69E+02
187.95	4	4	1.97E+02
191.35	4	2	7.5E+01
194.39	2	2	4.6E+01
203.35	4	2	7.8E+01
Ar XV			
25.05	1	3	1.7E+04
221.10	1	3	9.55E+01
*265.3	9	9	8.1E+01
Ar XVI			
*23.52	2	6	1.43E+04
*24.96	6	10	4.4E+04
353.88	2	4	1.5E+01
389.11	2	2	1.1E+01
1268	2	4	1.9E+00
1401	2	2	1.4E+00
2975	2	4	9.0E-02
3514	4	6	6.5E-02
Arsenic			
As I			
1890.4	4	6	2.0E+00
1937.6	4	4	2.0E+00
1972.6	4	2	2.0E+00
2288.1	6	4	2.8E+00
2344.0	2	4	3.5E-01
2349.8	4	2	3.1E+00
2369.7	4	4	6.0E-01
2370.8	4	6	4.2E-01
2456.5	6	4	7.2E-02
2492.9	4	2	1.2E-01
2745.0	2	4	2.6E-01
2780.2	4	4	7.8E-01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
2860.4	2	2	5.5E-01
2898.7	4	2	9.9E-02
Barium			
Ba I			
2409.2	1	3	8.6E-04
2414.1	1	3	1.5E-03
2420.1	1	3	2.3E-03
2427.4	1	3	5.6E-03
2432.5	1	3	7.2E-03
2438.8	1	3	1.4E-03
2444.6	1	3	4.5E-03
2452.4	1	3	8.1E-04
2473.2	1	3	4.6E-03
2500.2	1	3	1.5E-02
2543.2	1	3	4.1E-02
2596.6	1	3	1.2E-01
2646.5	1	3	1.1E-02
2702.6	1	3	2.5E-02
2739.2	1	3	9.1E-03
2785.3	1	3	2.8E-02
3071.6	1	3	4.1E-01
3501.1	1	3	1.9E-01
3889.3	1	3	8.8E-03
3909.9	3	5	4.9E-01
3935.7	5	7	4.7E-01
3937.9	5	5	1.1E-01
3993.4	7	9	5.5E-01
3995.7	7	7	8.8E-02
4132.4	1	3	7.1E-03
4239.6	5	3	2.4E-01
4242.6	3	5	5.6E-02
4264.4	1	3	1.5E-01
4283.1	5	7	6.4E-01
4323.0	3	5	1.5E-01
4325.2	5	7	7.1E-02
4332.9	3	3	1.5E-01
4350.3	3	5	6.0E-01
4402.5	3	5	2.7E-01
4406.8	5	5	1.0E-01
4431.9	1	3	1.2E+00
4467.1	5	7	6.6E-02
4489.0	5	7	4.2E-01
4493.6	5	5	3.6E-01
4505.9	3	3	1.1E+00
4523.2	5	5	9.6E-01
4573.9	3	1	1.21E+00
4579.6	5	5	7.0E-01
4591.8	5	5	1.6E-02
4599.7	3	1	4.07E-01
4605.0	3	1	7.7E-02
4619.9	1	3	9.3E-02
4628.3	5	3	6.0E-02
4673.6	7	5	6.5E-02
4691.6	5	3	1.6E+00
4700.4	3	3	2.4E-01
4726.4	5	3	4.6E-01
5519.1	3	5	5.0E-01
5535.5	1	3	1.19E+00

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
5777.6	5	7	6.5E-01
5784.0	3	5	2.1E-01
5800.2	5	5	9.9E-02
5805.7	7	7	1.1E-02
5826.3	5	3	5.6E-01
5907.6	3	5	1.5E-02
5971.7	5	5	1.8E-01
5997.1	3	3	2.7E-01
6019.5	3	1	1.4E+00
6063.1	5	3	5.7E-01
6083.4	3	1	1.1E-01
6110.8	7	5	5.5E-01
6129.2	3	1	6.0E-02
6341.7	5	7	1.9E-01
6450.9	3	5	1.1E-01
6482.9	5	7	4.4E-01
6498.8	7	7	8.6E-01
6527.3	5	5	5.9E-01
6595.3	3	3	3.9E-01
6675.3	5	3	1.9E-01
6693.8	7	5	2.8E-01
6865.7	5	5	2.3E-02
7059.9	7	9	7.1E-01
7120.3	3	5	2.1E-01
7195.2	1	3	2.4E-01
7280.3	5	7	5.3E-01
7392.4	3	3	5.0E-01
7417.5	7	5	2.5E-02
7488.1	7	7	1.0E-01
7528.2	5	5	2.7E-02
7672.1	3	5	3.1E-01
7780.5	5	5	1.3E-01
7905.8	5	3	6.3E-01
7911.3	1	3	2.98E-03
8147.7	5	5	6.3E-02
9645.6	7	5	1.1E-01
9704.3	3	1	1.6E-01
9821.5	3	1	5.5E-02
10370.3	3	5	1.3E-02
10649.1	5	5	2.7E-02
11075.7	3	3	3.6E-05
11303.1	5	3	1.2E-03
11373.8	3	1	1.3E-01
14158.4	9	7	2.0E-03
14723.2	3	5	8.6E-03
14999.9	5	3	2.8E-03
17123.7	7	7	3.3E-03
17187.1	3	1	2.7E-02
20563.9	5	7	2.6E-03
Ba II			
1413.4	6	8	1.7E-02
1417.1	4	6	3.8E-02
1444.9	4	6	8.1E-02
1461.5	6	8	8.7E-02
1487.0	4	6	1.4E-01
1503.9	6	8	1.5E-01
1554.4	4	6	2.6E-01
1572.7	6	8	2.4E-01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
1573.9	6	6	1.6E-02
1630.4	2	2	1.7E-02
1674.5	4	6	2.2E-01
1694.4	6	8	2.1E-01
1697.2	6	6	1.7E-02
1761.8	4	4	3.9E-03
1771.0	4	2	3.4E-02
1786.9	6	4	4.4E-02
1892.7	2	4	9.0E-02
1904.2	4	6	1.1E-02
1906.8	2	2	5.1E-02
1924.7	6	8	3.1E-02
1954.2	4	6	1.3E-01
1955.1	4	4	1.8E-02
1970.2	4	2	6.7E-02
1985.6	2	4	2.5E-01
1999.5	2	4	1.0E-01
2009.2	2	2	8.6E-02
2052.7	4	6	2.0E-01
2054.6	4	4	2.9E-02
2080.0	4	2	1.0E-01
2153.9	2	4	5.3E-01
2200.9	2	2	2.0E-01
2232.8	4	6	2.9E-01
2235.4	4	4	4.4E-02
2286.0	4	2	1.3E-01
2528.5	2	4	7.1E-01
2634.8	4	6	7.6E-01
2641.4	4	4	1.2E-01
2647.3	2	2	2.0E-01
2771.4	4	2	4.0E-01
3816.7	4	6	2.3E-03
3842.8	6	8	2.2E-03
3891.8	2	4	1.67E+00
4024.1	6	4	5.3E-03
4057.5	8	6	1.2E-02
4130.7	4	6	1.80E+00
4166.0	4	4	3.7E-01
4216.0	2	4	5.8E-02
4287.8	2	2	2.4E-02
4325.7	4	6	5.9E-02
4329.6	4	4	8.8E-03
4405.2	4	2	3.9E-02
4470.7	6	4	1.4E-02
4509.6	8	6	1.2E-02
4524.9	2	2	7.2E-01
4554.0	2	4	1.17E+00
4708.9	2	4	9.7E-02
4843.5	4	6	9.3E-02
4847.1	2	2	4.1E-02
4850.8	4	4	1.4E-02
4900.0	4	2	7.75E-01
4934.1	2	2	9.55E-01
4997.8	4	2	6.1E-02
5185.0	2	4	1.8E-02
5361.4	4	6	4.8E-02
5391.6	6	8	5.2E-02
5413.6	6	6	8.4E-04
5421.1	6	6	1.9E-03
5428.8	6	4	2.3E-02
5480.3	8	6	1.8E-02
5784.2	2	4	2.0E-01
5853.7	4	4	4.8E-02
5981.3	4	6	1.6E-01
5999.9	4	4	2.6E-02
6135.8	2	2	8.5E-02
6141.7	6	4	3.7E-01
6363.2	6	4	2.9E-03
6372.9	4	4	6.7E-04
6378.9	4	2	9.9E-02
6457.7	6	4	3.0E-03
6496.9	4	2	3.32E-01
7556.8	6	4	1.6E-03
7678.2	8	6	6.6E-04
8710.7	6	8	8.0E-01
8737.7	4	6	9.3E-01

Beryllium

Be I

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
1491.8	1	3	1.3E-02
1661.5	1	3	2.0E-01
2348.6	1	3	5.55E+00
*2494.7	9	15	1.6E+00
*2650.6	9	9	4.24E+00
4572.7	3	5	7.9E-01

Be II

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
1197.1	2	2	4.7E-01
1197.2	4	2	9.4E-01
1512.3	2	4	9.2E+00
1512.4	4	6	1.1E+01
1776.1	2	2	1.4E+00
1776.3	4	2	2.9E+00
*2453.8	2	6	1.42E-01
3046.5	2	4	4.8E-01
3046.7	4	6	5.9E-01
3130.4	2	4	1.14E+00
3131.1	2	2	1.15E+00
3241.6	2	2	1.41E-01
3241.8	4	2	2.8E-01
3274.6	2	4	1.9E-01
3274.7	2	2	1.9E-01
4360.7	2	4	9.2E-01
4361.0	4	6	1.1E+00
*5255.9	2	6	2.56E-02
5270.3	2	2	3.30E-01
5270.8	4	2	6.6E-01
6279.4	2	4	1.2E-01
6279.7	4	6	1.43E-01
6756.7	2	2	5.1E-02
6757.1	4	2	1.02E-01
7401.2	2	4	3.0E-02
7401.4	2	2	3.0E-02

Bismuth

Bi I

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
1954.5	4	6	1.2E+00
2021.2	4	4	6.0E-02
2061.7	4	6	9.9E-01
2110.3	4	2	9.1E-01
2177.3	4	2	2.6E-02
2228.3	4	4	8.9E-01
2230.6	4	6	2.6E+00
2276.6	4	4	2.5E-01
2515.7	4	6	4.3E-02
2627.9	4	4	4.7E-01
2696.8	4	6	6.4E-02
2780.5	4	2	3.09E-01
2798.7	6	6	3.6E-02
2898.0	4	2	1.53E+00
2938.3	6	4	1.23E+00
2989.0	4	4	5.5E-01
2993.3	4	6	1.6E-01
3024.6	6	6	8.8E-01
3067.7	4	2	2.07E+00
3076.7	4	4	3.5E-02
3397.2	6	4	1.81E-01
3402.9	6	6	1.6E-02
3510.9	6	4	6.8E-02
3596.1	2	4	1.98E-01
3888.2	2	2	6.9E-02
4121.5	2	2	1.64E-01
4308.5	2	4	1.6E-02
4493.0	2	4	1.5E-02
4722.5	4	2	1.17E-01
6134.8	4	4	1.8E-02

Boron

B I

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
1378.6	2	4	3.50E+00
1378.9	2	2	1.40E+01
1378.9	4	4	1.75E+01
1379.2	4	2	7.0E+00
1465.5	2	4	3.34E+00
1465.7	4	4	6.7E+00
1465.8	6	4	1.00E+01
1825.9	2	4	1.76E+00
1826.4	4	6	2.11E+00
2088.9	2	4	2.8E-01
2089.6	4	6	3.3E-01
2496.8	2	2	8.64E-01
2497.7	4	2	1.73E+00

Bromine

Br I

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
1488.5	4	4	1.2E+00
1540.7	4	4	1.4E+00
1574.8	2	4	2.0E-01
1576.4	4	6	2.1E-02
1633.4	2	4	8.1E-02
4365.1	2	4	7.5E-03
4425.1	4	2	4.2E-03
4441.7	6	4	7.5E-03
4472.6	4	4	9.3E-03
4477.7	6	8	1.3E-02
4513.4	6	4	2.8E-03

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
4525.6	6	6	7.2E-03
4575.7	4	4	1.6E-02
4614.6	4	6	5.4E-03
4979.8	4	4	2.6E-03
5245.1	2	4	3.1E-03
5345.4	2	4	7.6E-03
7348.5	4	6	1.2E-01
7513.0	6	4	1.2E-01
7803.0	2	4	5.3E-02
7938.7	6	6	1.9E-01
8131.5	2	4	3.8E-02
8343.7	2	2	2.2E-01
8446.6	4	4	1.2E-01
8638.7	6	4	9.7E-02
Br II			
4704.9	5	7	1.1E+00
4785.5	5	5	9.4E-01
4816.7	5	3	1.1E+00
Cadmium			
Cd I			
2288.0	1	3	5.3E+00
2836.9	1	3	2.8E-01
2880.8	3	5	4.2E-01
2881.2	3	3	2.4E-01
2980.6	5	7	5.9E-01
2981.4	5	5	1.5E-01
3261.1	1	3	4.06E-03
3403.7	1	3	7.7E-01
3466.2	3	5	1.2E+00
3467.7	3	3	6.7E-01
3610.5	5	7	1.3E+00
3612.9	5	5	3.5E-01
4140.5	3	5	4.7E-02
4662.4	3	5	5.5E-02
4678.1	1	3	1.3E-01
4799.9	3	3	4.1E-01
5085.8	5	3	5.6E-01
6438.5	3	5	5.9E-01
Cd II			
2144.4	2	4	2.8E+00
2265.0	2	2	3.0E+00
2572.9	2	2	1.7E+00
2748.5	4	2	2.8E+00
4415.6	4	6	1.4E-02
Calcium			
Ca I			
2275.5	1	3	3.01E-01
2995.0	1	3	3.67E-01
2997.3	3	5	2.41E-01
2999.6	3	3	2.79E-01
3000.9	3	1	1.58E+00
3006.9	5	5	7.5E-01
3009.2	5	3	4.30E-01
3344.5	1	3	1.51E-01
3350.2	3	5	1.78E-01
3361.9	5	7	2.23E-01
3624.1	1	3	2.12E-01
3630.8	3	5	2.97E-01
3631.0	3	3	1.53E-01
3644.4	5	7	3.55E-01
3644.8	5	5	9.4E-02
3870.5	3	5	7.2E-02
3957.1	3	3	9.8E-02
3973.7	5	3	1.75E-01
4092.6	3	5	1.1E-01
4094.9	5	7	1.2E-01
4098.5	7	9	1.3E-01
4108.5	5	7	9.0E-01
4226.7	1	3	2.18E+00
4283.0	3	5	4.34E-01
4289.4	1	3	6.0E-01
4299.0	3	3	4.66E-01
4302.5	5	5	1.36E+00
4307.7	3	1	1.99E+00
4318.7	5	3	7.4E-01
4355.1	5	7	1.9E-01
4425.4	1	3	4.98E-01
4435.0	3	5	6.7E-01
4435.7	3	3	3.42E-01
4454.8	5	7	8.7E-01
4455.9	5	5	2.0E-01
4526.9	5	3	4.1E-01
4578.6	3	5	1.76E-01
4581.4	5	7	2.09E-01
4585.9	7	9	2.29E-01
4685.3	3	5	8.0E-02
4878.1	5	7	1.88E-01
5041.6	5	3	3.3E-01
5188.9	3	5	4.0E-01
5261.7	3	3	1.5E-01
5262.2	3	1	6.0E-01
5264.2	5	5	9.1E-02
5265.6	5	3	4.4E-01
5270.3	7	5	5.0E-01
5582.0	5	7	6.0E-02
5588.8	7	7	4.9E-01
5590.1	3	5	8.3E-02
5594.5	5	5	3.8E-01
5598.5	3	3	4.3E-01
5601.3	7	5	8.6E-02
5602.9	5	3	1.4E-01
5857.5	3	5	6.6E-01
6102.7	1	3	9.6E-02
6122.2	3	3	2.87E-01
6161.3	5	5	3.3E-02
6162.2	5	3	3.54E-01
6163.8	3	3	5.6E-02
6166.4	3	1	2.2E-01
6169.1	5	3	1.7E-01
6169.6	7	5	1.9E-01
6439.1	7	9	5.3E-01
6449.8	3	5	9.0E-02
6462.6	5	7	4.7E-01
6471.7	7	7	5.9E-02
6493.8	3	5	4.4E-01
6499.7	5	5	8.1E-02
Ca II			
1341.9	2	4	1.5E-02
1342.5	2	2	1.5E-02
1649.9	2	4	3.2E-03
1652.0	2	2	3.1E-03
1673.9	2	4	2.24E-01
1680.1	4	6	2.65E-01
1680.1	4	4	4.41E-02
1807.3	2	4	3.54E-01
1814.5	4	6	4.2E-01
1814.7	4	4	7.0E-02
1843.1	2	2	1.6E-01
1850.7	4	2	3.08E-01
2103.2	2	4	8.2E-01
2112.8	4	6	9.7E-01
2113.2	4	4	1.6E-01
2197.8	2	2	3.1E-01
2208.6	4	2	6.2E-01
3158.9	2	4	3.1E+00
3179.3	4	6	3.6E+00
3181.3	4	4	5.8E-01
3706.0	2	2	8.8E-01
3736.9	4	2	1.7E+00
3933.7	2	4	1.47E+00
3968.5	2	2	1.4E+00
Ca III			
357.97	1	3	8.8E+02
439.69	1	3	1.9E-01
490.55	1	3	1.6E-02
Ca V			
558.60	5	3	2.2E+01
637.93	5	3	3.9E+00
643.12	3	1	9.1E+00
646.57	5	5	6.9E+00
647.88	3	3	2.3E+00
651.55	1	3	2.9E+00
656.76	3	5	2.1E+00
Ca VII			
550.20	5	5	1.8E+01
624.39	1	3	3.3E+00
630.54	3	5	4.5E+00
630.79	3	3	2.2E+00
639.15	5	7	5.7E+00
640.41	5	5	1.3E+00
Ca VIII			
182.71	2	2	1.6E+02
184.16	4	2	3.2E+02
Ca IX			
163.23	5	3	3.76E+02
371.89	1	3	8.8E+01
373.81	3	5	1.16E+02

λ Å	Weights g_i	g_k	*A* 10^8 s^{-1}
378.08	5	7	1.5E+02
395.03	3	5	2.2E+02
466.24	1	3	1.12E+02
498.01	3	5	2.49E+01
506.18	5	5	7.2E+01
515.57	5	3	3.75E+01
Ca X			
110.96	2	4	2.9E+02
111.20	2	2	2.92E+02
151.84	2	2	2.3E+02
153.02	4	2	4.5E+02
206.57	4	4	2.9E+01
206.75	6	4	2.6E+02
207.39	4	2	2.8E+02
411.70	2	4	8.3E+01
419.75	4	6	9.5E+01
420.47	4	4	1.6E+01
557.76	2	4	3.50E+01
574.01	2	2	3.2E+01
Ca XI			
30.448	1	3	6.2E+03
30.867	1	3	4.9E+04
35.212	1	3	2.0E+03
Ca XII			
140.05	4	2	3.7E+02
147.27	2	2	1.6E+02
Ca XV			
141.69	5	3	4.08E+02
*142.23	9	3	6.3E+02
161.00	5	5	1.9E+02
Ca XVII			
19.558	1	3	3.8E+04
21.198	3	5	4.9E+04
192.82	1	3	1.21E+02
218.82	3	5	2.76E+01
223.02	1	3	3.44E+01
228.72	3	3	2.37E+01
232.83	5	5	6.5E+01
244.06	5	3	3.28E+01
Ca XVIII			
*18.71	2	6	2.31E+04
*19.74	6	10	7.0E+04
302.19	2	4	2.0E+01
344.76	2	2	1.3E+01
Carbon			
C I			
945.191	1	3	3.79E+00
945.338	3	3	1.14E+01
945.579	5	3	1.89E+01
1193.24	5	7	1.22E+00
1260.74	1	3	5.32E-01
1260.93	3	1	1.70E+00
1261.00	3	3	4.42E-01
1261.12	3	5	3.71E-01
1261.43	5	3	7.06E-01
1261.55	5	5	1.27E+00
1274.11	5	7	1.03E-02
1277.25	1	3	1.27E+00
1277.28	3	5	1.73E+00
1277.51	3	3	9.12E-01
1277.55	5	7	2.31E+00
1277.72	5	5	6.35E-01
1277.95	5	3	5.56E-02
1279.23	5	7	1.10E-01
1279.89	3	5	3.08E-01
1280.14	1	3	3.11E-01
1280.33	5	5	5.77E-01
1280.40	3	3	1.73E-01
1280.60	3	1	8.22E-01
1280.85	5	3	3.33E-01
1328.83	1	3	7.95E-01
1329.09	3	1	2.41E+00
1329.58	5	5	1.79E+00
1329.60	5	3	1.00E+00
1355.84	5	7	1.04E+00
1364.16	5	5	1.57E-01
1431.60	5	7	2.11E+00
1432.10	5	5	2.01E+00
1432.53	5	3	2.11E+00
1459.03	5	3	4.76E-01
1463.34	5	7	1.88E+00
1467.40	5	3	5.49E-01
1468.41	5	3	3.90E-02
1470.09	5	7	1.37E-02
1472.23	5	3	8.01E-03
1481.76	5	5	3.92E-01
1560.31	1	3	6.57E-01
1561.34	5	5	2.94E-01
1561.44	5	7	1.18E+00
1656.27	3	5	8.58E-01
1656.93	1	3	1.13E+00
1657.01	5	5	2.52E+00
1657.38	3	3	8.64E-01
1657.91	3	1	3.43E+00
1658.12	5	3	1.44E+00
1751.83	1	3	9.07E-01
1763.91	1	3	3.59E-02
1765.37	1	3	1.04E-02
1930.90	5	3	3.51E+00
2478.56	1	3	3.40E-01
2902.23	1	3	4.32E-03
2903.27	3	3	1.29E-02
2905.00	5	3	2.15E-02
4371.37	3	3	1.27E-02
4762.31	1	3	3.37E-03
4762.53	3	5	2.72E-03
4766.67	3	3	2.36E-03
4770.03	3	1	1.07E-02
4771.74	5	5	7.97E-03
4775.90	5	3	4.84E-03
4812.92	1	3	4.03E-04
4817.37	3	3	8.76E-04
4826.80	5	3	6.28E-04
4932.05	3	1	6.02E-02
5023.84	7	9	1.81E-03
5039.06	7	9	4.73E-03
5041.48	3	5	5.25E-03
5041.79	5	7	3.28E-03
5052.17	3	5	2.60E-02
5380.34	3	3	1.86E-02
5545.05	3	3	3.04E-03
5668.94	3	3	2.35E-02
5793.12	7	5	3.44E-03
5794.47	5	5	6.44E-04
5800.23	3	3	1.04E-03
5800.60	5	3	3.04E-03
5805.20	3	1	4.12E-03
6001.12	5	5	3.22E-03
6006.02	7	5	1.79E-02
6007.18	3	3	5.34E-03
6010.68	3	1	2.13E-02
6013.17	7	5	1.79E-02
6013.21	7	9	4.35E-03
6014.83	5	3	1.60E-02
6016.45	5	7	3.86E-03
6587.61	3	3	5.09E-02
6655.52	3	3	5.03E-03
6828.12	3	5	9.89E-03
7111.47	3	5	2.17E-02
7113.18	7	9	2.47E-02
7115.17	5	7	2.19E-02
7115.18	3	1	4.43E-02
7116.99	7	5	3.26E-02
7119.66	5	3	3.12E-02
7860.88	5	5	1.53E-02
8058.62	5	5	1.09E-02
8335.15	3	1	3.51E-01
9061.44	3	5	7.31E-02
9062.49	1	3	9.48E-02
9078.29	3	3	7.07E-02
9088.51	3	1	3.00E-01
9094.83	5	5	2.28E-01
9111.81	5	3	1.35E-01
9405.73	3	5	2.91E-01
9603.03	1	3	3.06E-02
9620.78	3	3	8.62E-02
9658.43	5	3	1.25E-01
C II			
687.345	4	6	2.84E+01
858.092	2	2	1.18E+00
858.559	4	2	2.35E+00
903.623	2	4	6.85E+00
903.962	2	2	2.74E+01
904.142	4	4	3.42E+01
904.480	4	2	1.37E+01
1009.86	2	4	5.71E+00
1010.08	4	4	1.14E+01
1010.37	6	4	1.71E+01
1036.34	2	2	7.61E+00

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
1037.02	4	2	1.52E+01
1323.91	4	4	4.33E+00
1323.95	6	6	4.49E+00
1334.53	2	4	2.37E+00
1335.71	4	6	2.84E+00
2091.14	2	4	1.00E-01
2091.19	4	6	1.69E-01
2091.65	6	8	2.41E-01
2093.16	6	6	7.20E-02
2173.85	2	4	2.31E-01
2174.17	2	2	2.31E-01
2509.13	2	4	4.53E-01
2511.74	4	4	9.04E-02
2512.06	4	6	5.42E-01
2727.31	2	4	6.63E-02
2728.72	4	4	3.31E-01
2729.21	2	2	2.65E-01
2730.63	4	2	1.32E-01
5132.95	2	4	3.89E-01
5133.28	4	6	2.80E-01
5137.26	2	2	1.55E-01
5139.17	4	4	1.24E-01
5143.49	4	2	7.73E-01
5145.16	6	6	6.49E-01
5151.08	6	4	4.16E-01
5640.55	2	4	9.89E-02
5648.07	4	4	1.97E-01
5662.46	6	4	2.93E-01
5818.31	2	2	3.38E-02
5822.98	2	4	3.38E-03
5823.18	4	2	3.38E-02
5827.85	4	4	2.16E-02
5836.37	6	4	4.22E-02
5843.62	6	6	1.20E-02
5856.06	8	6	5.31E-02
6095.29	2	4	4.20E-01
6098.51	4	6	5.03E-01
6102.56	4	4	8.37E-02
6578.05	2	4	3.63E-01
6582.88	2	2	3.62E-01
6724.56	2	4	3.17E-02
6727.07	2	2	6.34E-02
6727.26	4	6	2.96E-02
6731.07	4	4	5.06E-02
6733.58	4	2	6.32E-02
6734.00	6	8	1.80E-02
6738.61	6	6	7.23E-02
6742.43	6	4	4.41E-02
6750.54	8	8	1.08E-01
6755.16	8	6	2.38E-02
6779.94	4	6	2.56E-01
6780.59	2	4	1.52E-01
6783.91	6	8	3.65E-01
6787.21	2	2	3.04E-01
6791.47	4	4	1.94E-01
6798.10	4	2	6.04E-02
6800.69	6	6	1.09E-01
6812.28	6	4	1.80E-02
7046.25	4	2	3.20E-01
7053.09	4	4	3.19E-01
7063.68	4	6	3.17E-01
7112.48	2	4	2.94E-01
7113.04	4	6	3.15E-01
7115.63	6	8	3.60E-01
7119.76	4	4	1.17E-01
7119.91	8	10	4.19E-01
7125.72	6	6	1.02E-01
7132.47	6	4	8.33E-03
7134.10	8	8	5.93E-02
7231.33	2	4	3.52E-01
7236.42	4	6	4.22E-01
7237.17	4	4	7.03E-02
8028.85	2	2	1.71E-02
8037.73	2	4	4.26E-02
8039.40	4	2	8.51E-02
8048.31	4	4	1.36E-02
8062.10	4	6	3.04E-02
8062.80	6	4	4.56E-02
8076.64	6	6	7.05E-02
9238.30	4	6	3.34E-02
9251.01	2	4	2.77E-02
9863.06	2	4	5.56E-02
9870.78	4	6	9.31E-02
9882.68	6	8	1.33E-01

C III

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
310.170	1	3	6.56E+00
386.203	1	3	3.46E+01
459.466	1	3	5.91E+01
459.514	3	5	7.97E+01
459.627	5	7	1.06E+02
574.281	3	5	6.24E+01
977.020	1	3	1.767E+01
1174.93	3	5	3.293E+00
1175.26	1	3	4.385E+00
1175.59	3	3	3.287E+00
1175.71	5	5	9.856E+00
1175.99	3	1	1.313E+01
1176.37	5	3	5.468E+00
1247.38	3	1	2.082E+01
2296.87	3	5	1.376E+00
2849.05	3	1	1.95E-01
3703.70	3	3	5.90E-01
4325.56	3	5	1.24E-01
4647.42	3	5	7.26E-01
4650.25	3	3	7.25E-01
4651.02	3	5	2.28E-01
4651.47	3	1	7.24E-01
4652.05	1	3	3.04E-01
4659.06	3	3	2.27E-01
4663.64	3	1	9.05E-01
4665.86	5	5	6.78E-01
4673.95	5	3	3.75E-01
5244.66	1	3	5.30E-02
5253.58	3	3	1.58E-01
5272.52	5	3	2.61E-01
5695.92	3	5	4.27E-01
5858.34	3	1	1.34E-01
5863.25	3	3	3.35E-02
5871.68	5	3	1.00E-01
5880.56	5	5	1.99E-02
5894.07	7	5	1.11E-01
6727.48	1	3	1.12E-01
6731.04	3	5	1.50E-01
6742.15	3	3	8.32E-02
6744.39	5	7	1.99E-01
6762.17	5	5	4.95E-02
6773.39	5	3	5.47E-03
6851.18	3	5	7.60E-03
6853.68	5	7	5.64E-03
6857.24	3	3	3.79E-02
6862.69	5	5	3.51E-02
6868.78	5	3	1.26E-02
6872.04	7	7	4.46E-02
6881.10	7	5	7.80E-03
7353.88	5	3	3.09E-02
7707.43	3	5	1.30E-01
7771.76	3	1	1.77E-01
7780.41	3	3	1.76E-01
7796.00	3	5	1.75E-01
8500.32	1	3	1.01E-01
9593.32	3	3	5.32E-03
9651.47	5	5	1.57E-02
9696.48	5	7	7.53E-03
9696.54	3	5	7.12E-03
9699.57	7	9	8.47E-03
9701.10	1	3	4.40E-02
9705.41	3	5	5.93E-02
9706.44	3	3	3.29E-02
9715.09	5	7	7.88E-02
9717.75	5	5	1.97E-02
9718.79	5	3	2.19E-03

C IV

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
*312.43	2	6	4.63E+01
*384.13	6	10	1.76E+02
1548.19	2	4	2.65E+00
1550.77	2	2	2.64E+00
5801.31	2	4	3.17E-01
5811.97	2	2	3.16E-01

C V

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
34.9728	1	3	2.554E+03
40.2678	1	3	8.873E+03
*227.19	3	9	1.363E+02
247.315	1	3	1.278E+02
*248.71	9	15	4.247E+02
*260.19	9	3	6.680E+01
267.267	3	5	3.947E+02
*2273.9	3	9	5.646E-01
3526.66	1	3	1.663E-01
8420.72	3	5	6.898E-02
*8433.2	3	9	6.868E-02
8448.12	3	1	6.832E-02

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
8449.19	3	3	6.829E-02

Cesium

Cs I

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
3203.5	2	4	7.6E-06
3205.3	2	4	7.9E-06
3207.5	2	4	8.5E-06
3210.0	2	4	9.4E-06
3212.8	2	4	1.19E-05
3216.2	2	4	1.49E-05
3220.1	2	4	1.7E-05
3220.2	2	2	1.07E-07
3224.8	2	4	2.0E-05
3225.0	2	2	1.43E-07
3230.5	2	4	2.5E-05
3230.7	2	2	1.97E-07
3237.4	2	4	2.8E-05
3237.6	2	2	2.63E-07
3245.9	2	4	3.45E-05
3246.2	2	2	3.7E-07
3256.7	2	4	4.25E-05
3257.1	2	2	7.0E-07
3270.5	2	4	5.6E-05
3271.0	2	2	9.8E-07
3288.6	2	4	1.0E-04
3289.3	2	2	2.7E-06
3313.1	2	4	1.6E-04
3314.0	2	2	5.2E-06
3347.5	2	4	2.2E-04
3348.8	2	2	1.1E-05
3397.9	2	4	4.0E-04
3400.0	2	2	2.4E-05
3476.8	2	4	6.6E-04
3480.0	2	2	6.6E-05
3611.4	2	4	1.5E-03
3617.3	2	2	2.5E-04
3876.1	2	4	3.8E-03
3888.6	2	2	9.7E-04
4555.3	2	4	1.88E-02
4593.2	2	2	8.0E-03
8521.1	2	4	3.276E-01
8943.5	2	2	2.87E-01

Chlorine

Cl I

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
1188.8	4	6	2.33E+00
1188.8	4	4	2.71E-01
1201.4	2	4	2.39E+00
1335.7	4	2	1.74E+00
1347.2	4	4	4.19E+00
1351.7	2	2	3.23E+00
1363.4	2	4	7.5E-01
4323.3	4	4	1.1E-02
4363.3	4	6	6.8E-03
4379.9	4	4	1.4E-02
4389.8	6	8	1.4E-02
4526.2	4	4	5.1E-02
4601.0	2	2	4.2E-02
4661.2	2	4	1.2E-02
7256.6	6	4	1.5E-01
7414.1	6	4	4.7E-02
7547.1	4	4	1.2E-01
7717.6	4	4	3.0E-02
7745.0	2	4	6.3E-02
7769.2	6	6	6.0E-02
7821.4	6	8	9.8E-02
7830.8	4	4	9.7E-02
7878.2	6	6	1.8E-02
7899.3	4	6	5.1E-02
7924.6	2	4	2.1E-02
7935.0	6	8	3.9E-02
7997.9	4	4	2.1E-02

Cl II

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
3329.1	5	7	1.5E+00
3522.1	7	7	1.4E+00
3798.8	5	7	1.6E+00
3805.2	7	9	1.8E+00
3809.5	3	5	1.5E+00
3851.0	5	7	1.8E+00
3851.4	5	5	1.6E+00
3854.7	3	5	2.2E+00
3861.9	5	7	2.4E+00
3868.6	7	9	2.7E+00
3913.9	9	9	8.2E-01
3990.2	5	7	8.4E-01
4132.5	5	5	1.6E+00
4276.5	9	7	7.6E-01
4768.7	3	5	7.7E-01
4781.3	5	7	1.0E+00
4794.6	5	7	1.04E+00
4810.1	5	5	9.9E-01
4819.5	5	3	1.00E+00
4904.8	5	7	8.1E-01
4917.7	3	5	7.5E-01
5078.3	7	7	7.7E-01
5219.1	3	9	8.6E-01
5392.1	5	7	1.0E+00

Cl III

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
2298.5	4	4	4.2E+00
2340.6	6	6	4.2E+00
2370.4	8	6	2.8E+00
2531.8	2	4	4.4E+00
2532.5	4	6	5.3E+00
2577.1	4	6	4.3E+00
2580.7	6	8	4.7E+00
2601.2	2	4	4.6E+00
2603.6	4	6	5.0E+00
2609.5	6	8	5.7E+00
2617.0	8	10	6.6E+00
2661.6	4	6	3.4E+00
2665.5	6	8	4.8E+00
2691.5	4	4	3.5E+00
2710.4	4	6	3.5E+00
3340.4	6	6	1.5E+00
3392.9	4	4	1.9E+00
3393.5	6	6	1.9E+00
3530.0	6	8	1.8E+00
3560.7	4	6	1.7E+00
3602.1	6	8	1.7E+00
3612.9	4	6	1.2E+00
3720.5	4	6	1.7E+00

Chromium

Cr I

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
1999.95	9	9	1.4E+00
2383.30	9	11	4.1E-01
2389.21	3	5	2.3E-01
2408.60	9	7	6.7E-01
2408.72	7	5	2.9E-01
2492.57	3	5	4.5E-01
2495.08	3	3	2.7E-01
2496.30	5	7	5.6E-01
2502.55	7	9	2.2E-01
2504.31	7	9	4.5E-01
2508.11	5	5	2.1E-01
2508.97	5	3	3.8E-01
2527.11	9	9	5.3E-01
2549.55	3	3	4.8E-01
2560.70	5	5	4.3E-01
2571.74	7	5	6.4E-01
2577.66	7	7	2.6E-01
2591.84	9	7	6.5E-01
2620.48	5	3	1.9E-01
2673.64	3	3	1.8E-01
2701.99	9	11	2.1E-01
2726.50	5	7	7.5E-01
2731.90	5	5	7.8E-01
2736.46	5	3	7.5E-01
2752.85	3	3	8.7E-01
2757.09	5	5	6.8E-01
2761.74	5	3	6.8E-01
2764.36	7	7	3.7E-01
2769.90	7	5	1.1E+00
2780.70	9	7	1.4E+00
2879.27	5	7	2.1E-01
2887.00	3	5	2.7E-01
2889.22	9	9	6.6E-01
2893.25	7	7	5.2E-01
2894.17	1	3	3.3E-01
2896.76	5	5	3.0E-01
2905.48	3	1	1.3E+00
2909.05	5	3	6.8E-01
2910.89	7	5	3.4E-01
2911.15	9	7	2.6E-01
2967.64	7	9	3.9E-01
2971.10	5	7	7.1E-01
2975.48	3	5	8.9E-01
2980.78	1	3	5.10E-01
2988.64	5	7	5.2E-01
2991.88	3	1	3.0E+00
2994.06	5	5	2.5E-01
2995.09	5	5	4.3E-01
2996.57	5	3	2.0E+00
2998.78	5	3	4.07E-01
3000.88	7	5	1.6E+00

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
3005.06	9	7	9.2E-01
3013.72	3	5	8.3E-01
3015.20	1	3	1.63E+00
3020.67	3	3	1.5E+00
3021.58	9	11	2.91E+00
3024.36	5	5	1.27E+00
3029.17	5	3	3.8E-01
3030.25	7	7	1.1E+00
3031.35	5	3	3.1E-01
3034.19	7	7	3.5E-01
3037.05	9	9	5.4E-01
3040.84	7	5	7.4E-01
3053.87	9	7	7.97E-01
3148.44	9	11	5.6E-01
3155.16	11	13	5.7E-01
3163.76	13	15	6.0E-01
3237.73	9	9	1.3E+00
3238.09	11	11	2.0E-01
3578.68	7	9	1.48E+00
3593.48	7	7	1.50E+00
3605.32	7	5	1.62E+00
3639.80	13	11	1.8E+00
3743.89	13	13	7.61E-01
3757.66	7	7	4.13E-01
3768.24	5	5	5.10E-01
3804.80	9	9	6.9E-01
3963.69	13	15	1.3E+00
3969.75	11	13	1.2E+00
3983.90	7	9	1.05E+00
3991.12	5	7	1.07E+00
4001.44	9	11	6.8E-01
4039.10	15	15	6.7E-01
4048.78	13	13	6.4E-01
4058.78	11	11	6.7E-01
4065.71	9	11	3.5E-01
4165.52	11	13	7.5E-01
4204.48	13	11	3.1E-01
4254.33	7	9	3.15E-01
4263.15	15	17	6.4E-01
4274.81	7	7	3.07E-01
4275.98	11	11	2.2E-01
4280.42	13	15	4.7E-01
4289.73	7	5	3.16E-01
4291.97	7	5	2.4E-01
4297.75	11	13	4.9E-01
4298.05	9	9	2.6E-01
4300.52	9	7	1.9E-01
4301.19	11	9	2.6E-01
4302.78	11	11	2.5E-01
4319.66	5	3	1.8E-01
4337.25	5	7	2.0E-01
4373.65	9	9	2.8E-01
4376.80	13	13	3.2E-01
4413.86	7	5	2.7E-01
4422.70	5	5	2.7E-01
4424.29	9	7	2.1E-01
4429.93	3	3	2.4E-01
4432.16	1	3	1.8E-01
4432.77	15	15	4.9E-01
4443.72	3	1	4.5E-01
4482.88	3	3	3.0E-01
4490.55	9	7	3.9E-01
4492.31	5	3	4.47E-01
4495.28	9	7	2.0E-01
4500.29	7	7	2.1E-01
4506.84	13	11	2.7E-01
4540.72	11	11	3.14E-01
4564.17	11	13	5.1E-01
4595.60	13	13	4.7E-01
4622.47	7	7	4.1E-01
4663.33	3	3	2.0E-01
4665.90	3	3	3.0E-01
4689.38	7	5	2.3E-01
4698.46	9	7	2.2E-01
4708.02	11	9	4.31E-01
4718.43	13	11	3.4E-01
4730.69	7	5	3.83E-01
4737.33	9	7	3.38E-01
4741.09	3	5	2.2E-01
4752.07	13	13	6.2E-01
4756.09	11	9	4.0E-01
4792.49	7	5	2.6E-01
4801.02	9	7	3.06E-01
4816.13	9	9	1.8E-01
4870.79	7	9	3.5E-01
4887.01	9	11	3.2E-01
4922.28	11	13	4.0E-01
4966.80	3	1	3.0E-01
5204.51	5	3	5.09E-01
5206.02	5	5	5.14E-01
5208.42	5	7	5.06E-01
5243.38	5	3	2.19E-01
5297.37	7	9	3.88E-01
5297.99	7	7	3.0E-01
5328.36	9	11	6.2E-01
5329.17	9	9	2.25E-01
5783.11	3	3	2.1E-01
5783.89	5	5	2.02E-01
5787.97	5	7	2.35E-01
Cr II			
2653.57	4	6	3.5E-01
2658.59	2	4	5.8E-01
2666.02	6	8	5.9E-01
2668.71	4	2	1.4E+00
2671.80	6	4	1.0E+00
2672.83	8	6	5.5E-01
2744.97	4	6	8.5E-01
2787.61	6	6	1.5E+00
2822.38	14	16	2.3E+00
2835.63	10	12	2.0E+00
2840.01	10	12	2.7E+00
2843.24	8	10	6.4E-01
2849.83	6	8	9.2E-01
2851.35	8	10	2.2E+00
2856.77	4	6	4.3E-01
2857.40	6	8	2.8E-01
2860.92	2	4	6.9E-01
2862.57	8	8	6.3E-01
2866.72	4	4	1.2E+00
2867.09	4	4	1.1E+00
2867.65	2	2	1.1E+00
2870.43	6	6	1.3E+00
2873.81	4	2	8.8E-01
2880.86	6	4	7.9E-01
2898.53	10	12	1.2E+00
2921.81	8	10	9.0E-01
2930.83	2	4	1.1E+00
2935.12	6	8	1.8E+00
2953.34	2	2	1.8E+00
2966.03	10	8	5.4E-01
2971.90	14	14	2.0E+00
2979.73	12	12	1.8E+00
2985.32	10	10	2.2E+00
2989.18	8	8	2.2E+00
3118.64	2	4	1.7E+00
3120.36	4	6	1.5E+00
3122.59	12	12	4.4E-01
3128.69	4	4	8.1E-01
3136.68	6	6	6.4E-01
4588.22	8	6	1.2E-01
Cr V			
434.306	9	9	1.5E+01
436.351	9	7	2.4E+01
436.601	7	5	2.1E+01
437.420	7	7	1.4E+01
437.655	5	5	1.3E+01
441.056	5	3	2.3E+01
456.357	1	3	9.5E+00
456.637	3	1	3.3E+01
456.743	3	3	9.1E+00
457.028	5	5	2.7E+01
457.504	5	3	1.2E+01
464.015	9	7	3.6E+01
469.634	5	5	2.3E+01
1106.25	7	9	1.2E+01
1121.07	7	9	2.1E+01
1127.63	9	11	3.5E+01
1465.86	5	3	1.1E+01
1481.65	3	1	1.0E+01
1519.03	5	7	9.5E+00
1579.70	7	9	8.6E+00
Cr VI			
161.687	6	6	1.7E+02
168.088	4	6	2.0E+02
201.007	4	4	2.5E+03
201.224	4	6	1.8E+02
201.388	6	4	2.7E+02
201.606	6	6	2.6E+03
202.442	6	4	1.0E+03
202.739	4	2	1.2E+03
226.241	6	8	7.2E+02

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
227.202	4	6	6.6E+02
Cr X			
216.72	6	8	9.0E+02
223.86	4	2	7.7E+02
224.74	4	4	7.6E+02
226.24	4	6	7.3E+02
227.42	4	4	5.2E+02
227.50	4	6	1.8E+01
228.63	6	4	8.1E+01
228.71	6	6	4.5E+02
231.21	2	4	1.2E+02
232.96	4	4	4.4E+02
242.20	2	4	5.0E+01
244.19	4	6	5.8E+01
395.984	4	4	2.4E+01
398.150	6	6	2.1E+01
Cr XI			
214.31	5	7	1.4E+01
226.45	5	7	6.0E+02
232	3	1	4.1E+02
235.53	5	7	5.5E+02
240.76	1	3	4.8E+02
250.28	5	7	1.0E+01
366.491	3	3	1.2E+01
366.942	3	1	3.0E+01
374.927	5	5	2.3E+01
422.083	3	5	1.0E+01
Cr XII			
216	4	6	2.4E+02
218	6	8	2.4E+02
239	2	2	1.6E+02
244.70	2	4	3.0E+02
247	4	2	2.4E+02
247	2	2	3.3E+02
248	6	8	1.4E+02
250	6	8	3.5E+02
250	6	6	2.2E+02
251.52	4	6	3.4E+02
252	4	6	2.0E+02
256	2	2	1.5E+02
259	2	4	3.2E+02
269	2	2	2.1E+02
300.32	2	2	1.4E+02
305.81	4	4	2.76E+02
309	4	2	2.7E+02
309	6	6	1.6E+02
311.55	4	2	1.6E+02
324	4	6	2.2E+02
327	6	8	2.2E+02
332.06	6	4	1.4E+02
Cr XIII			
49.59	1	3	9.9E+02
67.01	1	3	1.67E+03
228	5	7	1.8E+02
267.73	5	7	1.9E+02
270	3	1	1.7E+02
276.4	5	7	2.2E+02
277	1	3	2.1E+02
279.32	3	5	3.5E+02
286	3	1	4.6E+02
328.29	1	3	1.86E+02
345	7	9	1.74E+02
Cr XIV			
*38.036	2	6	2.47E+02
39.796	2	4	3.05E+02
40.018	4	6	3.6E+02
40.782	2	4	3.9E+02
40.800	2	2	3.9E+02
41.556	2	4	4.5E+02
41.788	4	6	5.3E+02
44.597	2	4	7.1E+02
44.869	4	6	8.3E+02
46.125	4	2	3.1E+02
46.468	2	4	6.6E+02
46.527	2	2	6.7E+02
48.300	4	6	5.9E+02
48.338	6	8	6.3E+02
50.821	2	4	1.2E+03
51.172	4	6	1.4E+03
51.180	4	4	2.3E+02
52.321	4	6	1.0E+03
52.363	6	8	1.1E+03
53.760	2	2	3.0E+02
54.164	4	2	5.9E+02
60.699	4	6	2.05E+03
60.756	6	8	2.19E+03
63.324	2	4	1.07E+03
63.539	2	2	1.13E+03
68.594	2	4	1.98E+03
69.213	4	6	2.31E+03
69.247	4	4	3.8E+02
86.060	4	6	5.3E+03
86.169	6	8	5.9E+03
86.185	6	6	3.9E+02
101.05	6	4	4.4E+02
101.42	4	2	4.83E+02
104.4	4	6	3.0E+02
104.5	6	8	3.1E+02
109.8	2	4	2.3E+02
110.4	4	6	2.8E+02
118.3	4	2	2.1E+02
125.2	4	6	5.0E+02
125.3	6	8	5.4E+02
148.5	2	4	2.18E+02
149.1	2	2	2.1E+02
157.1	2	4	3.3E+02
158.4	4	6	3.7E+02
187.02	4	6	9.3E+02
187.30	6	8	9.6E+02
189.1	2	2	2.13E+02
191.0	4	2	4.11E+02
222.9	4	2	2.2E+02
346.3	4	6	2.4E+02
346.5	6	8	2.5E+02
Cr XV			
18.497	1	3	1.62E+05
18.782	1	3	2.8E+04
19.015	1	3	6.3E+02
20.863	1	3	6.0E+03
21.153	1	3	5.6E+03
102	3	3	1.6E+02
102.18	5	3	7.0E+02
103	3	1	3.8E+02
105	7	5	5.3E+02
111.27	3	3	1.7E+02
Cr XVI			
17.073	4	6	1.2E+04
17.242	2	4	8.6E+04
17.299	4	4	2.5E+04
17.372	4	4	1.4E+05
17.438	4	2	1.1E+05
17.514	2	4	1.1E+05
17.587	2	4	2.0E+04
17.656	2	2	2.0E+04
19.442	4	2	9.9E+03
19.714	2	2	1.1E+04
Cr XVII			
16.31	5	3	9.6E+03
16.32	5	7	3.2E+04
16.37	3	1	9.7E+04
16.44	5	7	1.3E+05
16.59	3	1	5.7E+04
16.65	5	5	1.1E+04
16.66	1	3	1.8E+05
16.68	5	7	6.8E+04
16.80	5	7	4.4E+04
16.97	1	3	2.63E+04
16.97	3	3	1.5E+04
17.968	5	3	8.6E+03
18.336	5	3	1.7E+04
18.336	5	5	1.6E+04
18.389	1	3	9.2E+03
Cr XVIII			
95.77	4	2	3.08E+02
102.32	4	4	1.54E+02
104.98	6	4	8.7E+02
106.84	4	2	3.4E+02
110.41	4	2	7.9E+02
112.27	4	2	4.24E+02
119.62	2	2	3.2E+02
123.87	6	4	3.9E+02
125.51	4	4	3.4E+02
128.10	6	6	2.8E+02
136.52	4	2	1.66E+02
139.87	4	4	1.49E+02
140.82	4	2	2.66E+02
155.46	2	2	2.84E+02
157.40	4	4	2.83E+02

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
Cr XIX			
14.73	3	3	7.1E+04
14.80	1	3	1.3E+05
14.81	5	3	3.4E+04
14.84	5	7	1.3E+05
109.64	3	3	2.46E+02
110.37	5	3	6.0E+02
113.97	5	3	5.5E+02
118.31	3	1	3.29E+02
118.67	5	3	2.1E+02
118.83	3	3	1.35E+02
126.30	1	3	1.56E+02
126.33	5	5	4.35E+02
130.99	7	5	2.9E+02
134.89	3	1	1.98E+02
138.15	3	1	1.75E+02
138.45	5	5	1.71E+02
140.92	5	3	1.38E+02
143.57	3	1	7.2E+02
163.94	5	5	3.1E+02
179.18	3	1	1.45E+02
Cr XX			
14.13	2	4	1.1E+05
14.26	4	6	1.3E+05
128.42	4	4	3.8E+02
131.31	6	4	1.27E+02
133.82	2	4	8.3E+01
135.26	4	2	2.41E+02
140.75	4	4	1.35E+02
148.99	6	4	1.75E+02
156.00	2	4	8.4E+01
167.97	6	6	1.12E+02
180.85	4	4	1.6E+02
Cr XXI			
12.97	3	1	4.8E+04
12.98	5	5	3.9E+04
13.02	3	5	3.8E+04
13.02	5	7	3.9E+04
13.08	1	3	5.2E+04
13.22	3	1	4.6E+04
13.34	3	5	5.2E+04
13.49	1	3	9.0E+04
13.53	3	3	6.6E+04
13.55	3	5	1.2E+05
13.65	5	7	1.5E+05
13.66	3	1	1.2E+05
13.67	5	5	3.9E+04
13.68	3	3	8.2E+04
13.75	5	3	4.5E+04
13.75	5	5	9.5E+04
13.76	1	3	1.51E+05
13.78	5	7	1.7E+05
13.84	5	7	2.59E+05
13.87	3	5	8.5E+04
13.92	3	5	8.5E+04
13.93	5	7	4.2E+04
13.95	5	5	3.8E+04
14.04	3	5	1.2E+05
14.24	1	3	1.41E+05
Cr XXII			
2.190	4	2	1.7E+06
2.191	2	2	2.5E+06
2.198	4	4	4.5E+06
2.199	2	4	2.3E+06
2.202	4	6	1.6E+06
2.203	4	2	1.3E+06
13.149	2	4	1.29E+05
13.292	4	6	1.54E+05
Cr XXIII			
1.7632	1	3	3.68E+05
1.8557	1	3	8.97E+05
2.095	3	1	3.5E+06
2.101	1	3	2.0E+06
2.101	5	5	7.9E+05
2.102	3	5	2.1E+06
2.103	3	5	1.2E+06
2.104	1	3	1.4E+06
2.105	3	3	9.6E+05
2.106	3	3	2.0E+06
2.107	5	5	2.3E+06
2.107	3	5	3.3E+06
2.109	5	3	1.7E+06
2.113	3	5	5.9E+05
2.119	3	1	2.7E+05
2.129	3	1	5.1E+05
2.1818	1	3	3.37E+06
2.1923	1	3	2.34E+05
Cobalt			
Co I			
2287.80	8	8	8.6E-01
2295.22	10	8	2.2E-01
2309.03	10	10	5.6E-01
2323.13	8	8	5.0E-01
2325.53	6	8	1.1E-01
2335.98	6	6	5.1E-01
2338.66	4	4	7.7E-01
2353.36	8	10	1.5E-01
2355.48	6	8	1.3E-01
2358.18	4	6	1.4E-01
2365.06	10	10	1.3E-01
2371.85	6	8	7.3E-02
2384.86	10	8	2.4E-01
2392.03	6	6	4.0E-01
2402.06	8	6	5.1E-01
2407.25	10	12	3.6E+00
2412.76	4	6	6.5E-01
2414.46	6	8	3.4E+00
2415.29	4	6	3.6E+00
2424.93	10	10	3.2E+00
2432.21	8	8	2.6E+00
2436.66	6	6	2.6E+00
2439.04	4	4	2.7E+00
2460.80	4	6	1.2E-01
2467.69	6	8	7.0E-02
2470.27	10	12	1.5E-01
2476.64	10	8	2.2E-01
2504.52	10	8	1.8E-01
2511.02	10	10	9.2E-01
2521.36	10	8	3.0E+00
2528.97	8	6	2.8E+00
2530.13	6	6	7.1E-02
2535.96	6	4	1.9E+00
2536.50	8	8	3.0E-01
2544.25	4	2	3.0E+00
2562.12	4	4	3.9E-01
2567.34	6	6	3.0E-01
2574.35	8	8	1.7E-01
2685.34	6	8	5.5E-02
3017.55	8	6	6.9E-02
3044.00	10	10	1.9E-01
3048.89	6	4	7.5E-02
3061.82	8	8	1.6E-01
3072.34	6	6	1.5E-01
3086.78	4	4	1.9E-01
3354.37	8	6	1.1E-01
3367.11	10	8	6.0E-02
3385.22	8	6	1.1E-01
3388.16	6	4	2.4E-01
3395.37	6	8	2.9E-01
3405.12	10	10	1.0E+00
3409.17	8	8	4.2E-01
3412.34	8	10	6.1E-01
3412.63	10	8	1.2E-01
3414.74	4	4	8.8E-02
3417.15	6	6	3.2E-01
3431.58	8	6	1.1E-01
3433.05	4	4	1.0E+00
3442.92	6	4	1.2E-01
3443.64	8	8	6.9E-01
3449.17	6	6	7.6E-01
3449.44	10	10	1.8E-01
3453.51	10	12	1.1E+00
3455.24	4	2	1.9E-01
3462.80	4	6	7.9E-01
3465.79	10	12	9.2E-02
3474.02	6	8	5.6E-01
3483.41	8	10	5.5E-02
3489.40	8	6	1.3E+00
3491.32	4	4	5.0E-02
3495.68	4	6	4.9E-01
3502.28	10	8	8.0E-01
3502.63	6	6	5.2E-02
3506.32	8	6	8.2E-01
3509.84	6	8	3.2E-01
3512.64	6	4	1.0E+00
3513.48	8	10	7.8E-02
3518.34	6	4	1.6E+00
3521.58	10	8	1.8E-01
3523.42	4	2	9.8E-01
3526.85	10	10	1.3E-01
3529.03	6	8	8.8E-02
3529.82	8	10	4.6E-01

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
3533.36	4	6	9.1E-02
3560.89	4	4	2.3E-01
3564.95	6	8	7.0E-02
3569.37	8	8	1.6E+00
3574.97	6	6	1.5E-01
3575.36	8	8	9.6E-02
3585.15	8	8	7.1E-02
3587.19	6	6	1.4E+00
3594.87	6	6	9.2E-02
3602.08	4	4	1.0E-01
3704.06	6	8	1.2E-01
3745.49	8	8	7.5E-02
3842.05	8	6	1.3E-01
3845.47	8	10	4.6E-01
3861.16	6	4	1.4E-01
3873.12	10	8	1.2E-01
3873.95	8	6	1.0E-01
3881.87	6	4	8.2E-02
3894.07	6	8	6.9E-01
3894.98	4	2	8.8E-02
3935.96	8	10	6.2E-02
3995.31	8	10	2.5E-01
3997.90	6	8	7.0E-02
4092.39	8	8	5.7E-02
4110.53	6	6	5.5E-02
4118.77	6	8	1.6E-01
4121.32	8	10	1.9E-01
5146.75	8	8	1.5E-01
5212.70	10	10	1.9E-01
5265.79	6	8	5.0E-02
5280.63	10	8	2.8E-01
5352.05	12	10	2.7E-01
5477.09	6	8	6.8E-02
5483.96	8	10	7.3E-02
6082.43	10	10	5.4E-02
6455.00	8	10	9.0E-02
7838.12	8	10	5.4E-02
8093.93	12	10	2.0E-01
8372.79	10	10	8.7E-02
Co II			
2286.15	11	13	3.3E+00
2307.85	9	11	2.6E+00
2311.61	7	9	2.8E+00
2314.05	5	7	2.8E+00
2314.97	3	5	2.7E+00
2330.36	5	3	1.32E+00
2344.28	3	3	1.5E+00
2353.41	7	7	1.9E+00
2363.80	9	9	2.1E+00
2378.62	11	9	1.9E+00
2383.45	9	7	1.8E+00
2388.92	11	11	2.8E+00
2389.54	5	3	1.5E+00
2404.17	3	3	1.5E+00
2417.66	9	9	8.5E-01
Copper			
Cu I			
*2024.3	2	6	9.8E-02
2165.1	2	4	5.1E-01
2178.9	2	4	9.13E-01
2181.7	2	2	1.0E+00
2225.7	2	2	4.6E-01
2244.3	2	4	1.19E-02
2441.6	2	2	2.0E-02
2492.2	2	4	3.11E-02
2618.4	6	4	3.07E-01
2766.4	4	4	9.6E-02
2824.4	6	6	7.8E-02
2961.2	6	8	3.76E-02
3063.4	4	4	1.55E-02
3194.1	4	4	1.55E-02
3247.5	2	4	1.39E+00
3274.0	2	2	1.37E+00
3337.8	6	8	3.8E-03
4022.6	2	4	1.90E-01
4062.6	4	6	2.10E-01
4249.0	2	2	1.95E-01
4275.1	6	8	3.45E-01
4480.4	2	2	3.0E-02
4509.4	4	2	2.75E-01
4530.8	4	2	8.4E-02
4539.7	6	4	2.12E-01
4587.0	8	6	3.20E-01
4651.1	10	8	3.80E-01
4704.6	8	8	5.5E-02
5105.5	6	4	2.0E-02
5153.2	2	4	6.0E-01
5218.2	4	6	7.5E-01
5220.1	4	4	1.50E-01
5292.5	8	8	1.09E-01
5700.2	4	4	2.4E-03
5782.1	4	2	1.65E-02
Cu II			
2489.7	5	5	1.5E-02
2544.8	9	7	1.1E+00
2689.3	7	7	4.1E-01
2701.0	5	5	6.7E-01
2703.2	3	3	1.2E+00
2713.5	5	5	6.8E-01
2769.7	7	7	6.1E-01
Dysprosium			
Dy I			
2862.7	17	15	6.5E-02
2964.6	17	17	6.5E-02
3147.7	15	17	1.1E-01
3263.2	15	13	1.4E-01
3511.0	15	13	3.1E-01
3571.4	15	13	2.0E-01
3757.1	17	19	3.0E+00
3868.8	17	17	3.1E+00
3967.5	17	19	8.7E-01
4046.0	17	15	1.5E+00
4103.9	13	11	1.7E+00
4186.8	17	17	1.32E+00
4194.8	17	17	7.2E-01
4211.7	17	19	2.08E+00
4218.1	15	15	1.85E+00
4221.1	15	17	1.52E+00
4225.2	13	15	4.5E+00
4268.3	15	15	3.6E-02
4276.7	13	13	7.3E-01
4292.0	15	15	5.8E-02
4577.8	17	19	2.2E-02
4589.4	17	15	1.3E-01
4612.3	17	15	8.2E-02
5077.7	17	17	5.7E-03
5301.6	17	15	1.1E-02
5547.3	17	17	2.7E-03
5639.5	17	19	4.7E-03
5974.5	17	17	4.0E-03
5988.6	17	15	5.3E-03
6010.8	15	15	2.6E-02
6088.3	15	13	3.5E-02
6168.4	15	17	2.5E-02
6259.1	17	19	8.5E-03
6579.4	17	15	7.5E-03
Erbium			
Er I			
3862.9	13	13	2.5E+00
4008.0	13	15	2.6E+00
4151.1	13	11	1.8E+00
Europium			
Eu I			
2372.9	8	6	1.9E-01
2375.3	8	8	2.0E-01
2379.7	8	10	2.0E-01
2619.3	8	10	7.0E-03
2643.8	8	8	6.6E-03
2659.4	8	10	1.2E-02
2682.6	8	6	1.2E-02
2710.0	8	10	1.4E-01
2724.0	8	8	1.2E-01
2731.4	8	8	3.1E-02
2732.6	8	6	3.7E-02
2735.3	8	10	4.7E-02
2738.6	8	10	1.3E-02
2743.3	8	6	1.1E-01
2745.6	8	6	5.0E-02
2747.8	8	8	5.2E-02
2772.9	8	6	1.0E-02
2878.9	8	10	2.8E-02
2892.5	8	8	1.0E-01
2893.0	8	6	1.0E-01

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
2909.0	8	10	6.9E-02
2958.9	8	6	1.6E-02
3059.0	8	8	3.8E-02
3067.0	8	10	9.1E-03
3106.2	8	10	5.5E-02
3111.4	8	10	3.0E-01
3168.3	8	10	6.9E-02
3185.5	8	10	5.8E-03
3210.6	8	8	1.1E-01
3212.8	8	8	2.9E-01
3213.8	8	6	1.8E-01
3235.1	8	10	1.0E-02
3241.4	8	8	2.3E-02
3246.0	8	6	1.4E-02
3247.6	8	8	2.3E-02
3322.3	8	6	3.5E-02
3334.3	8	6	3.4E-01
3350.4	8	10	1.5E-02
3353.7	8	8	5.8E-03
3457.1	8	8	8.4E-03
3467.9	8	8	1.0E-02
3589.3	8	6	6.9E-03
4594.0	8	10	1.4E+00
4627.2	8	8	1.3E+00
4661.9	8	6	1.3E+00
5645.8	8	6	5.4E-03
5765.2	8	8	1.1E-02
6018.2	8	10	8.5E-03
6291.3	8	6	1.8E-03
6864.5	8	10	5.8E-03
7106.5	8	8	2.6E-03

Fluorine

F I

λ Å	g_i	g_k	A 10^8 s^{-1}
806.96	4	6	3.3E+00
809.60	2	4	2.8E+00
951.87	4	2	2.6E+00
954.83	4	4	5.77E+00
955.55	2	2	5.1E+00
958.52	2	4	1.3E+00
6239.7	6	4	2.5E-01
6348.5	4	4	1.8E-01
6413.7	2	4	1.1E-01
6708.3	6	4	1.4E-02
6774.0	6	6	1.0E-01
6795.5	4	2	5.2E-02
6834.3	4	4	2.1E-01
6856.0	6	8	4.94E-01
6870.2	2	2	3.8E-01
6902.5	4	6	3.2E-01
6909.8	2	4	2.2E-01
6966.4	4	2	1.1E-01
7037.5	4	4	3.0E-01
7127.9	2	2	3.8E-01
7309.0	6	8	4.7E-01
7311.0	4	2	3.9E-01
7314.3	4	6	4.8E-01
7332.0	6	4	3.1E-01
7398.7	6	6	2.85E-01
7425.7	4	2	3.4E-01
7482.7	4	4	5.6E-02
7489.2	2	2	1.1E-01
7514.9	2	2	5.2E-02
7552.2	4	6	7.8E-02
7573.4	2	4	1.0E-01
7607.2	4	4	7.0E-02
7754.7	4	6	3.82E-01
7800.2	2	4	2.1E-01

Gallium

Ga I

λ Å	g_i	g_k	A 10^8 s^{-1}
2195.4	2	2	1.9E-02
2199.7	4	2	3.3E-02
2214.4	4	6	1.2E-02
2235.9	4	2	4.3E-02
2255.0	2	2	3.1E-02
2259.2	4	6	3.1E-02
2294.2	2	4	7.0E-02
2297.9	4	2	5.8E-02
2338.2	4	6	9.8E-02
2371.3	2	2	5.7E-02
2418.7	4	2	1.0E-01
2450.1	2	4	2.8E-01
2500.2	4	6	3.4E-01
2659.9	2	2	1.2E-01
2719.7	4	2	2.3E-01
2874.2	2	4	1.2E+00
2943.6	4	6	1.4E+00
2944.2	4	4	2.7E-01
4033.0	2	2	4.9E-01
4172.0	4	2	9.2E-01

Ga II

λ Å	g_i	g_k	A 10^8 s^{-1}
829.60	1	3	2.2E-01
1414.4	1	3	1.88E+01

Germanium

Ge I

λ Å	g_i	g_k	A 10^8 s^{-1}
1944.7	3	1	7.0E-01
1955.1	3	3	2.8E-01
1988.3	5	3	2.5E-01
1998.9	5	5	5.5E-01
2041.7	1	3	1.1E+00
2065.2	3	3	8.5E-01
2068.7	3	5	1.2E+00
2086.0	3	5	4.0E-01
2094.3	5	7	9.7E-01
2105.8	5	5	1.7E-01
2256.0	5	5	3.2E-02
2417.4	5	5	9.6E-01
2498.0	1	3	1.3E-01
2533.2	3	3	1.0E-01
2589.2	5	3	5.1E-02
2592.5	3	5	7.1E-01
2651.2	5	5	2.0E+00
2651.6	1	3	8.5E-01
2691.3	3	3	6.1E-01
2709.6	3	1	2.8E+00
2754.6	5	3	1.1E+00
3039.1	5	3	2.8E+00
3124.8	5	5	3.1E-02
3269.5	5	3	2.9E-01
4226.6	1	3	2.1E-01
4685.8	1	3	9.5E-02

Ge II

λ Å	g_i	g_k	A 10^8 s^{-1}
999.10	2	4	1.9E+00
1016.6	4	6	2.1E+00
1017.1	4	4	3.5E-01
1055.0	2	2	6.9E-01
1075.1	4	2	1.3E+00
1237.1	2	4	1.9E+01
1261.9	4	6	2.2E+01
1264.7	4	4	3.5E+00
1602.5	2	2	3.4E+00
1649.2	4	2	6.5E+00
4741.8	2	4	4.6E-01
4814.6	4	6	5.1E-01
4824.1	4	4	8.6E-02
5131.8	4	6	1.9E+00
5178.5	6	6	1.3E-01
5178.6	6	8	2.0E+00
5893.4	2	4	9.2E-01
6021.0	2	2	8.4E-01
6336.4	2	2	4.4E-01
6484.2	4	2	8.5E-01

Gold

Au I

λ Å	g_i	g_k	A 10^8 s^{-1}
2427.95	2	4	1.99E+00
2675.95	2	2	1.64E+00
3122.78	6	4	1.90E-01
6278.30	4	2	3.4E-02

Helium

He I

λ Å	g_i	g_k	A 10^8 s^{-1}
510.00	1	3	4.6224E-01
512.10	1	3	7.3174E-01
515.62	1	3	1.2582E+00
522.21	1	3	2.4356E+00
537.03	1	3	5.6634E+00
584.33	1	3	1.7989E+01
*2677.1	3	9	4.4174E-03
*2696.1	3	9	6.0234E-03
*2723.2	3	9	8.4996E-03
*2763.8	3	9	1.2508E-02
*2829.1	3	9	1.9389E-02
*2945.1	3	9	3.2006E-02
*3187.7	3	9	5.6361E-02
3231.3	1	3	5.1015E-03
3258.3	1	3	6.9627E-03
3296.8	1	3	9.8432E-03
3354.6	1	3	1.4537E-02
3447.6	1	3	2.2691E-02
*3554.4	9	15	7.5971E-03
*3563.0	9	3	4.8362E-03
*3587.3	9	15	1.8107E-02

λ (Å)	Weights g_i	Weights g_k	A (10^8 s^{-1})
3613.6	1	3	3.8022E-02
*3634.2	9	15	2.6062E-02
*3652.0	9	3	9.7444E-03
*3705.0	9	15	3.9528E-02
*3819.6	9	15	6.4351E-02
3833.6	3	5	9.6470E-03
*3867.5	9	3	2.4465E-02
3871.8	3	5	1.3386E-02
*3888.7	3	9	9.4746E-02
3926.5	3	5	1.9371E-02
3935.9	3	1	7.4475E-03
3964.7	1	3	6.9507E-02
4009.3	3	5	2.9612E-02
4024.0	3	1	1.1281E-02
*4026.2	9	15	1.1600E-01
*4120.8	9	3	4.4529E-02
4143.8	3	5	4.8812E-02
4169.0	3	1	1.8298E-02
4387.9	3	5	8.9889E-02
4437.6	3	1	3.2689E-02
*4471.5	9	15	2.4578E-01
*4713.2	9	3	9.5209E-02
4921.9	3	5	1.9863E-01
5015.7	1	3	1.3372E-01
5047.7	3	1	6.7712E-02
*5875.7	9	15	7.0703E-01
6678.2	3	5	6.3705E-01
*7065.2	9	3	2.7853E-01
7281.4	3	1	1.8299E-01
*8361.7	3	9	3.8126E-03
*9463.6	3	9	5.6868E-03
9603.4	1	3	5.8286E-03
*9702.6	9	3	8.6511E-03
*10311	9	15	1.9945E-02
*10668	9	3	1.4471E-02
*10830	3	9	1.0216E-01
*10913	15	21	1.9801E-02
10917	5	7	1.6083E-02
*10997	15	9	1.4253E-03
11013	1	3	9.2496E-03
11045	3	5	1.8457E-02
11226	3	1	1.1168E-02
*11969	9	15	3.4781E-02
*12528	3	9	7.0932E-03
12756	5	3	1.2754E-03
*12785	15	21	4.1339E-02
12791	5	7	3.2475E-02
*12846	9	3	2.7317E-02
12968	3	5	3.3615E-02
*12985	15	9	2.7292E-03
Indium			
In I			
2560.2	2	4	4.0E-01
2710.3	4	6	4.0E-01
3039.4	2	4	1.3E+00
3256.1	4	6	1.3E+00
4101.8	2	2	5.6E-01
4511.3	4	2	1.02E+00
In II			
2941.1	3	1	1.4E+00
Iodine			
I I			
1782.8	4	4	2.71E+00
1830.4	4	6	1.6E-01
Iridium			
Ir I			
2475.12	10	10	2.1E-01
2502.98	10	12	3.2E-01
2639.71	10	10	4.7E-01
2661.98	10	10	2.5E-01
2664.79	10	8	4.0E-01
2694.23	10	12	4.8E-01
2849.72	10	10	2.2E-01
2853.31	10	10	2.0E-03
2882.64	10	8	7.2E-02
2924.79	10	12	1.42E-01
2934.64	8	10	2.0E-01
2951.22	10	8	2.8E-02
3003.63	8	10	5.9E-02
3168.88	8	10	5.47E-02
3220.78	10	8	2.4E-01
3558.99	6	8	1.5E-02
3573.72	8	10	5.4E-02
3617.21	6	8	2.0E-02
3628.67	8	8	2.8E-02
3661.71	8	10	4.0E-02
3734.77	8	8	2.7E-02
4033.76	8	10	2.7E-02
4069.92	6	8	3.6E-02
4913.35	12	12	3.3E-02
4939.24	10	12	2.5E-03
Iron			
Fe I			
1934.54	9	7	2.5E-01
1937.27	9	7	2.2E-01
1940.66	7	5	2.6E-01
2084.12	9	7	3.7E-01
2102.35	7	7	8.8E-02
2112.97	1	3	1.9E-01
2132.02	9	9	7.6E-02
2145.19	7	7	5.7E-02
2153.01	5	5	6.9E-02
2161.58	3	5	5.0E-02
2166.77	9	7	2.7E+00
2171.30	5	7	5.1E-02
2173.21	3	5	8.3E-02
2176.84	1	3	1.0E-01
2191.20	1	3	7.3E-02
2191.84	5	5	1.2E+00
2196.04	3	3	1.2E+00
2200.72	3	5	2.8E-01
2259.51	9	11	7.0E-02
2267.08	7	5	7.1E-02
2272.07	7	9	3.8E-02
2276.03	9	7	1.7E-01
2277.11	7	5	3.7E+01
2287.25	5	3	3.4E-01
2292.52	7	9	4.3E-02
2294.41	3	1	6.1E-01
2300.14	5	7	8.0E-02
2301.68	1	3	1.3E-01
2303.42	1	3	9.4E-02
2303.58	3	5	7.6E-02
2309.00	3	5	1.5E-01
2313.10	5	7	1.4E-01
2320.36	7	9	1.2E-01
2371.43	5	5	5.2E-02
2373.62	7	7	6.7E-02
2374.52	1	3	2.9E-01
2381.83	3	5	5.4E-02
2389.97	5	7	5.0E-02
2462.18	7	5	1.5E-01
2462.65	9	9	5.8E-01
2479.78	5	5	1.8E+00
2483.27	9	11	4.9E+00
2488.14	7	9	4.7E+00
2490.64	5	7	3.8E+00
2491.15	3	5	3.0E+00
2501.13	9	7	6.8E-01
2510.83	7	5	1.3E+00
2518.10	5	3	1.9E+00
2522.85	9	9	2.9E+00
2524.29	3	1	3.4E+00
2527.43	7	7	1.9E+00
2529.13	5	5	9.8E-01
2535.61	1	3	9.7E-01
2540.97	3	5	9.2E-01
2545.98	5	7	6.7E-01
2549.61	7	9	3.6E-01
2584.54	11	13	4.6E-01
2606.83	9	11	4.2E-01
2618.02	7	7	4.0E-01
2623.53	7	9	3.3E-01
2656.15	13	15	2.8E-01
2669.49	11	13	1.7E-01
2679.06	11	11	1.9E-01
2719.03	9	7	1.4E+00
2720.90	7	5	1.1E+00
2723.58	5	3	6.4E-01
2733.58	11	9	8.6E-01
2735.48	9	7	6.2E-01
2737.31	3	3	8.5E-01
2742.41	5	5	6.3E-01
2744.07	1	3	3.5E-01
2750.14	7	7	3.9E-01
2756.33	3	5	2.0E-01
2788.10	11	13	6.3E-01
2894.50	5	5	6.2E-01
2899.42	5	3	5.9E-01
2920.69	5	5	5.2E-02
2923.29	11	11	1.6E+00
2925.36	7	9	1.8E-01
2929.01	7	5	7.3E-02

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
2936.90	9	9	1.3E-01
2941.34	5	3	5.6E-02
2947.88	7	7	2.0E-01
2953.94	5	5	1.89E-01
2954.65	5	7	1.0E-01
2957.36	3	3	1.77E-01
2965.25	1	3	1.16E-01
2966.90	9	11	2.72E-01
2969.36	3	1	3.66E-02
2973.13	5	7	1.35E-01
2973.24	7	9	1.83E-01
2980.53	7	7	2.2E-01
2981.45	7	5	6.54E-02
2983.57	9	7	2.80E-01
2987.29	9	7	6.6E-02
2990.39	9	11	3.9E-01
2994.43	7	5	4.4E-01
2996.39	3	5	1.6E-01
2999.51	11	11	2.3E-01
3000.95	5	3	6.42E-01
3008.14	3	1	1.07E+00
3009.09	13	11	6.7E-02
3009.57	9	9	1.7E-01
3011.48	7	9	4.7E-01
3015.92	11	9	5.9E-02
3016.18	5	3	8.5E-02
3017.63	3	3	6.82E-02
3018.98	7	7	1.3E-01
3021.07	7	7	4.56E-01
3024.03	3	5	4.88E-02
3025.84	1	3	3.48E-01
3026.46	5	5	1.1E-01
3031.63	3	3	1.5E-01
3037.39	3	5	3.2E-01
3042.02	3	5	4.9E-02
3042.66	5	7	5.7E-02
3047.60	5	7	2.84E-01
3053.07	3	5	1.5E-01
3057.45	11	9	4.4E-01
3059.09	7	9	1.7E-01
3067.24	9	7	3.4E-01
3068.17	5	3	9.8E-02
3075.72	7	5	2.9E-01
3083.74	5	3	3.0E-01
3091.58	3	1	5.4E-01
3098.19	11	11	1.1E-01
3100.67	7	7	1.4E-01
3119.49	11	9	8.2E-02
3120.43	9	7	8.9E-02
3156.27	7	7	5.4E-01
3160.66	9	9	1.9E-01
3161.95	11	13	1.2E-01
3166.44	9	7	1.14E-01
3168.85	5	7	5.7E-02
3175.45	11	11	1.3E-01
3176.36	5	3	9.2E-02
3196.93	9	11	9.0E-01
3199.53	9	9	2.6E-01
3205.40	3	3	1.2E+00
3215.94	5	5	8.0E-01
3217.38	11	9	2.2E-01
3219.58	7	9	6.2E-01
3222.07	11	11	3.3E-01
3225.79	11	13	8.8E-01
3227.80	9	7	1.4E+00
3228.25	5	3	4.5E-01
3229.99	9	11	4.5E-01
3230.21	5	5	1.9E-01
3230.96	7	5	3.9E-01
3233.05	13	15	5.4E-01
3233.97	9	9	2.0E-01
3246.96	5	3	9.9E-02
3248.20	7	7	2.2E-01
3253.60	7	9	1.8E-01
3254.36	11	13	5.1E-01
3257.59	7	5	1.4E-01
3265.62	7	5	3.8E-01
3268.23	3	3	5.9E-02
3271.00	5	3	6.6E-01
3280.26	9	11	5.4E-01
3282.89	3	5	3.0E-01
3284.59	5	5	5.4E-02
3290.99	3	5	6.0E-02
3292.02	7	9	6.1E-01
3292.59	3	3	2.6E-01
3298.13	3	5	8.1E-02
3305.97	5	7	4.7E-01
3306.36	3	5	6.1E-01
3307.23	13	13	2.0E-01
3314.74	5	7	6.9E-01
3322.47	9	11	6.2E-02
3323.74	5	5	3.0E-01
3328.87	11	11	2.7E-01
3337.66	11	9	5.7E-02
3347.93	5	5	4.0E-02
3354.06	1	3	7.7E-02
3355.23	9	9	3.2E-01
3369.55	9	9	2.4E-01
3370.78	11	11	3.3E-01
3380.11	7	7	2.4E-01
3383.98	7	7	9.3E-02
3392.65	7	7	2.6E-01
3394.58	5	3	9.9E-02
3399.33	5	5	3.8E-01
3402.26	13	13	2.8E-01
3406.44	3	5	3.0E-01
3407.46	7	9	5.8E-01
3410.17	3	5	4.7E-01
3411.35	9	9	5.5E-02
3413.13	5	7	3.6E-01
3417.84	3	3	5.1E-01
3418.51	3	1	1.3E+00
3424.28	7	7	2.0E-01
3425.01	9	7	2.8E-01
3427.12	7	9	5.5E-01
3428.19	5	5	2.1E-01
3428.75	7	5	2.7E-01
3440.99	7	5	8.4E-02
3442.36	5	5	4.55E-02
3443.88	5	3	6.2E-02
3445.15	5	7	2.8E-01
3447.28	5	5	9.1E-02
3450.33	3	3	2.0E-01
3476.70	1	3	5.4E-02
3477.85	3	1	4.2E-02
3485.34	5	3	1.4E-01
3495.29	9	7	9.46E-02
3497.10	7	7	1.4E-01
3505.07	5	3	9.9E-02
3506.50	5	5	7.1E-02
3508.49	9	11	5.7E-02
3510.44	1	3	4.4E-02
3516.56	7	5	3.7E-02
3521.84	3	5	9.6E-02
3523.31	5	3	7.6E-02
3524.08	7	5	7.5E-02
3524.24	5	7	4.2E-02
3527.79	9	9	2.0E-01
3529.82	3	3	7.6E-01
3536.56	5	7	7.8E-01
3537.73	5	3	1.1E-01
3537.90	11	11	8.4E-02
3540.12	7	9	1.2E-01
3541.08	9	11	6.2E-01
3542.08	7	9	7.4E-01
3543.67	3	5	1.8E-01
3548.02	5	3	9.7E-02
3552.11	3	5	4.5E-02
3552.83	5	5	1.5E-01
3553.74	11	9	8.1E-01
3556.88	9	11	4.4E-01
3559.50	3	3	1.9E-01
3560.70	7	9	6.5E-02
3565.38	7	9	3.8E-01
3567.03	5	7	6.5E-02
3568.42	5	3	5.3E-02
3568.82	7	9	5.6E-02
3570.10	9	11	6.77E-01
3572.00	11	11	2.4E-01
3573.39	5	7	7.5E-02
3576.76	11	9	9.6E-02
3578.38	1	3	6.3E-02
3581.19	11	13	1.02E+00
3582.20	13	11	2.5E-01
3583.33	1	3	2.3E-01
3585.32	7	7	1.3E-01
3585.71	9	9	3.75E-02
3586.98	5	5	1.6E-01
3591.48	1	3	6.0E-02
3592.67	7	5	4.0E-02
3594.63	9	9	2.7E-01
3595.30	5	5	5.4E-02
3597.02	5	3	1.7E-01
3599.62	11	9	1.8E-01
3603.20	11	11	2.6E-01
3603.82	3	3	1.7E-01
3605.45	9	9	6.4E-01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
3606.68	11	13	8.2E-01
3608.86	3	5	8.14E-01
3610.16	13	13	4.8E-01
3610.70	5	3	7.1E-02
3612.07	11	13	7.5E-02
3613.45	7	7	6.7E-02
3615.19	3	3	5.8E-02
3617.79	5	7	6.5E-01
3618.77	5	7	7.3E-01
3621.46	9	11	5.1E-01
3622.00	7	7	5.1E-01
3623.19	13	13	7.4E-02
3624.06	5	3	5.4E-02
3630.35	9	7	7.6E-02
3631.46	7	9	5.17E-01
3632.04	3	5	4.8E-01
3632.55	11	9	5.2E-02
3635.19	5	3	1.4E-01
3637.86	9	9	5.5E-02
3638.30	7	9	2.6E-01
3640.39	9	11	3.8E-01
3644.80	7	5	7.8E-02
3645.82	1	3	5.7E-01
3647.84	9	11	2.92E-01
3649.51	11	9	4.2E-01
3650.03	7	7	9.9E-02
3651.47	7	9	6.2E-01
3655.46	5	5	1.0E-01
3659.52	9	9	5.8E-02
3667.25	9	7	1.4E-01
3669.15	9	7	7.4E-02
3669.52	9	7	3.0E-01
3670.09	11	13	7.6E-02
3674.77	5	3	6.7E-02
3676.31	9	11	4.63E-02
3677.31	5	7	3.1E-01
3677.63	7	5	8.0E-01
3678.86	3	5	4.1E-02
3682.24	5	5	1.7E+00
3684.11	9	7	3.4E-01
3686.00	9	11	2.6E-01
3686.26	3	1	1.2E-01
3687.46	11	9	8.01E-02
3688.48	7	9	6.9E-02
3690.73	11	11	2.7E-01
3694.01	5	7	6.8E-01
3697.43	7	7	2.1E-01
3698.60	5	7	3.8E-02
3699.15	5	7	4.5E-02
3701.09	7	9	4.8E-01
3702.03	3	1	3.5E-01
3703.69	9	11	5.3E-02
3703.82	1	3	1.2E-01
3704.46	11	9	1.3E-01
3709.25	9	7	1.56E-01
3711.41	3	5	7.3E-02
3718.41	7	7	5.3E-02
3719.93	9	11	1.62E-01
3722.56	5	5	4.97E-02
3724.38	5	7	1.3E-01
3726.93	5	5	4.6E-01
3727.09	9	7	2.0E-01
3727.62	7	5	2.25E-01
3730.39	9	11	1.3E-01
3730.95	5	7	3.8E-02
3732.40	5	5	2.8E-01
3733.32	3	3	6.2E-02
3734.86	11	11	9.02E-01
3735.32	9	9	2.4E-01
3737.13	7	9	1.42E-01
3738.31	11	13	3.8E-01
3740.24	7	9	1.4E-01
3742.62	9	9	1.0E-01
3743.36	5	3	2.60E-01
3744.10	5	3	3.6E-01
3745.56	5	7	1.15E-01
3745.90	1	3	7.33E-02
3746.93	7	7	2.2E-01
3748.26	3	5	9.15E-02
3749.48	9	9	7.64E-01
3753.61	7	5	9.3E-02
3756.94	11	11	2.4E-01
3757.45	5	3	1.2E-01
3758.23	7	7	6.34E-01
3760.05	13	15	4.47E-02
3760.53	3	5	4.8E-02
3763.79	5	5	5.44E-01
3765.54	13	15	9.8E-01
3766.67	5	3	9.7E-02
3767.19	3	3	6.40E-01
3768.03	3	1	8.4E-02
3774.82	3	3	4.7E-02
3778.51	7	5	1.2E-01
3781.94	5	7	3.7E-02
3785.95	11	13	4.2E-02
3786.19	5	5	1.2E-01
3787.16	5	5	1.0E-01
3787.88	3	5	1.29E-01
3789.82	9	7	3.9E-02
3791.73	5	3	6.3E-02
3793.87	3	3	7.4E-02
3794.34	9	11	3.8E-02
3795.00	5	7	1.15E-01
3799.55	7	9	7.32E-02
3801.68	5	7	6.6E-02
3802.00	11	13	3.5E-02
3802.28	5	5	5.0E-02
3804.01	11	9	4.7E-02
3805.35	9	11	9.8E-01
3806.22	3	3	2.3E-01
3806.70	11	11	5.4E-01
3807.54	3	5	8.0E-02
3808.73	9	9	3.54E-02
3810.76	5	3	2.0E-01
3813.88	13	11	8.7E-02
3815.84	9	7	1.3E+00
3817.64	11	11	8.3E-02
3819.50	7	5	4.6E-02
3820.43	11	9	6.68E-01
3821.18	11	13	7.0E-01
3821.83	5	5	7.8E-02
3825.88	9	7	5.98E-01
3827.82	7	5	1.05E+00
3833.31	9	9	4.69E-02
3834.22	7	5	4.53E-01
3836.33	5	5	3.7E-01
3839.26	9	9	2.8E-01
3839.61	3	5	3.9E-01
3840.44	5	3	4.70E-01
3841.05	5	3	1.3E+00
3843.26	9	7	4.7E-01
3845.17	3	3	6.8E-02
3845.69	5	7	4.9E-02
3846.00	9	7	4.3E-02
3846.41	11	9	1.9E-01
3846.80	7	7	6.6E-01
3849.96	3	1	6.06E-01
3856.37	7	5	4.64E-02
3859.21	13	11	8.5E-02
3859.91	9	9	9.70E-02
3865.52	3	3	1.55E-01
3867.22	5	5	3.4E-01
3871.75	11	11	6.7E-02
3872.50	5	5	1.05E-01
3873.76	11	9	8.0E-02
3878.02	7	7	7.72E-02
3878.57	5	3	6.6E-02
3883.28	7	7	1.6E-01
3884.36	11	9	3.5E-02
3885.51	3	5	5.8E-02
3886.28	7	7	5.30E-02
3887.05	9	9	3.52E-02
3888.51	5	5	2.6E-01
3888.82	5	3	2.7E-01
3891.93	3	3	4.0E-01
3893.39	11	11	1.3E-01
3895.66	3	1	9.40E-02
3900.52	7	7	7.5E-02
3902.95	7	7	2.14E-01
3903.90	9	9	9.6E-02
3906.75	5	7	6.7E-02
3907.93	7	5	6.7E-02
3909.66	3	5	5.3E-02
3909.83	3	3	6.5E-02
3914.27	3	3	5.4E-02
3916.73	13	11	1.2E-01
3919.07	9	9	3.9E-02
3925.20	1	3	5.7E-02
3931.12	5	7	4.5E-02
3941.28	5	5	8.4E-02
3942.44	3	5	9.0E-02
3946.99	9	11	4.4E-02
3948.77	11	9	2.2E-01
3949.14	3	3	3.9E-02
3949.95	7	5	5.9E-02
3951.16	3	5	3.6E-01
3952.60	11	11	4.1E-02

λ Å	Weights g_i	g_k	A 10^8 s^{-1}	λ Å	Weights g_i	g_k	A 10^8 s^{-1}	λ Å	Weights g_i	g_k	A 10^8 s^{-1}
3953.15	7	9	3.7E-02	4109.07	1	3	4.5E-02	4250.79	7	7	1.0E-01
3955.34	3	3	1.4E-01	4109.80	3	3	1.6E-01	4260.47	11	11	3.2E-01
3955.96	3	3	5.7E-02	4112.96	11	13	1.4E-01	4267.83	1	3	9.4E-02
3956.45	13	11	2.1E-01	4114.45	5	5	4.7E-02	4268.75	5	3	4.2E-02
3957.02	5	7	1.6E-01	4118.54	11	13	5.8E-01	4271.15	7	9	1.82E-01
3960.28	5	7	4.2E-02	4126.18	11	11	3.9E-02	4271.76	9	11	2.28E-01
3963.10	3	5	1.7E-01	4127.61	1	3	1.3E-01	4282.40	7	5	1.1E-01
3967.42	9	7	2.3E-01	4132.06	5	7	1.2E-01	4300.83	5	5	4.7E-02
3967.96	7	9	6.3E-02	4132.90	3	5	9.4E-02	4305.45	5	3	6.0E-02
3969.26	9	7	2.3E-01	4134.68	5	7	1.8E-01	4307.90	7	9	3.4E-01
3970.39	3	1	3.5E-01	4137.00	3	5	2.2E-01	4315.08	5	5	7.7E-02
3971.32	11	9	5.7E-02	4137.42	5	7	6.1E-02	4325.76	5	7	5.0E-01
3973.65	5	7	6.6E-02	4142.63	3	5	7.4E-02	4327.09	5	5	7.8E-02
3976.61	3	5	1.8E-01	4143.87	7	9	1.5E-01	4352.73	3	5	3.9E-02
3977.74	5	5	7.0E-02	4149.37	11	13	3.6E-02	4369.77	9	9	7.2E-02
3981.77	9	9	3.9E-02	4150.25	3	3	7.1E-02	4383.54	9	11	5.00E-01
3983.96	9	7	7.6E-02	4153.90	7	9	2.3E-01	4387.89	3	3	3.9E-02
3985.39	5	5	6.7E-02	4154.80	9	11	1.5E-01	4388.41	7	7	1.3E-01
3989.86	5	7	5.0E-02	4156.80	5	5	1.9E-01	4401.29	7	7	5.9E-02
3996.97	9	9	6.7E-02	4158.79	3	5	1.6E-01	4404.75	7	9	2.75E-01
3997.39	9	11	1.5E-01	4170.90	5	5	6.1E-02	4415.12	5	7	1.19E-01
3998.05	11	9	6.6E-02	4172.12	7	5	9.7E-02	4422.57	3	3	8.8E-02
4003.76	3	3	7.1E-02	4175.64	3	5	1.6E-01	4430.61	3	1	7.45E-02
4005.24	7	5	2.04E-01	4181.75	5	7	3.6E-01	4433.22	5	3	2.3E-01
4006.31	11	9	4.7E-02	4182.38	5	5	4.9E-02	4438.34	3	1	7.9E-02
4007.27	7	5	4.2E-02	4184.89	5	5	1.1E-01	4442.34	5	5	3.76E-02
4009.71	3	5	5.2E-02	4187.04	7	5	2.15E-01	4443.19	1	3	1.1E-01
4014.53	11	11	2.4E-01	4187.79	9	7	1.52E-01	4446.83	3	3	5.3E-02
4017.15	9	11	4.5E-02	4191.68	1	3	4.8E-02	4447.72	3	3	5.11E-02
4021.87	7	9	1.0E-01	4196.21	7	7	9.8E-02	4454.38	5	5	3.8E-02
4024.72	7	9	8.9E-02	4198.30	11	9	8.03E-02	4455.03	9	7	3.9E-02
4031.96	3	5	7.1E-02	4198.64	5	5	1.3E-01	4466.55	5	7	1.2E-01
4040.64	5	7	4.4E-02	4199.09	9	11	6.1E-01	4469.37	5	7	2.6E-01
4044.61	5	3	1.1E-01	4200.09	7	7	4.0E-02	4481.61	3	3	4.2E-02
4045.81	9	9	8.63E-01	4200.92	7	9	4.2E-02	4484.22	7	9	7.0E-02
4054.87	5	3	1.6E-01	4202.03	9	9	8.22E-02	4485.67	3	3	1.1E-01
4058.22	9	7	4.9E-02	4203.67	7	9	8.6E-02	4528.61	7	9	5.44E-02
4059.73	5	3	8.1E-02	4203.94	13	13	1.3E-01	4533.13	3	1	3.7E-02
4062.44	3	3	2.2E-01	4205.54	5	5	3.6E-02	4547.85	5	7	7.6E-02
4063.59	7	7	6.8E-01	4207.13	5	3	4.3E-02	4619.29	7	5	4.7E-02
4065.40	3	1	1.9E-01	4210.34	3	3	1.7E-01	4669.17	5	3	4.0E-02
4067.98	9	9	1.7E-01	4213.65	3	1	1.9E-01	4673.16	5	7	4.6E-02
4070.77	7	5	1.3E-01	4217.55	3	5	2.3E-01	4678.85	7	9	7.4E-02
4071.74	5	5	7.65E-01	4219.36	11	13	3.8E-01	4704.95	3	1	8.1E-02
4073.76	5	3	1.6E-01	4220.34	3	1	1.9E-01	4736.77	9	11	4.9E-02
4074.79	9	9	4.8E-02	4222.21	7	7	5.77E-02	4789.65	5	5	7.2E-02
4076.63	9	9	1.9E-01	4224.17	9	11	1.3E-01	4859.74	5	3	1.3E-01
4078.35	5	3	4.2E-02	4224.51	3	5	7.1E-02	4871.32	7	5	2.2E-01
4079.18	5	5	5.1E-02	4225.45	5	7	1.7E-01	4872.14	3	3	2.4E-01
4079.84	1	3	6.3E-02	4226.42	3	3	3.7E-02	4878.21	1	3	9.1E-02
4080.21	3	1	2.4E-01	4233.60	3	5	1.85E-01	4890.75	5	5	2.1E-01
4082.44	3	3	3.8E-02	4235.94	9	9	1.88E-01	4891.49	9	7	2.9E-01
4084.49	11	9	1.1E-01	4238.81	7	9	2.2E-01	4892.87	3	3	4.8E-02
4085.00	3	5	4.2E-02	4240.37	5	3	5.7E-02	4903.31	3	5	4.7E-02
4085.30	7	7	1.1E-01	4245.26	1	3	8.3E-02	4917.23	5	3	6.1E-02
4085.98	7	5	5.0E-02	4246.08	7	5	5.7E-02	4918.01	1	3	4.0E-02
4088.57	5	3	3.9E-02	4247.43	9	11	2.0E-01	4918.99	7	7	1.7E-01
4098.18	7	7	6.8E-02	4248.22	3	5	3.5E-02	4920.50	11	9	3.5E-01
4107.49	5	3	2.5E-01	4250.12	5	7	2.08E-01	4930.31	3	3	4.1E-02

λ Å	Weights g_i	Weights g_k	*A* 10^8 s^{-1}
4969.92	3	3	1.8E-01
4973.10	3	3	1.0E-01
4978.60	5	3	1.1E-01
4988.95	7	7	4.9E-02
4991.27	5	7	8.2E-02
5001.86	9	7	3.9E-01
5004.04	5	3	3.5E-02
5014.94	7	5	3.0E-01
5022.24	5	3	2.6E-01
5074.75	9	11	1.5E-01
5090.78	7	5	2.0E-01
5109.65	3	5	5.4E-02
5121.64	5	5	7.9E-02
5125.11	9	7	2.6E-01
5133.69	11	13	2.7E-01
5137.38	11	9	1.1E-01
5159.06	5	3	1.3E-01
5162.27	11	11	2.4E-01
5184.26	5	7	3.5E-02
5208.59	7	5	5.2E-02
5232.94	9	11	1.4E-01
5263.30	5	5	5.2E-02
5266.55	7	9	8.6E-02
5283.62	7	7	8.0E-02
5302.30	3	5	6.3E-02
5324.18	9	9	1.5E-01
5339.93	5	7	7.0E-02
5353.39	9	7	4.8E-02
5364.87	5	7	5.5E-01
5367.47	7	9	5.8E-01
5369.96	9	11	4.7E-01
5373.71	7	9	3.5E-02
5383.37	11	13	5.6E-01
5389.48	7	7	1.3E-01
5398.29	5	5	9.8E-02
5400.50	9	9	1.8E-01
5410.91	7	9	4.8E-01
5415.20	11	13	5.6E-01
5424.07	13	15	5.0E-01
5432.95	5	5	4.1E-02
5445.04	11	11	2.0E-01
5463.27	9	9	3.2E-01
5466.39	9	7	7.5E-02
5473.90	7	7	5.5E-02
5480.87	3	1	1.2E-01
5487.74	7	5	8.6E-02
5554.89	9	9	8.7E-02
5569.62	5	3	2.1E-01
5572.84	7	5	2.1E-01
5576.09	3	1	2.1E-01
5586.76	9	7	1.9E-01
5598.30	5	5	1.8E-01
5615.64	11	9	1.7E-01
5624.54	5	5	5.3E-02
5633.97	11	13	8.7E-02
5638.27	9	7	4.0E-02
5650.01	3	5	5.0E-02
5655.18	7	9	5.3E-02
5658.82	7	7	3.6E-02
5679.02	5	7	3.6E-02
5686.53	9	11	4.4E-02
5691.51	3	1	6.2E-02
5705.99	7	9	6.7E-02
5717.85	1	3	5.0E-02
5753.12	3	5	7.0E-02
5762.99	5	7	1.0E-01
5816.36	9	11	3.7E-02
5905.67	5	3	1.2E-01
5927.80	5	3	5.1E-02
5930.17	5	7	1.6E-01
6020.17	7	9	1.1E-01
6024.07	9	11	1.3E-01
6055.99	7	9	7.0E-02
6170.49	5	5	1.3E-01
6336.84	3	3	4.9E-02
6338.90	5	3	4.8E-02
6400.00	7	9	5.5E-02
6411.65	5	7	3.5E-02
6419.98	7	7	1.3E-01
6469.21	3	3	9.0E-02
6495.78	3	3	6.0E-02
6496.46	5	5	8.5E-02
6569.23	7	9	6.5E-02
6633.76	7	7	3.6E-02
6733.16	3	1	3.9E-02
6841.35	5	7	3.6E-02
7130.94	3	5	4.3E-02
Fe II			
1144.94	10	12	4.8E+00
1635.40	8	6	2.4E+00
1641.76	6	4	1.8E+00
1647.16	6	6	5.2E-01
2208.41	10	10	1.8E+00
2213.66	14	14	4.4E-01
2218.27	8	10	1.9E+00
2327.40	6	4	5.9E-01
2331.31	10	8	2.9E-01
2332.80	8	6	1.5E+00
2338.01	4	4	1.1E+00
2343.49	10	8	1.7E+00
2343.96	8	6	2.9E-01
2344.28	2	4	8.2E-01
2348.11	10	8	5.1E-01
2348.30	6	6	1.2E+00
2351.67	6	6	1.7E+00
2352.31	2	4	4.2E+00
2353.68	8	8	1.3E+00
2354.89	6	4	2.4E-01
2360.00	10	10	2.4E-01
2360.29	8	6	5.9E-01
2362.02	8	8	1.3E-01
2363.86	8	10	5.1E+00
2364.83	8	8	6.1E-01
2365.77	6	6	2.1E+00
2366.59	6	6	9.9E-02
2368.60	6	4	5.9E-01
2369.95	10	12	5.7E+00
2370.50	4	4	1.4E-01
2373.74	10	10	3.3E-01
2375.19	4	2	9.8E-01
2379.27	8	8	1.5E-01
2380.76	6	8	3.1E-01
2382.04	10	12	3.8E+00
2382.90	12	14	2.2E-01
2383.25	6	6	3.4E-01
2384.39	4	4	2.3E-01
2388.37	10	12	2.2E-01
2388.63	8	8	1.0E+00
2390.10	14	16	5.5E+00
2390.77	6	6	9.3E-01
2395.42	6	4	3.3E-01
2395.62	8	10	2.5E+00
2399.24	6	6	1.4E+00
2400.06	12	14	5.2E+00
2401.29	6	8	2.5E+00
2404.43	4	2	7.1E-01
2404.89	6	8	1.7E+00
2406.66	4	4	1.6E+00
2410.52	4	6	1.5E+00
2411.07	2	2	2.4E+00
2413.31	2	4	1.1E+00
2416.45	8	10	1.6E+00
2418.44	6	8	1.6E+00
2423.21	4	6	1.4E+00
2428.36	8	10	2.7E+00
2432.87	14	14	3.2E+00
2434.06	8	6	7.0E-01
2434.24	8	10	2.0E+00
2434.73	12	12	3.2E+00
2439.30	12	14	2.8E+00
2445.11	12	12	1.9E+00
2445.80	4	6	1.5E+00
2446.47	12	14	2.9E-01
2447.20	6	6	1.2E+00
2453.98	8	10	7.3E-01
2455.71	8	8	1.0E+00
2458.78	10	12	2.7E+00
2458.97	6	4	2.0E+00
2460.44	10	12	5.3E+00
2461.28	6	8	2.6E+00
2461.86	8	10	2.6E+00
2466.52	2	4	2.1E+00
2469.51	8	6	2.8E+00
2472.61	8	10	3.7E+00
2475.12	4	6	3.9E+00
2475.54	6	8	3.5E+00
2481.05	12	12	1.9E-01
2484.44	8	8	2.3E+00
2492.34	10	12	1.6E-01
2493.26	14	16	3.4E+00
2501.31	2	2	1.4E+00
2503.87	10	10	2.4E+00
2508.34	8	10	2.7E+00
2533.63	12	12	1.3E+00
2534.42	8	8	1.2E+00
2535.36	6	4	3.3E+00

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
2535.49	10	8	5.4E-01
2536.67	12	12	4.0E-01
2537.14	10	10	1.4E+00
2538.20	14	12	1.2E+00
2538.50	8	6	3.3E-01
2538.80	12	10	8.2E-01
2538.91	10	8	7.8E-01
2538.99	14	12	1.2E+00
2540.52	2	2	1.5E+00
2541.10	8	6	7.3E-01
2541.84	8	6	7.7E-01
2542.73	2	2	1.9E+00
2543.38	10	12	4.4E-01
2543.43	6	4	7.1E-01
2544.97	4	6	4.0E-01
2545.22	8	10	3.3E-01
2545.44	8	10	1.4E-01
2546.67	8	8	6.2E-01
2547.34	8	8	2.0E-01
2548.33	4	6	2.0E-01
2548.59	10	10	1.9E-01
2548.74	4	2	1.7E+00
2548.92	12	10	4.8E-01
2549.08	10	8	1.5E+00
2549.40	4	4	1.3E+00
2549.46	6	6	8.0E-01
2549.77	8	6	2.5E-01
2550.03	10	10	1.2E+00
2550.15	8	10	4.0E-01
2550.68	12	12	8.9E-01
2551.21	10	8	3.2E-01
2555.07	6	8	1.8E-01
2555.45	4	6	2.5E-01
2557.51	10	8	1.3E-01
2559.77	6	8	2.4E-01
2559.92	6	8	2.4E-01
2560.28	4	4	1.5E+00
2562.09	4	2	1.5E+00
2562.54	8	6	1.5E+00
2563.48	6	4	1.3E+00
2566.22	8	10	2.5E+00
2566.40	8	6	2.1E+00
2566.91	4	2	1.1E+00
2568.41	2	4	4.4E-01
2569.78	2	4	1.2E+00
2570.53	6	8	1.2E+00
2570.85	8	6	1.7E+00
2573.21	8	10	1.4E-01
2574.36	6	4	1.6E+00
2576.86	10	12	1.1E+00
2577.92	2	2	1.3E+00
2582.41	6	8	2.4E-01
2582.58	4	4	7.7E-01
2585.63	10	10	3.6E-01
2585.88	10	8	8.1E-01
2587.95	8	10	1.4E+00
2588.18	2	2	1.6E-01
2590.55	4	6	9.1E-02
2591.54	6	6	5.1E-01
2592.78	14	16	2.1E+00
2593.72	2	4	1.3E-01
2594.96	8	8	1.0E-01
2598.37	8	6	1.3E+00
2599.40	10	10	2.2E+00
2604.05	8	8	1.1E-01
2605.04	6	8	2.1E+00
2605.34	4	4	1.6E+00
2605.42	6	6	2.6E-01
2605.90	4	2	1.2E+00
2606.51	6	6	1.8E+00
2607.09	6	4	1.7E+00
2609.13	8	10	3.0E-01
2609.87	8	8	1.8E-01
2611.87	8	8	1.1E+00
2613.82	4	2	2.0E+00
2617.62	6	6	4.4E-01
2619.07	10	10	2.7E-01
2620.17	6	6	1.3E-01
2620.70	8	8	3.3E-01
2621.67	2	2	4.9E-01
2623.11	14	14	1.1E-01
2623.73	6	6	2.2E-01
2625.49	12	14	2.2E+00
2625.67	8	10	3.4E-01
2626.50	4	6	3.4E-01
2628.29	2	4	8.6E-01
2629.59	6	8	6.2E-01
2630.07	4	6	5.7E-01
2631.05	4	6	7.7E-01
2631.32	6	8	6.0E-01
2631.61	10	12	5.3E-01
2633.20	6	4	1.7E+00
2636.69	4	4	1.2E-01
2637.50	6	6	5.2E-01
2637.64	2	4	8.3E-01
2639.56	2	2	1.1E+00
2642.01	6	6	3.6E-01
2649.47	6	8	1.8E+00
2650.48	6	8	1.6E+00
2654.63	4	4	7.7E-01
2658.25	8	8	3.2E-01
2662.56	2	2	9.6E-01
2664.66	8	10	1.5E+00
2666.64	6	8	1.7E+00
2667.22	4	6	9.2E-01
2669.93	2	4	4.7E-01
2671.40	2	4	5.6E-01
2682.51	8	10	7.0E-01
2683.00	4	6	6.4E-01
2684.75	8	10	1.4E+00
2692.60	10	12	1.2E+00
2697.33	4	4	2.7E-01
2697.46	4	2	1.8E+00
2699.20	4	4	6.6E-01
2703.99	8	8	1.2E+00
2707.13	4	6	8.5E-01
2709.05	4	6	3.7E-01
2711.84	12	14	3.8E-01
2712.39	10	12	1.3E-01
2714.41	8	6	5.5E-01
2716.22	6	6	1.1E+00
2716.56	14	12	1.6E+00
2717.87	16	14	1.4E+00
2718.64	10	8	1.3E+00
2719.30	6	8	3.7E-01
2722.06	8	8	1.1E-01
2722.74	6	8	7.8E-01
2724.88	6	6	9.7E-01
2727.38	12	10	3.2E-01
2727.54	6	4	8.5E-01
2728.91	8	10	8.8E-02
2730.73	4	4	2.5E-01
2732.94	8	6	7.8E-01
2739.55	8	8	1.9E+00
2741.40	6	6	1.7E-01
2743.20	2	4	1.8E+00
2746.48	4	6	1.9E+00
2746.98	6	6	1.6E+00
2749.18	4	4	1.1E+00
2749.32	6	8	2.1E+00
2749.49	2	2	1.1E+00
2753.29	10	12	1.2E+00
2754.91	8	6	8.4E-01
2755.73	8	10	2.1E+00
2761.81	2	4	1.1E-01
2762.34	6	6	3.7E-01
2763.66	14	12	1.3E+00
2765.13	10	8	1.2E+00
2767.50	12	14	1.9E+00
2769.36	12	14	1.6E-01
2774.69	2	4	2.4E-01
2776.91	8	8	3.0E-01
2779.30	10	8	7.6E-01
2779.91	2	4	2.3E-01
2780.04	2	2	2.9E-01
2783.69	12	10	7.0E-01
2785.19	12	10	1.0E+00
2787.24	8	6	1.3E-01
2793.89	10	12	9.6E-02
2796.63	10	10	1.0E-01
2799.29	10	8	1.1E-01
2809.78	8	8	1.6E-01
2817.09	6	4	2.1E-01
2831.56	4	6	5.8E-01
2833.09	6	6	2.7E-01
2835.71	4	6	3.1E-01
2838.22	4	2	4.2E-01
2839.51	10	8	9.9E-01
2839.80	8	10	4.1E-01
2840.65	2	4	5.3E-01
2840.76	10	12	1.1E-01
2844.96	2	2	4.5E-01
2847.77	4	4	3.3E-01
2848.11	6	6	7.0E-01
2848.32	6	4	1.1E+00
2855.69	8	10	1.0E-01
2856.38	6	8	2.7E-01

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
2856.91	8	8	8.7E-01
2857.17	6	8	9.5E-02
2872.39	10	8	1.5E-01
2873.40	8	10	3.4E-01
2875.35	8	10	9.5E-02
2883.71	12	14	1.0E-01
2884.77	6	8	1.4E-01
2895.22	8	10	8.0E-02
2897.27	6	4	1.4E-01
2944.40	4	2	4.6E-01
2947.66	6	4	2.0E-01
2949.18	10	8	2.0E-01
2959.84	8	6	1.6E-01
2964.63	2	2	9.3E-02
2969.93	8	6	1.8E-01
2982.06	4	6	2.1E-01
2984.82	6	6	3.6E-01
2985.55	2	4	1.8E-01
2997.30	6	8	8.3E-02
3002.65	4	6	1.4E-01
3036.96	6	6	1.6E-01
3048.99	4	4	2.8E-01
3062.23	12	10	1.2E-01
3071.12	2	4	1.9E-01
3076.44	4	6	2.8E-01
3077.17	14	12	1.1E-01
3078.68	6	8	4.2E-01
3135.36	6	6	8.4E-02
3154.20	10	10	1.5E-01
3167.86	8	8	1.3E-01
3177.54	8	8	8.1E-02
3179.50	6	8	9.9E-02
5247.95	4	6	1.7E+00
5506.20	12	14	1.4E+00
5961.71	10	12	7.7E-01
Fe III			
1843.4	9	7	4.8E+00
1844.3	7	5	4.9E+00
1846.9	5	3	5.5E+00
1854.38	3	1	5.7E+00
1865.20	7	7	6.1E+00
1893.98	11	9	5.5E+00
1896.80	13	11	5.0E+00
1904.3	5	5	5.7E+00
1907.58	15	13	5.3E+00
1915.08	13	15	6.0E+00
1922.79	11	13	5.5E+00
1930.39	9	11	5.1E+00
1931.51	9	11	5.3E+00
1937.35	7	9	5.1E+00
1943.48	5	7	5.0E+00
1950.33	13	15	5.5E+00
1951.01	11	11	5.3E+00
1952.65	9	9	4.9E+00
1953.32	7	7	5.1E+00
1987.50	13	13	4.9E+00

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
Fe VII			
150.807	5	7	1.3E+03
150.852	7	9	1.3E+03
151.023	9	11	1.6E+03
151.046	7	7	2.2E+02
151.145	9	9	2.1E+02
151.432	5	7	2.2E+02
151.512	5	5	5.3E+02
151.675	7	7	3.9E+02
151.782	9	9	2.4E+02
154.307	3	1	8.9E+02
154.335	5	7	1.2E+03
154.363	3	3	4.2E+02
154.565	5	3	3.5E+02
154.650	5	5	8.8E+02
154.848	1	3	7.7E+02
154.921	3	5	9.7E+02
154.941	3	3	2.4E+02
154.949	5	7	1.0E+03
155.994	9	11	1.8E+03
158.481	9	9	2.3E+02
165.087	1	3	6.9E+02
165.919	7	5	2.8E+03
166.365	9	7	2.9E+03
173.441	9	9	3.6E+03
176.744	9	9	2.7E+03
176.928	7	7	2.4E+03
177.172	5	5	1.5E+03
235.221	5	3	1.7E+02
240.053	3	1	1.3E+02
243.379	9	7	2.1E+02
Fe VIII			
112.472	4	4	3.6E+02
112.486	6	6	4.3E+02
116.196	4	6	4.5E+02
117.197	6	8	3.8E+02
167.486	4	4	3.0E+03
168.172	6	6	3.1E+03
168.545	6	4	2.0E+03
168.929	4	2	2.1E+03
185.213	6	8	1.0E+03
186.601	4	6	9.4E+02
Fe X			
76.822	2	2	1.8E+03
77.865	4	6	1.6E+03
100.026	8	10	2.6E+03
101.733	6	8	1.8E+03
101.846	4	6	1.7E+03
102.095	10	12	2.9E+03
102.192	10	12	2.9E+03
102.829	4	6	2.1E+03
103.319	6	8	2.6E+03
103.724	6	8	1.7E+03
104.638	8	10	2.1E+03
174.534	4	6	1.8E+03

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
175.266	2	4	1.72E+03
Fe XI			
72.166	5	7	2.9E+03
72.310	5	5	1.5E+03
72.635	5	7	1.6E+03
91.394	5	7	2.6E+03
91.472	7	9	2.5E+03
91.63	3	5	2.3E+03
91.63	7	9	3.4E+03
91.63	5	7	2.8E+03
91.733	9	11	4.1E+03
92.81	9	11	3.7E+03
92.87	11	13	3.9E+03
93.433	9	11	3.2E+03
179.762	5	7	1.67E+03
Fe XII			
65.905	4	4	2.0E+03
66.526	6	8	1.7E+03
66.960	4	6	1.6E+03
67.164	4	2	1.1E+03
67.821	4	6	1.4E+03
68.382	2	4	1.7E+03
80.541	6	6	8.7E+02
81.943	6	4	1.4E+03
82.226	4	2	1.9E+03
84.48	4	6	4.5E+03
84.48	8	10	4.9E+03
84.52	10	12	5.2E+03
84.52	6	8	4.0E+03
84.85	6	8	2.3E+03
85.14	8	10	3.4E+03
85.477	10	12	4.6E+03
186.880	6	8	1.0E+03
192.394	4	2	9.0E+02
193.509	4	4	9.1E+02
195.119	4	6	8.6E+02
Fe XIII			
62.353	1	3	2.0E+03
62.46	5	7	1.2E+03
62.699	3	5	2.3E+03
63.188	5	7	3.9E+03
64.139	1	3	2.1E+03
74.845	5	5	1.0E+03
75.892	5	3	7.7E+02
76.117	5	3	2.1E+03
78.452	9	11	6.3E+03
84.270	7	9	5.5E+03
107.384	7	5	1.8E+03
Fe XIV			
58.963	2	4	2.7E+03
59.579	4	6	3.1E+03
69.176	4	6	5.6E+02
69.386	2	4	7.6E+02

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
69.66	2	2	8.9E+02
69.66	6	6	1.3E+03
70.251	6	4	8.1E+02
70.613	4	2	1.7E+03
72.80	10	12	7.9E+03
76.022	4	6	6.6E+03
76.152	6	8	7.0E+03
91.009	6	4	5.1E+02
91.273	4	2	5.6E+02
188	4	6	2.7E+02
190	6	8	2.8E+02
207	2	2	2.1E+02
211.316	2	4	3.6E+02
213	4	2	2.8E+02
214	2	2	4.0E+02
216	6	8	1.7E+02
217	6	8	4.0E+02
217	6	6	2.6E+02
219	2	4	4.8E+02
219	4	6	2.4E+02
219.123	4	6	3.9E+02
220	4	4	3.2E+02
221	4	6	5.9E+02
226	2	4	3.9E+02
234	2	2	2.8E+02
264.787	4	4	3.38E+02
265	4	4	1.5E+02
266	6	4	1.7E+02
268	6	6	2.1E+02
268	4	2	3.3E+02
270.524	4	2	2.1E+02
274.203	2	2	1.8E+02
280	4	6	2.8E+02
283	6	8	2.7E+02
288.45	6	4	1.6E+02
Fe XV			
38.95	1	3	1.69E+03
52.911	1	3	2.94E+03
59.404	3	5	3.4E+03
63.959	5	7	1.6E+03
65.370	1	3	3.2E+02
65.612	3	3	9.8E+02
66.238	5	3	1.6E+03
68.860	9	11	9.2E+03
69.7	3	1	1.9E+03
69.942	3	5	7.4E+03
69.989	5	7	7.9E+03
70.052	7	9	8.8E+03
70.224	1	3	4.13E+03
70.53	7	5	2.6E+02
70.59	7	7	1.7E+03
73.199	7	9	8.8E+03
73.473	5	7	6.2E+03
233.857	5	7	2.2E+02
235	1	3	2.5E+02
243	1	3	2.4E+02
243	5	7	2.3E+02
243.790	3	5	4.2E+02

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
248	3	1	5.4E+02
284.160	1	3	2.28E+02
Fe XVI			
31.041	2	4	5.2E+02
31.242	4	6	6.1E+02
32.166	2	4	6.8E+02
32.192	2	2	6.7E+02
32.433	2	4	7.7E+02
32.652	4	6	9.1E+02
34.857	2	4	1.23E+03
35.106	4	6	1.44E+03
35.333	4	6	6.4E+02
35.368	6	8	6.8E+02
36.01	4	2	5.0E+02
36.749	2	4	1.1E+03
36.803	2	2	1.2E+03
37.096	4	6	1.0E+03
37.138	6	8	1.07E+03
39.827	2	4	2.1E+03
40.153	4	6	2.5E+03
40.161	4	4	4.1E+02
40.199	4	6	1.7E+03
40.245	6	8	1.8E+03
41.91	2	2	4.72E+02
42.30	4	2	9.2E+02
46.661	4	6	3.46E+03
46.718	6	8	3.7E+03
50.350	2	4	1.86E+03
50.555	2	2	1.98E+03
54.142	2	4	3.41E+03
54.728	4	6	4.16E+03
54.769	4	4	6.97E+02
62.879	2	2	1.05E+03
63.719	4	2	2.18E+03
66.263	4	6	9.39E+03
66.368	6	8	1.00E+04
66.392	6	6	6.69E+02
76.502	6	4	6.7E+02
76.796	4	2	7.72E+02
80.192	4	6	5.2E+02
80.270	6	8	5.4E+02
85.587	2	4	4.0E+02
86.133	4	6	4.8E+02
96.256	4	6	8.7E+02
96.348	6	8	9.3E+02
117.2	2	4	3.93E+02
117.7	2	2	3.9E+02
123.4	2	4	5.9E+02
124.5	4	6	7.0E+02
144.06	4	6	1.6E+03
144.25	6	8	1.6E+03
148	4	2	6.5E+02
266.7	4	6	3.9E+02
267.0	6	8	4.3E+02
Fe XVII			
11.023	1	3	2.1E+04
12.123	1	3	8.0E+04

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
12.264	1	3	5.9E+04
12.526	1	3	3.0E+03
12.681	1	3	3.5E+03
13.823	1	3	3.3E+04
13.891	1	3	3.4E+03
15.015	1	3	2.28E+05
15.262	1	3	6.0E+04
16.777	1	3	8.29E+03
17.054	1	3	9.33E+03
41.37	9	11	4.8E+03
49.427	3	3	4.0E+03
50.26	7	9	6.0E+03
58.76	9	11	1.2E+04
Fe XIX			
13.413	5	3	1.3E+04
13.426	5	7	4.8E+04
13.47	3	1	1.5E+05
13.520	5	7	2.0E+05
13.56	3	5	1.0E+04
13.68	3	1	8.0E+04
13.69	5	7	2.3E+04
13.700	1	3	2.7E+05
13.71	5	5	2.2E+04
13.738	5	7	1.0E+04
13.796	5	7	7.0E+04
13.83	5	5	1.4E+04
13.934	1	3	4.51E+04
13.961	3	3	2.0E+04
14.668	5	7	1.1E+04
14.671	5	3	1.1E+04
14.929	3	3	1.2E+04
14.966	5	3	2.5E+04
14.995	5	5	2.2E+04
15.015	1	3	1.4E+04
16.668	3	1	1.1E+04
Fe XX			
12.67	6	6	1.0E+04
12.69	4	6	1.2E+04
12.73	4	2	4.0E+04
12.77	4	4	2.1E+05
12.78	4	2	6.9E+04
12.78	2	4	1.4E+05
12.79	6	4	1.7E+04
12.82	4	4	1.1E+05
12.88	6	4	2.7E+04
12.89	4	4	4.4E+04
12.90	4	2	6.2E+03
12.90	4	6	1.4E+05
12.92	2	4	1.7E+04
12.93	4	6	1.6E+05
12.93	2	2	1.2E+04
12.98	2	2	6.7E+04
12.99	6	6	5.1E+04
13.00	6	4	1.1E+04
13.01	2	4	3.0E+04
13.03	4	2	8.6E+04
13.07	6	4	8.2E+03

λ (Å)	Weights g_i	g_k	A (10^8 s^{-1})
13.13	2	4	8.9E+04
13.24	4	4	1.2E+04
13.28	4	4	6.1E+03
13.70	4	6	1.1E+04
13.71	2	2	9.9E+03
13.78	4	4	1.0E+04
13.79	6	6	1.2E+04
13.83	4	2	9.8E+03
13.90	4	2	1.2E+04
13.98	6	4	1.6E+04
13.99	4	2	2.2E+04
14.05	4	4	1.7E+04
14.23	2	2	6.3E+03

Fe XXI

λ (Å)	Weights g_i	g_k	A (10^8 s^{-1})
8.53	3	1	1.8E+04
8.53	3	5	6.1E+03
8.53	3	3	1.5E+04
8.56	5	7	2.0E+04
8.56	1	3	2.1E+04
8.56	5	3	6.5E+03
8.64	5	7	1.5E+04
8.65	5	7	3.9E+04
8.66	5	5	4.4E+03
8.74	1	3	2.5E+04
9.42	3	1	4.3E+04
9.42	3	3	3.3E+04
9.44	3	5	1.7E+04
9.45	1	3	5.2E+04
9.46	5	3	1.5E+04
9.47	5	7	4.9E+04
9.47	5	5	6.1E+03
9.52	3	3	8.1E+03
9.58	5	5	5.2E+03
9.59	5	5	1.0E+04
9.67	1	3	5.7E+04
9.68	5	7	4.0E+03
9.74	5	3	5.3E+03
12.02	1	3	1.3E+04
12.13	3	3	1.8E+04
12.18	5	7	2.2E+04
12.19	5	3	6.4E+03
12.21	3	1	1.5E+05
12.21	3	3	1.2E+05
12.25	1	3	2.1E+05
12.28	5	3	5.2E+04
12.30	5	7	2.1E+05
12.36	3	3	3.6E+04
12.37	5	7	3.1E+05
12.38	5	3	6.9E+03
12.47	5	7	5.8E+04
12.47	5	3	1.3E+04
12.49	5	7	1.3E+04
12.53	5	5	1.5E+04
12.57	1	3	7.2E+04
12.73	5	5	8.2E+03
12.95	3	5	6.2E+03
13.00	1	3	7.2E+03
13.03	5	5	1.3E+04
13.14	3	1	2.0E+04
13.41	1	3	7.3E+03

Fe XXII

λ (Å)	Weights g_i	g_k	A (10^8 s^{-1})
9.002	4	6	5.5E+04
9.006	6	8	5.7E+04
9.006	6	6	5.3E+04
9.163	4	6	6.9E+04
9.183	6	8	8.3E+04
9.241	4	6	5.1E+04
11.748	4	4	1.2E+05
11.748	4	6	1.6E+05
11.748	4	2	1.8E+05
11.763	2	4	1.6E+05
11.789	2	2	2.6E+05
11.789	6	8	1.2E+05
11.797	2	4	1.7E+05
11.823	6	4	7.9E+04
11.837	6	8	2.3E+05
11.837	6	6	1.7E+05
11.886	4	6	1.3E+05
11.898	2	4	8.2E+04
11.922	4	6	1.8E+05
11.976	6	8	5.9E+04
12.027	2	4	6.9E+04
12.045	6	8	2.4E+05
12.045	4	4	9.7E+04
12.053	4	6	6.1E+04
12.077	2	4	1.0E+05
12.077	4	6	2.4E+05
12.095	6	6	7.8E+04
12.193	2	4	7.2E+04
12.193	4	6	9.9E+04
12.325	2	2	1.5E+05

Fe XXIII

λ (Å)	Weights g_i	g_k	A (10^8 s^{-1})
7.733	5	7	3.0E+04
7.849	5	7	4.9E+04
8.307	1	3	4.8E+04
8.529	1	3	4.3E+04
8.550	3	5	6.0E+04
8.552	3	3	3.2E+04
8.614	5	7	7.7E+04
8.664	3	3	4.4E+04
8.669	5	7	6.1E+04
8.672	1	3	6.8E+04
8.752	5	7	1.2E+05
8.764	5	7	4.6E+04
8.814	3	5	6.2E+04
10.902	5	5	5.3E+04
10.910	3	1	6.7E+04
10.927	5	7	6.0E+04
10.934	3	5	5.4E+04
10.979	1	3	7.9E+04
11.018	1	3	4.9E+04
11.086	3	1	6.5E+04
11.165	3	5	6.7E+04
11.255	3	3	3.7E+04
11.298	1	3	1.3E+05
11.325	3	5	1.7E+05
11.338	3	3	9.3E+04
11.429	3	1	1.7E+05
11.433	3	3	1.2E+05
11.441	5	7	2.2E+05
11.445	5	5	5.6E+04
11.485	3	5	1.40E+05
11.491	5	3	5.9E+04
11.519	5	5	1.16E+05
11.520	1	3	2.16E+05
11.524	5	7	2.3E+05
11.593	5	7	3.58E+05
11.613	3	5	1.0E+05
11.615	3	3	4.4E+04
11.691	5	7	7.7E+04
11.698	5	5	7.3E+04
11.737	3	5	1.8E+05
11.898	1	3	2.03E+05

Fe XXIV

λ (Å)	Weights g_i	g_k	A (10^8 s^{-1})
1.8523	2	2	1.0E+05
1.8552	2	4	4.82E+06
1.8563	4	2	2.43E+06
1.8572	2	2	3.06E+06
1.858	2	4	1.2E+05
1.8614	4	4	6.24E+06
1.8626	2	4	3.16E+06
1.8627	2	2	5.47E+06
1.8637	2	2	1.91E+06
1.8655	4	6	2.14E+06
1.8672	4	2	1.63E+06
1.8678	4	4	3.5E+05
1.8721	4	6	3.2E+05
1.8721	2	2	2.0E+05
1.8730	2	4	1.5E+05
1.8739	4	4	8.3E+04
1.891	2	2	9.7E+04
1.897	4	2	9.8E+04
8.231	2	4	6.10E+04
8.316	4	6	7.07E+04
10.619	2	4	7.28E+04
10.663	2	2	7.51E+04
11.030	2	4	1.84E+05
11.171	4	6	2.18E+05

Fe XXV

λ (Å)	Weights g_i	g_k	A (10^8 s^{-1})
1.4607	1	3	2.54E+05
1.4945	1	3	5.05E+05
1.5730	1	3	1.24E+06
1.5749	1	3	1.5E+05
1.778	3	3	8.7E+04
1.782	3	1	4.69E+06
1.787	1	3	2.57E+06
1.787	5	5	1.19E+06
1.788	3	5	2.68E+06
1.788	3	5	1.63E+06
1.789	1	3	1.78E+06
1.790	3	3	1.23E+06
1.791	3	5	4.10E+06

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
1.791	3	3	2.59E+06
1.792	3	1	4.92E+06
1.792	5	5	2.81E+06
1.793	3	1	2.67E+06
1.794	5	3	2.22E+06
1.797	3	5	8.8E+05
1.798	3	3	1.0E+05
1.800	1	3	8.6E+04
1.802	3	1	4.1E+05
1.810	3	1	5.9E+05
1.8502	1	3	4.57E+06
1.8593	1	3	4.42E+05
10.038	3	3	8.08E+04
Krypton			
Kr I			
1164.9	1	3	3.16E+00
1235.8	1	3	3.12E+00
4274.0	5	5	2.6E-02
4351.4	3	1	3.2E-02
4362.6	5	3	8.4E-03
4376.1	3	1	5.6E-02
4400.0	3	5	2.0E-02
4410.4	3	3	4.4E-03
4425.2	3	3	9.7E-03
4453.9	3	5	7.8E-03
4463.7	3	3	2.3E-02
4502.4	3	5	9.2E-03
5562.2	5	5	2.8E-03
5570.3	5	3	2.1E-02
5649.6	1	3	3.7E-03
5870.9	3	5	1.8E-02
6904.7	3	5	1.3E-02
7224.1	3	5	1.4E-02
7587.4	3	1	5.1E-01
7601.5	5	5	3.1E-01
7685.2	3	1	4.9E-01
7694.5	5	3	5.6E-02
7854.8	1	3	2.3E-01
8059.5	1	3	1.9E-01
8104.4	5	5	1.3E-01
8112.9	5	7	3.6E-01
8190.1	3	5	1.1E-01
8263.2	3	5	3.5E-01
8281.1	3	3	1.9E-01
8298.1	3	3	3.2E-01
8508.9	3	3	2.4E-01
8776.7	3	5	2.7E-01
8928.7	5	3	3.7E-01
Kr II			
4250.6	4	4	1.2E-01
4292.9	4	4	9.6E-01
4355.5	6	8	1.0E+00
4431.7	2	2	1.8E+00
4436.8	2	4	6.6E-01
4577.2	6	8	9.6E-01
4583.0	6	4	7.6E-01
4615.3	4	4	5.4E-01

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
4619.2	4	6	8.1E-01
4633.9	4	6	7.1E-01
4658.9	6	4	6.5E-01
4739.0	6	6	7.6E-01
4762.4	2	4	4.2E-01
4765.7	4	6	6.7E-01
4811.8	2	4	1.7E-01
4825.2	2	4	1.9E-01
4832.1	4	2	7.3E-01
5208.3	4	4	1.4E-01
5308.7	4	6	2.4E-02
7407.0	6	6	7.0E-02
Lead			
Pb I			
2022.0	1	3	5.2E-02
2053.3	1	3	1.2E-01
2170.0	1	3	1.5E+00
2401.9	3	3	1.9E-01
2446.2	3	3	2.5E-01
2476.4	3	5	2.8E-01
2577.3	5	3	5.0E-01
2613.7	3	3	2.7E-01
2614.2	3	5	1.9E+00
2628.3	5	3	3.1E-02
2657.1	3	5	9.8E-04
2663.2	5	5	7.1E-01
2802.0	5	7	1.6E+00
2823.2	5	5	2.6E-01
2833.1	1	3	5.8E-01
2873.3	5	5	3.7E-01
3572.7	5	3	9.9E-01
3639.6	3	3	3.4E-01
3671.5	5	3	4.4E-01
3683.5	3	1	1.5E+00
3739.9	5	5	7.3E-01
4019.6	5	7	3.5E-02
4057.8	5	3	8.9E-01
4062.1	5	3	9.2E-01
4168.0	5	5	1.2E-02
5005.4	1	3	2.7E-01
5201.4	1	3	1.9E-01
7229.0	5	3	8.9E-03
Lithium			
Li I			
*2741.2	2	6	1.3E-02
*3232.7	2	6	1.17E-02
*4602.9	6	10	2.23E-01
*6103.6	6	10	6.860E-01
*6707.8	2	6	3.691E-01
Lutetium			
Lu I			
3376.5	4	4	2.23E+00
3567.8	4	6	5.9E-01
3620.3	6	4	1.1E-02
3841.2	6	6	2.5E-01
4518.6	4	4	2.1E-01

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
Magnesium			
Mg I			
2025.8	1	3	8.4E-01
*2779.8	9	9	5.2E+00
*2850.0	9	15	2.3E-01
2852.1	1	3	4.95E+00
*3094.9	9	15	5.2E-01
3329.9	1	3	3.3E-02
3332.2	3	3	9.7E-02
3336.7	5	3	1.6E-01
*3835.3	9	15	1.68E+00
4703.0	3	5	2.55E-01
5167.3	1	3	1.16E-01
5172.7	3	3	3.46E-01
5183.6	5	3	5.75E-01
5528.4	3	5	1.99E-01
Mg II			
1239.9	2	4	1.4E-02
1240.4	2	2	1.4E-02
*2660.8	10	14	3.8E-01
2790.8	2	4	4.0E+00
2795.5	2	4	2.6E+00
2797.9	4	4	7.9E-01
2798.1	4	6	4.8E+00
2802.7	2	2	2.6E+00
2928.8	2	2	1.2E+00
2936.5	4	2	2.3E+00
*3104.8	10	14	8.1E-01
3848.2	6	4	2.8E-02
3848.3	4	4	3.0E-03
3850.4	4	2	3.0E-02
*4481.2	10	14	2.23E+00
9218.3	2	4	3.6E-01
9244.3	2	2	3.6E-01
Mg IV			
320.99	4	2	1.2E+02
323.31	2	2	5.9E+01
1219.0	6	6	5.9E+00
1375.5	4	4	4.5E+00
1459.6	6	4	4.6E+00
1495.5	4	6	6.4E+00
1510.7	4	4	6.7E+00
1683.0	6	8	5.8E+00
1698.8	4	6	3.9E+00
1893.9	6	6	2.8E+00
Mg VI			
*269.92	10	6	3.1E+02
*292.53	6	6	9.0E+01
*314.64	6	2	1.8E+02
*349.15	10	10	6.1E+01
*387.94	6	10	1.3E+01
399.29	4	2	2.8E+01
400.68	4	4	2.8E+01
403.32	4	6	2.7E+01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
Mg VII			
277.01	3	3	9.5E+01
278.41	5	3	1.5E+02
280.74	5	3	2.0E+02
319.02	5	5	8.9E+01
*366.42	9	9	4.4E+01
*433.04	9	15	1.6E+01
1334.3	5	5	5.3E+00
1410.0	5	5	2.57E+00
1487.0	3	5	3.02E+00
1487.9	5	7	3.66E+00
Mg VIII			
*74.976	6	10	4.3E+03
315.02	4	4	1.2E+02
*342.29	10	6	6.3E+01
353.86	4	4	3.89E+01
356.00	6	4	5.7E+01
*428.52	10	10	3.24E+01
*434.62	6	10	1.6E+01
*489.33	6	6	3.9E+01
*686.92	6	10	9.4E+00
Mg IX			
62.751	1	3	2.87E+03
*67.189	9	15	6.20E+03
*71.965	9	3	1.22E+03
72.312	3	5	4.43E+03
77.737	3	1	3.92E+02
368.07	1	3	5.27E+01
438.69	3	1	7.9E+01
*443.74	9	9	4.19E+01
749.55	3	5	8.2E+00
1639.8	3	5	2.1E+00
2814.2	1	3	3.35E-01
Mg X			
57.876	2	4	2.09E+03
57.920	2	2	2.09E+03
63.152	2	4	5.6E+03
63.295	4	6	6.7E+03
609.79	2	4	7.53E+00
624.94	2	2	7.01E+00
2212.5	2	4	9.64E-01
2278.7	2	2	8.82E-01
5918.7	2	4	3.20E-02
6229.6	4	6	3.30E-02
Mg XI			
7.310	1	3	1.15E+04
7.473	1	3	2.27E+04
7.850	1	3	5.50E+04
9.169	1	3	1.97E+05
Manganese			
Mn I			
2794.82	6	8	3.7E+00
2798.27	6	6	3.6E+00
2801.08	6	4	3.7E+00
3007.65	6	8	1.8E-01
3011.38	8	10	3.1E-01
3016.45	10	12	2.9E-01
3043.36	8	8	5.9E-01
3044.57	10	8	5.7E-01
3045.59	10	10	6.7E-01
3045.80	8	10	1.7E-01
3047.03	12	12	6.1E-01
3054.36	8	6	4.6E-01
3070.27	6	6	1.9E-01
3073.18	4	4	3.7E-01
3082.71	14	14	2.9E-01
3110.68	6	8	2.7E-01
3113.80	12	10	2.6E-01
3118.10	4	6	1.7E-01
3122.88	10	10	1.9E-01
3126.85	8	6	2.3E-01
3132.28	10	10	2.1E-01
3132.79	8	8	2.7E-01
3175.58	8	10	1.8E-01
3201.11	4	6	2.2E-01
3228.09	10	12	6.4E-01
3230.23	10	12	1.9E-01
3230.72	8	8	3.5E-01
3240.88	6	4	2.2E-01
3243.78	6	6	5.3E-01
3251.13	4	2	2.3E-01
3252.95	4	4	1.8E-01
3256.14	4	6	5.0E-01
3258.41	2	2	9.7E-01
3260.24	2	4	3.8E-01
3267.79	14	14	3.5E-01
3268.72	6	8	3.3E-01
3270.35	12	12	2.6E-01
3273.02	10	10	2.7E-01
3298.23	6	4	2.8E-01
3303.28	4	4	1.9E-01
3463.66	8	8	3.2E-01
3470.01	6	8	2.4E-01
3511.83	12	12	2.7E-01
3535.30	10	10	1.7E-01
3559.81	6	6	2.1E-01
3577.87	10	8	9.4E-01
3595.11	6	4	1.8E-01
3601.27	12	10	2.3E-01
3607.53	8	8	2.3E-01
3608.49	6	6	3.6E-01
3610.30	4	4	4.2E-01
3635.70	10	8	2.1E-01
3660.40	12	14	9.1E-01
3675.67	6	8	2.2E-01
3676.96	10	12	7.3E-01
3680.15	12	10	1.9E-01
3682.09	8	10	7.6E-01
3684.87	6	8	2.6E-01
3706.08	12	14	1.4E+00
3718.92	10	12	9.6E-01
3731.94	8	10	1.0E+00
3771.44	14	14	1.9E-01
3773.86	12	12	2.5E-01
3800.55	6	8	2.7E-01
3806.72	10	12	5.9E-01
3823.51	8	10	5.21E-01
3823.89	6	6	2.31E-01
3833.87	4	4	3.14E-01
3834.37	6	8	4.29E-01
3839.78	2	2	4.64E-01
3841.07	4	6	3.3E-01
3843.99	2	4	2.11E-01
3889.46	12	14	3.1E-01
3898.37	6	8	1.7E-01
3899.34	4	6	2.4E-01
3924.08	2	4	9.4E-01
3926.48	6	8	5.4E-01
3951.98	2	2	3.1E-01
3952.84	6	6	4.1E-01
3975.88	2	4	1.8E-01
3982.16	4	2	3.5E-01
3982.58	6	4	2.3E-01
3982.90	6	4	5.5E-01
3991.60	2	2	2.1E-01
4011.91	8	8	2.3E-01
4018.11	10	8	2.54E-01
4030.76	6	8	1.7E-01
4033.07	6	6	1.65E-01
4034.49	6	4	1.58E-01
4041.36	10	10	7.87E-01
4048.75	6	4	7.5E-01
4052.48	6	8	3.8E-01
4055.55	8	8	4.31E-01
4058.94	4	2	7.25E-01
4061.74	8	6	1.9E-01
4063.53	6	6	1.69E-01
4065.08	12	14	2.5E-01
4066.24	10	8	2.2E-01
4070.28	2	2	2.3E-01
4079.42	2	4	3.8E-01
4082.95	4	6	2.95E-01
4083.63	6	8	2.8E-01
4089.94	8	10	1.7E-01
4105.37	10	8	1.7E-01
4135.03	12	12	3.0E-01
4141.06	10	10	2.6E-01
4148.80	8	8	2.3E-01
4176.61	14	12	2.4E-01
4189.99	12	10	2.0E-01
4201.78	10	8	2.3E-01
4235.30	8	6	9.17E-01
4239.74	4	2	3.9E-01
4257.67	2	2	3.7E-01
4265.93	4	4	4.92E-01
4281.10	6	6	2.3E-01
4411.87	12	10	2.6E-01
4414.89	8	6	2.93E-01
4419.77	10	8	2.1E-01
4436.36	6	4	4.37E-01
4451.58	8	8	7.98E-01
4453.01	4	2	5.44E-01

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
4455.82	4	6	1.7E-01
4457.04	6	4	2.34E-01
4457.55	6	6	4.27E-01
4458.26	6	8	4.62E-01
4461.09	8	8	1.7E-01
4462.03	8	10	7.00E-01
4464.68	6	6	4.39E-01
4470.14	4	4	3.00E-01
4472.79	2	2	4.35E-01
4479.40	8	10	3.4E-01
4490.08	2	4	2.49E-01
4498.90	4	6	2.49E-01
4502.22	6	8	1.86E-01
4605.37	10	12	3.6E-01
4626.54	12	14	3.6E-01
4709.71	8	8	1.72E-01
4727.46	6	6	1.7E-01
4739.11	4	4	2.40E-01
4754.05	6	8	3.03E-01
4761.53	2	4	5.35E-01
4762.38	8	10	7.83E-01
4765.86	4	6	4.1E-01
4766.43	6	8	4.6E-01
4783.43	8	8	4.01E-01
4823.53	10	8	4.99E-01
6013.48	4	6	1.72E-01
6021.79	8	6	3.32E-01
Mn II			
2593.72	7	7	2.6E+00
2605.68	7	5	2.7E+00
2933.05	5	3	2.0E+00
2939.31	5	5	1.9E+00
2949.20	5	7	1.9E+00
3441.99	9	7	4.3E-01
3460.32	7	5	3.2E-01
3474.13	5	3	1.5E-01
3482.90	5	5	2.0E-01
3488.68	3	3	2.5E-01
Mn VI			
307.999	9	9	3.7E+01
309.440	9	7	5.7E+01
309.579	7	5	4.4E+01
310.058	7	7	3.4E+01
310.182	5	5	2.8E+01
311.748	5	3	5.7E+01
320.598	3	5	1.5E+01
320.681	1	3	2.2E+01
320.874	3	1	7.8E+01
320.979	3	3	2.2E+01
321.176	5	5	6.0E+01
321.541	5	3	2.7E+01
325.146	9	7	1.3E+02
328.431	5	5	4.4E+01
328.558	3	5	1.2E+01
329.043	1	3	1.1E+01
1236.23	5	3	1.3E+01
1255.77	3	1	1.2E+01

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
1285.10	5	7	1.1E+01
1333.87	7	9	1.0E+01
Mercury			
Hg I			
2536.52	1	3	8.00E-02
2652.04	3	5	3.88E-01
2655.13	3	5	1.1E-01
2752.78	1	3	6.10E-02
2856.94	3	1	1.1E-02
2893.60	3	3	1.6E-01
2925.4	5	3	7.7E-02
2967.3	1	3	4.5E-01
3021.50	5	7	5.09E-01
3023.48	5	5	9.4E-02
3027.49	5	5	2.0E-02
3125.66	3	5	6.56E-01
3341.48	5	3	1.68E-01
3650.15	5	7	1.3E+00
3654.83	5	5	1.8E-01
4046.56	1	3	2.1E-01
4077.81	3	1	4.0E-02
4108.1	3	1	3.0E-02
4339.22	3	5	2.88E-02
4347.50	3	5	8.4E-02
4358.34	3	3	5.57E-01
4916.07	3	1	5.8E-02
5025.64	3	3	2.7E-04
5460.75	5	3	4.87E-01
5769.59	3	5	2.36E-01
6234.4	1	3	5.3E-03
6716.4	1	3	4.3E-03
6907.5	3	5	2.8E-02
7728.8	1	3	9.7E-03
10139.79	3	1	2.71E-01
Molybdenum			
Mo I			
2616.79	3	5	7.34E-01
2621.06	7	7	1.16E-01
2628.96	3	3	2.81E-01
2629.85	5	7	7.75E-01
2631.50	1	3	2.54E-01
2638.30	5	5	7.57E-01
2640.98	7	5	1.20E+00
2644.36	5	7	1.96E-01
2649.46	7	9	9.84E-01
2655.02	9	7	4.08E-01
2658.11	7	7	6.43E-01
2665.09	7	9	1.32E-01
2679.85	9	11	1.31E+00
2684.16	9	9	4.18E-01
2706.11	3	5	2.03E-01
2710.74	3	3	1.57E-01
2725.15	3	5	2.79E-01
2728.71	3	3	1.26E-01
2733.39	5	7	2.95E-01
2743.71	1	3	2.47E-01
2745.38	13	11	1.29E-01

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
2751.47	7	9	2.54E-01
2756.26	5	3	1.18E-01
2761.53	9	11	2.06E-01
2763.02	3	1	4.44E-01
2766.25	3	5	1.17E-01
2787.83	9	7	2.85E-01
2792.96	5	3	1.53E-01
2798.02	7	5	1.22E-01
2801.47	5	7	1.24E-01
2825.68	5	7	2.53E-01
2826.75	7	7	4.23E-01
2876.54	9	9	2.84E-01
2886.60	11	11	4.74E-01
2906.06	3	3	8.04E-01
2913.52	5	3	1.38E-01
2915.38	5	3	7.31E-01
2918.84	5	3	3.79E-01
2930.39	1	3	1.91E-01
2936.50	11	11	2.33E-01
2945.43	7	7	3.66E-01
2945.66	3	3	4.08E-01
2946.01	5	5	1.68E-01
2951.45	9	9	1.43E-01
2959.48	9	11	1.75E-01
2972.96	5	3	2.69E-01
2977.27	9	7	3.28E-01
2978.28	7	5	1.50E-01
2983.04	1	3	2.82E-01
2987.92	3	5	8.43E-01
2988.23	5	7	4.28E-01
2988.68	7	9	1.61E-01
2989.80	9	7	9.27E-01
3000.24	9	9	1.40E-01
3000.44	5	5	1.25E-01
3000.85	5	7	2.58E-01
3001.43	5	5	2.31E-01
3007.71	7	5	1.90E-01
3013.39	7	5	6.06E-01
3016.78	9	9	2.75E-01
3025.00	5	5	8.49E-01
3036.31	3	5	5.81E-01
3041.70	13	11	5.94E-01
3046.80	13	11	1.63E-01
3047.31	11	9	5.01E-01
3055.32	9	7	4.29E-01
3057.56	7	5	2.64E-01
3061.59	7	5	4.41E-01
3064.27	13	13	8.46E-01
3065.04	13	13	3.08E-01
3069.51	5	5	1.52E-01
3069.96	11	11	2.72E-01
3070.89	9	11	1.87E-01
3074.37	11	11	1.42E+00
3079.88	9	11	9.55E-01
3080.40	7	9	3.61E-01
3081.16	3	5	2.35E-01
3085.62	9	9	1.63E+00
3089.13	11	9	1.53E-01
3089.71	5	7	2.34E-01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
3094.66	7	7	1.63E+00
3099.92	9	7	1.45E-01
3100.88	7	9	1.20E+00
3101.34	5	5	1.92E+00
3106.34	7	5	2.21E-01
3117.54	13	13	1.89E-01
3123.03	3	3	2.81E-01
3125.03	5	3	1.98E-01
3132.59	7	9	1.79E+00
3135.90	9	11	3.68E-01
3136.75	9	11	1.57E-01
3142.75	3	5	4.10E-01
3147.35	13	11	2.41E-01
3155.19	7	7	2.75E-01
3158.17	7	7	4.63E-01
3170.34	7	7	1.37E+00
3171.38	5	7	2.03E-01
3175.59	13	11	8.40E-01
3179.78	11	13	2.33E-01
3183.03	11	9	3.98E-01
3184.58	7	5	2.77E-01
3185.10	7	7	2.54E-01
3185.71	5	3	6.10E-01
3188.10	7	9	3.45E-01
3188.41	5	7	4.40E-01
3192.79	9	11	1.88E-01
3193.98	7	5	1.53E+00
3194.88	9	11	1.75E-01
3195.96	9	7	4.10E-01
3197.18	1	3	1.47E-01
3198.85	15	13	7.22E-01
3200.89	3	5	1.82E-01
3205.22	1	3	4.27E-01
3205.43	9	11	2.55E-01
3205.89	9	9	5.35E-01
3208.84	7	5	2.77E-01
3210.97	7	5	6.94E-01
3214.44	9	7	2.01E-01
3215.07	3	5	4.20E-01
3216.78	15	13	2.10E-01
3221.73	3	1	1.41E+00
3228.21	5	7	3.85E-01
3229.79	9	11	1.44E-01
3233.14	13	13	6.33E-01
3237.06	7	9	2.95E-01
3244.47	5	3	2.80E-01
3247.61	5	5	1.71E-01
3249.93	5	3	1.87E-01
3251.65	3	5	3.05E-01
3256.21	5	3	6.89E-01
3256.72	3	3	1.31E-01
3259.16	11	13	1.62E-01
3262.63	7	9	3.62E-01
3264.40	11	9	5.42E-01
3265.14	5	7	2.60E-01
3266.16	9	11	1.95E-01
3270.90	7	7	3.59E-01
3276.07	11	9	1.18E-01
3285.03	1	3	1.41E-01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
3285.35	9	7	4.49E-01
3287.38	5	5	1.38E-01
3289.01	9	9	5.08E-01
3290.82	7	5	5.44E-01
3305.56	5	3	1.74E-01
3305.91	7	9	3.06E-01
3307.13	7	9	1.25E-01
3312.33	7	5	1.62E-01
3323.95	9	7	2.82E-01
3325.13	5	3	2.26E-01
3325.67	5	5	1.72E-01
3327.30	1	3	2.88E-01
3336.56	9	9	1.64E-01
3340.16	5	3	1.20E-01
3344.73	3	5	6.04E-01
3346.83	11	11	1.13E-01
3347.00	3	3	2.72E-01
3358.12	5	7	7.59E-01
3361.37	9	9	1.38E-01
3363.78	5	7	2.74E-01
3363.87	5	7	1.39E-01
3373.81	3	3	2.03E-01
3375.22	7	7	1.38E-01
3375.65	7	9	1.56E-01
3378.19	3	1	1.88E-01
3378.46	13	13	3.75E-01
3379.96	5	5	4.11E-01
3382.48	3	3	2.66E-01
3384.61	7	9	7.32E-01
3385.87	9	11	3.30E-01
3389.79	5	7	1.85E-01
3392.17	9	9	1.97E-01
3393.65	11	11	2.08E-01
3404.33	7	7	2.10E-01
3413.37	11	11	1.25E-01
3415.27	9	9	1.83E-01
3415.61	7	9	1.29E-01
3416.14	9	11	2.45E-01
3418.52	5	3	1.41E-01
3419.69	7	7	1.15E-01
3420.04	5	5	3.28E-01
3422.31	9	9	2.52E-01
3425.13	11	11	2.29E-01
3427.90	11	13	4.09E-01
3434.79	7	7	1.75E-01
3435.45	15	15	1.50E+00
3437.21	11	9	8.06E-01
3438.87	1	3	2.34E-01
3441.87	5	3	1.34E-01
3442.66	3	3	2.94E-01
3445.03	7	9	1.53E-01
3445.26	7	5	2.96E-01
3445.80	9	9	1.14E-01
3447.12	9	11	8.75E-01
3447.29	5	3	1.79E-01
3449.07	7	9	1.52E-01
3449.85	5	7	1.65E-01
3452.60	7	7	2.48E-01
3456.15	5	5	3.60E-01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
3456.52	3	3	2.96E-01
3460.22	5	3	2.77E-01
3460.78	9	7	6.03E-01
3465.84	3	1	9.99E-01
3466.19	9	7	2.11E-01
3466.96	7	7	1.52E-01
3467.85	5	7	2.63E-01
3469.22	5	3	6.96E-01
3469.63	13	15	1.51E-01
3470.92	3	5	2.91E-01
3475.03	3	3	4.68E-01
3479.42	7	5	2.26E-01
3483.67	7	7	1.13E-01
3483.83	7	5	1.41E-01
3489.43	7	7	3.27E-01
3504.41	7	9	8.06E-01
3505.31	7	9	2.25E-01
3508.11	9	9	1.59E-01
3510.77	13	13	4.75E-01
3517.55	11	11	5.41E-01
3518.21	3	3	3.64E-01
3521.38	9	9	1.39E-01
3521.41	9	11	6.06E-01
3524.65	5	3	3.10E-01
3524.98	7	9	2.25E-01
3538.92	11	11	2.24E-01
3540.57	5	3	4.46E-01
3542.17	7	5	4.93E-01
3552.71	9	7	3.64E-01
3555.64	3	3	3.46E-01
3558.09	5	7	5.43E-01
3563.75	1	3	1.53E-01
3566.05	9	9	2.67E-01
3566.74	7	7	1.43E-01
3570.64	15	15	7.18E-01
3573.88	3	5	3.58E-01
3580.54	13	11	5.49E-01
3581.88	11	13	3.81E-01
3584.25	3	3	1.73E-01
3585.57	7	5	3.95E-01
3588.95	7	7	1.18E-01
3590.74	7	9	2.23E-01
3595.55	5	5	2.32E-01
3598.88	13	11	5.67E-01
3600.73	9	9	2.07E-01
3601.88	7	9	1.15E-01
3602.94	5	7	2.96E-01
3604.07	9	7	3.25E-01
3610.61	5	3	1.78E-01
3611.99	7	7	1.16E-01
3615.16	7	9	1.96E-01
3623.22	11	9	5.58E-01
3624.46	9	11	5.27E-01
3624.62	5	7	1.37E-01
3638.20	5	3	3.51E-01
3638.21	5	3	3.33E-01
3640.62	7	5	1.94E-01
3647.84	7	7	2.11E-01
3648.70	7	5	1.15E-01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
3654.58	3	3	1.80E-01
3657.36	5	7	2.03E-01
3658.13	9	9	1.86E-01
3659.36	7	9	6.70E-01
3660.92	3	5	1.34E-01
3662.15	7	9	1.45E-01
3662.99	11	11	3.48E-01
3663.27	7	5	2.30E-01
3664.81	11	13	9.54E-01
3664.88	1	3	1.92E-01
3669.34	9	7	2.16E-01
3672.81	9	11	1.95E-01
3672.82	9	9	1.13E-01
3676.23	3	1	5.22E-01
3680.68	11	11	2.96E-01
3681.72	9	7	1.68E-01
3683.01	3	5	1.20E-01
3687.96	5	7	2.12E-01
3688.97	11	9	3.26E-01
3690.59	11	9	2.07E-01
3694.94	5	7	6.36E-01
3696.04	11	11	3.59E-01
3698.07	7	5	1.48E-01
3708.55	7	9	1.28E-01
3715.75	9	7	2.38E-01
3718.48	5	7	1.34E-01
3720.25	7	9	2.86E-01
3725.55	7	7	1.60E-01
3727.68	9	11	1.51E-01
3728.30	7	5	1.55E-01
3728.50	7	9	2.20E-01
3733.02	7	7	1.45E-01
3733.41	13	13	2.80E-01
3735.62	11	11	1.66E-01
3742.28	7	7	1.56E-01
3747.19	5	7	3.07E-01
3748.48	9	11	3.95E-01
3755.10	3	5	1.41E-01
3755.16	9	9	2.48E-01
3758.52	9	9	1.22E-01
3759.60	9	7	1.82E-01
3760.88	9	9	2.16E-01
3768.73	9	9	2.88E-01
3769.99	7	9	2.46E-01
3777.72	13	11	1.66E-01
3788.25	7	9	2.87E-01
3794.43	9	9	1.22E-01
3797.47	7	5	1.48E-01
3798.25	7	9	6.90E-01
3801.84	9	7	3.16E-01
3805.99	5	5	2.44E-01
3819.78	9	11	1.47E-01
3824.78	5	7	1.40E-01
3827.15	7	7	1.94E-01
3828.88	7	7	1.35E-01
3830.81	5	5	1.83E-01
3831.07	7	9	1.20E-01
3832.11	9	9	3.05E-01
3833.75	9	9	1.70E-01
3834.64	3	5	1.20E-01
3846.18	7	7	1.26E-01
3847.25	3	1	2.41E-01
3848.30	9	9	1.26E-01
3851.99	11	9	1.78E-01
3864.10	7	7	6.24E-01
3866.69	3	5	1.74E-01
3867.67	5	3	2.22E-01
3869.08	5	3	1.35E-01
3874.15	7	5	1.67E-01
3902.95	7	5	6.17E-01
3909.54	9	7	1.13E-01
3911.94	5	5	1.15E-01
3915.43	5	5	1.40E-01
3916.43	5	3	1.78E-01
3919.55	11	13	2.24E-01
3955.48	13	11	1.71E-01
3973.76	11	13	4.39E-01
3977.90	9	7	1.35E-01
3980.20	5	3	2.70E-01
3991.85	11	9	1.29E-01
4010.13	5	3	4.38E-01
4021.01	9	11	2.65E-01
4051.18	13	11	1.36E-01
4062.08	11	9	1.96E-01
4069.88	13	11	3.25E-01
4076.19	9	9	1.16E-01
4084.37	9	7	1.94E-01
4102.15	5	3	1.22E-01
4107.46	7	5	2.02E-01
4120.09	13	15	6.05E-01
4131.92	9	11	1.56E-01
4148.98	9	11	1.56E-01
4157.40	13	11	2.17E-01
4157.90	9	11	1.60E-01
4185.82	11	13	3.82E-01
4188.32	11	13	3.32E-01
4194.56	11	11	2.70E-01
4232.59	9	11	3.17E-01
4240.83	5	5	1.68E-01
4246.02	11	13	2.00E-01
4251.88	13	11	1.76E-01
4254.95	7	9	2.01E-01
4269.28	11	11	1.36E-01
4276.91	7	9	2.85E-01
4277.24	9	11	1.35E-01
4317.92	15	15	1.28E-01
4325.80	3	3	1.84E-01
4326.14	5	7	2.56E-01
4340.74	5	7	1.23E-01
4381.63	13	13	2.93E-01
4382.41	11	13	3.83E-01
4409.94	13	13	1.38E-01
4411.69	11	11	2.63E-01
4434.95	9	9	2.51E-01
4446.42	11	11	1.90E-01
4457.35	7	7	1.28E-01
4474.57	5	5	2.10E-01
4491.65	11	11	2.09E-01
4536.80	13	15	5.03E-01
4598.23	1	3	1.47E-01
4624.23	9	9	1.32E-01
4633.08	3	5	2.35E-01
4649.06	3	1	1.25E-01
4652.24	5	7	1.55E-01
4686.08	3	3	1.72E-01
4688.21	13	15	1.54E-01
4707.25	7	9	3.63E-01
4718.86	5	5	2.17E-01
4723.05	9	9	1.23E-01
4731.44	9	11	4.49E-01
4758.50	11	9	3.01E-01
4760.18	11	13	4.67E-01
4764.11	9	7	2.16E-01
4811.05	13	11	4.36E-01
4819.25	11	9	2.71E-01
4830.51	9	7	4.07E-01
4858.39	13	11	1.24E-01
4868.02	7	5	3.11E-01
5037.18	9	7	1.14E-01
5044.36	7	5	1.31E-01
5047.70	3	1	2.61E-01
5163.18	9	11	2.03E-01
5171.06	5	7	1.84E-01
5172.94	5	5	4.11E-01
5174.18	5	3	5.83E-01
5191.45	7	9	1.62E-01
5238.21	7	9	3.74E-01
5240.87	7	7	3.89E-01
5242.80	7	5	2.01E-01
5261.53	5	7	1.13E-01
5280.85	5	5	1.28E-01
5355.52	9	9	1.21E-01
5356.46	11	11	2.11E-01
5360.51	9	11	6.19E-01
5364.28	9	9	2.26E-01
5460.50	5	3	3.46E-01
5493.76	7	5	2.13E-01
5506.49	5	7	3.61E-01
5533.03	5	5	3.72E-01
5570.44	5	3	3.30E-01
5849.71	3	3	3.02E-01
5851.50	3	5	1.55E-01
5893.36	5	5	2.60E-01
5895.93	5	7	3.12E-01
5926.37	7	7	1.63E-01
5928.88	7	9	5.32E-01
7154.11	9	9	3.45E-01

Neodymium
Nd II

λ Å	g_i	g_k	A 10^8 s^{-1}
3780.4	16	18	1.4E-01
3805.4	14	16	6.9E-01
3807.2	10	12	4.9E-02
3863.3	8	10	1.5E-01
3941.5	10	10	6.1E-01
3951.2	12	12	6.0E-01
3973.3	18	18	6.3E-01

λ Å	Weights g_i	g_k	*A* 10^8 s^{-1}
3979.5	10	12	2.7E-01
3990.1	16	16	5.2E-01
4012.3	18	20	5.5E-01
4061.1	16	18	4.4E-01
4106.6	14	16	6.8E-02
4109.5	14	16	3.7E-01
4133.4	14	12	1.5E-01
4156.1	12	14	3.4E-01
4205.6	18	16	1.8E-01
4284.5	18	18	8.5E-02
4303.6	8	10	4.7E-01
4325.8	16	16	1.6E-01
4358.2	14	14	1.5E-01
4382.7	12	10	4.0E-02
4400.8	10	10	6.8E-02
4451.6	12	14	2.5E-01
4456.4	16	18	6.4E-02
4463.0	14	16	1.8E-01
4958.1	12	10	1.2E-02
5130.6	22	20	1.6E-01
5192.6	20	18	1.7E-01
5249.6	18	16	1.8E-01
5276.9	12	10	1.2E-01
5293.2	16	14	1.2E-01
5302.3	20	18	1.1E-01
5311.5	14	12	1.1E-01
5319.8	12	10	1.6E-01
5357.0	18	16	1.8E-01
5371.9	20	20	5.1E-02
5485.7	18	18	5.7E-02
5594.4	16	16	7.0E-02
5620.6	18	18	1.3E-01
5688.5	14	14	5.9E-02
5718.1	16	16	8.7E-02
5726.8	10	10	5.6E-02
5740.9	12	12	7.2E-02
5804.0	10	10	4.6E-02
5865.1	16	18	1.3E-02
6051.9	12	10	1.1E-02

Neon

Ne I

λ Å	Weights g_i	g_k	*A* 10^8 s^{-1}
615.63	1	3	3.8E-01
618.67	1	3	9.3E-01
619.10	1	3	3.3E-01
626.82	1	3	7.4E-01
629.74	1	3	4.8E-01
735.90	1	3	6.11E+00
743.72	1	3	4.86E-01
3369.8	5	5	1.0E-03
3369.9	5	3	7.6E-03
3375.6	5	3	2.2E-03
3417.9	3	5	9.2E-03
3418.0	3	3	2.2E-03
3423.9	3	3	1.0E-03
3447.7	5	5	2.1E-02
3450.8	5	3	4.9E-03
3454.2	3	1	3.7E-02
3460.5	1	3	7.0E-03
3464.3	5	5	6.7E-03
3466.6	1	3	1.3E-02
3472.6	5	7	1.7E-02
3498.1	3	5	5.1E-03
3501.2	3	3	1.2E-02
3510.7	5	3	2.2E-03
3515.2	3	5	6.9E-03
3520.5	3	1	9.3E-02
3593.5	3	5	9.9E-03
3593.6	3	3	6.6E-03
3600.2	3	3	4.3E-03
3633.7	3	1	1.1E-02
3682.2	3	5	1.6E-03
3685.7	3	3	3.9E-03
3701.2	3	5	2.2E-03
4536.3	3	3	5.0E-03
4702.5	3	3	2.1E-03
4708.9	3	3	4.2E-02
4955.4	3	3	3.3E-03
5113.7	3	3	1.0E-02
5120.5	3	3	5.6E-03
5154.4	3	3	1.9E-02
5191.3	3	3	1.3E-02
5326.4	3	3	6.8E-03
5333.3	3	3	5.3E-03
5341.1	3	3	1.1E-01
5400.6	3	1	9.0E-03
5418.6	3	3	5.2E-03
5433.7	3	3	2.83E-03
5652.6	3	3	8.9E-03
5662.5	3	3	6.9E-03
5852.5	3	1	6.82E-01
5868.4	3	3	1.4E-02
5881.9	5	3	1.15E-01
5913.6	3	3	4.8E-02
5939.3	5	3	2.00E-03
5944.8	5	5	1.13E-01
5961.6	3	3	3.3E-02
5975.5	5	3	3.51E-02
6030.0	3	3	5.61E-02
6046.1	3	3	2.26E-03
6074.3	3	1	6.03E-01
6096.2	3	5	1.81E-01
6118.0	5	3	6.09E-03
6128.5	3	3	6.7E-03
6143.1	5	5	2.82E-01
6150.3	3	3	1.5E-02
6163.6	1	3	1.46E-01
6217.3	5	3	6.37E-02
6266.5	1	3	2.49E-01
6273.0	3	3	9.7E-03
6293.7	3	3	6.39E-03
6304.8	3	5	4.16E-02
6328.2	5	3	3.39E-02
6330.9	3	3	2.3E-02
6334.4	5	5	1.61E-01
6351.9	1	3	3.45E-03
6383.0	3	3	3.21E-01
6401.1	3	3	1.39E-02
6402.2	5	7	5.14E-01
6506.5	3	5	3.00E-01
6532.9	1	3	1.08E-01
6599.0	3	3	2.32E-01
6602.9	3	3	5.9E-03
6652.1	3	1	2.9E-03
6678.3	3	5	2.33E-01
6717.0	3	3	2.17E-01
6721.1	3	3	4.9E-04
6929.5	3	5	1.74E-01
7024.1	3	3	1.89E-02
7032.4	5	3	2.53E-01
7051.3	3	3	3.0E-02
7059.1	3	5	6.8E-02
7173.9	3	5	2.87E-02
7245.2	3	3	9.35E-02
7304.8	1	3	2.55E-03
7438.9	1	3	2.31E-02
7472.4	3	3	4.0E-02
7535.8	3	3	4.3E-01
7937.0	5	5	7.8E-03
8082.5	3	3	1.2E-03
8118.5	3	3	4.9E-02
8128.9	3	5	7.2E-03
8259.4	5	5	2.03E-02
8571.4	3	3	5.5E-02
8582.9	3	5	1.00E-02
8647.0	5	5	3.91E-02
8681.9	3	3	2.1E-01
8767.5	3	3	1.1E-03
8771.7	3	3	1.6E-01
8783.8	3	5	3.13E-01
8865.3	3	3	9.4E-03
9201.8	3	3	9.1E-02
9433.0	3	3	1.1E-03
9486.7	3	3	2.5E-02
9534.2	3	3	6.3E-02
10621	3	3	2.4E-03
11409	3	3	4.2E-02
11525	3	3	8.4E-02
11767	3	3	6.9E-02
12459	3	3	1.5E-02

Ne II

λ Å	Weights g_i	g_k	*A* 10^8 s^{-1}
*357.03	6	10	3.8E+01
*361.77	6	2	1.6E+01
*406.28	6	10	1.8E+01
*446.37	6	6	4.07E+01
460.73	4	2	4.7E+01
462.39	2	2	2.3E+01
1907.5	4	2	2.8E-01
1916.1	4	4	6.9E-01
1930.0	2	2	5.7E-01
1938.8	2	4	1.3E-01
2858.0	6	6	7.9E-01
2870.0	6	6	1.7E-01
2873.0	6	4	3.8E-01
2876.3	4	6	7.8E-01
2876.5	6	4	3.3E-01

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
2878.1	2	2	6.9E-02
2888.4	4	6	7.0E-02
2891.5	4	4	6.1E-02
2897.0	6	8	5.2E-02
2906.8	2	4	5.5E-01
2910.1	4	2	1.7E+00
2910.4	2	4	5.9E-01
2916.2	6	4	9.6E-02
2925.6	2	2	5.6E-01
2933.7	6	6	6.9E-02
2955.7	6	4	1.2E+00
3001.7	4	4	8.7E-01
3017.3	6	4	3.5E-01
3027.0	6	6	1.4E+00
3028.7	4	2	8.5E-01
3028.9	2	4	4.7E-01
3034.5	6	8	3.1E+00
3037.7	4	4	2.1E+00
3045.6	2	2	2.5E+00
3047.6	4	6	1.8E+00
3054.7	2	4	9.4E-01
3092.9	6	6	1.3E+00
3097.1	8	8	1.3E+00
3118.0	8	6	4.2E-02
3134.1	6	4	2.6E-01
3140.4	8	6	2.4E-01
3151.1	6	6	4.8E-02
3154.8	8	6	1.8E-02
3164.4	8	8	1.6E-01
3165.7	6	6	1.2E-01
3173.6	6	4	4.5E-02
3176.1	4	6	6.0E-02
3187.6	4	6	1.4E-02
3188.7	6	6	3.9E-01
3190.9	4	6	1.5E-01
3194.6	4	4	5.2E-01
3198.6	6	8	1.7E+00
3198.9	4	4	2.3E-01
3209.0	8	8	1.6E-01
3209.4	2	4	6.0E-01
3213.7	2	4	1.7E+00
3214.3	4	6	2.2E+00
3218.2	8	10	3.6E+00
3224.8	6	8	3.5E+00
3229.5	8	8	1.3E-01
3229.6	8	10	3.6E+00
3230.1	6	6	1.8E+00
3230.4	4	6	1.4E-01
3232.0	6	4	2.7E-01
3232.4	4	4	1.6E+00
3243.4	6	6	2.3E-01
3244.1	6	8	1.5E+00
3248.1	4	4	2.4E-01
3255.4	6	4	3.8E-02
3263.4	2	4	3.9E-01
3269.9	4	6	5.1E-01
3270.8	6	4	5.7E-02
3297.7	6	6	4.3E-01
3309.7	4	2	3.1E-01
3310.5	4	4	6.9E-02
3311.3	4	2	2.6E-01
3314.7	6	6	4.4E-02
3319.7	4	2	1.6E+00
3320.2	8	6	2.1E-01
3323.7	4	4	1.6E+00
3327.2	4	4	9.1E-01
3329.2	8	8	8.8E-01
3330.7	6	6	3.9E-02
3334.8	6	8	1.8E+00
3336.1	4	6	1.1E+00
3344.4	2	2	1.5E+00
3345.5	6	4	1.4E+00
3345.8	4	4	2.2E-01
3353.6	4	2	1.2E-01
3355.0	4	6	1.3E+00
3356.3	6	6	2.0E-01
3357.8	6	6	5.0E-01
3360.3	2	4	8.6E-01
3360.6	2	4	8.2E-01
3362.9	4	2	3.5E-01
3371.8	4	6	2.2E-01
3374.1	4	4	3.0E-01
3378.2	2	2	1.7E+00
3379.3	2	2	3.0E-01
3386.2	4	6	5.5E-02
3388.4	4	6	2.2E+00
3390.6	2	4	7.7E-02
3392.8	2	4	4.4E-01
3404.8	4	6	1.9E+00
3407.0	6	8	2.3E+00
3411.4	4	2	6.1E-01
3413.2	4	4	1.8E+00
3414.9	4	6	1.8E-02
3416.9	6	6	6.4E-01
3417.7	6	8	1.6E+00
3438.9	2	2	1.4E+00
3440.7	2	4	3.5E-01
3453.1	4	4	4.6E-01
3454.8	4	4	1.6E+00
3456.6	2	4	9.6E-01
3457.1	4	6	9.9E-02
3459.3	6	6	1.6E+00
3475.2	4	4	1.2E-02
3477.6	4	6	4.3E-01
3481.9	4	2	1.4E+00
3503.6	2	2	2.0E+00
3522.7	4	2	2.3E-02
3538.0	4	2	7.6E-01
3539.9	4	4	3.6E-02
3542.2	6	4	6.0E-01
3542.9	4	6	1.2E+00
3546.2	2	4	6.3E-02
3551.6	2	4	3.7E-02
3557.8	2	2	1.9E-01
3561.2	4	6	2.1E-01
3565.8	4	4	6.2E-01
3568.5	6	8	1.4E+00
3571.2	4	4	6.3E-01
3574.2	6	6	1.0E-01
3574.6	4	6	1.3E+00
3590.4	4	6	3.6E-02
3594.2	4	2	1.3E+00
3612.3	2	4	2.6E-01
3628.0	4	4	6.0E-01
3632.7	4	4	1.3E-01
3643.9	4	4	3.2E-01
3644.9	2	4	9.9E-01
3659.9	4	6	6.7E-02
3664.1	6	4	7.0E-01
3679.8	4	2	3.2E-01
3694.2	6	6	1.0E+00
3697.1	2	2	2.8E-01
3701.8	4	6	2.7E-01
3709.6	4	2	1.1E+00
3713.1	4	6	1.3E+00
3721.8	4	6	2.0E-01
3726.9	4	4	1.2E-01
3727.1	2	4	9.8E-01
3734.9	4	4	1.9E-01
3744.6	2	4	2.6E-01
3751.2	2	2	1.8E-01
3753.8	4	6	4.5E-01
3766.3	4	6	2.9E-01
3777.1	2	4	4.2E-01
3800.0	4	4	3.7E-01
3818.4	2	4	6.1E-01
3829.8	4	6	8.4E-01
3942.3	4	6	1.0E-02
Ne V			
*142.61	9	9	6.7E+02
*143.32	9	15	1.2E+03
147.13	5	7	1.5E+03
151.23	5	5	3.38E+02
154.50	1	3	7.0E+02
*167.69	9	9	1.5E+02
*358.93	9	3	2.1E+02
365.59	5	3	1.35E+02
*482.15	9	9	3.01E+01
*571.04	9	15	1.0E+01
2259.6	3	5	1.9E+00
2265.7	5	7	2.4E+00
Ne VII			
97.502	1	3	1.07E+03
*115.46	9	3	4.8E+02
116.69	3	5	1.6E+03
127.66	3	1	1.9E+02
465.22	1	3	4.09E+01
558.61	3	5	8.11E+00
559.95	1	3	1.07E+01
561.38	3	3	7.99E+00
561.73	5	5	2.39E+01
562.99	3	1	3.17E+01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
564.53	5	3	1.31E+01
Ne VIII			
*88.09	2	6	8.4E+02
*98.208	6	10	2.77E+03
770.41	2	4	5.90E+00
780.32	2	2	5.69E+00
2820.7	2	4	7.20E-01
2860.1	2	2	6.88E-01
Nickel			
Ni I			
1963.85	7	7	1.1E-01
1976.87	7	9	1.1E+00
1981.61	5	5	1.3E-01
1990.25	5	7	8.3E-01
2007.01	5	5	1.7E-01
2007.69	7	7	9.0E-02
2014.25	3	5	9.3E-01
2025.40	7	5	2.3E-01
2026.62	9	7	2.4E-01
2047.35	7	5	1.8E-01
2052.04	9	9	9.7E-02
2055.50	5	3	3.3E-01
2059.92	7	5	2.1E-01
2060.20	5	3	2.3E-01
2064.39	3	1	4.0E-01
2069.52	5	5	1.1E-01
2085.57	5	5	2.6E+00
2089.09	7	5	9.7E-02
2095.13	5	7	1.1E-01
2114.43	5	5	9.7E-02
2121.40	7	5	2.8E-01
2124.80	5	3	3.8E-01
2147.80	5	3	4.7E-01
2157.83	5	3	4.1E-01
2158.31	7	5	6.9E-01
2161.04	5	5	1.3E-01
2173.54	5	3	1.5E-01
2174.48	3	1	8.9E-01
2182.38	7	5	1.3E-01
2183.91	5	5	1.2E-01
2190.22	5	5	3.0E-01
2197.35	3	3	7.8E-01
2201.59	5	3	7.3E-01
2221.94	5	3	2.2E-01
2244.46	5	5	3.8E-01
2253.57	7	7	1.9E-01
2254.81	9	9	9.6E-02
2258.15	7	5	1.7E-01
2259.56	5	3	2.0E-01
2261.42	9	7	9.1E-02
2287.32	3	5	1.8E-01
2289.98	9	7	2.1E+00
2293.11	5	5	3.8E-01
2300.77	7	7	7.5E-01
2302.97	3	3	4.5E-01
2307.35	5	7	1.6E-01
2312.34	7	7	5.5E+00
2313.98	5	5	5.0E+00
2317.16	7	5	3.8E+00
2320.03	9	11	6.9E+00
2321.38	5	7	5.6E+00
2324.65	7	9	1.8E-01
2325.79	7	9	3.5E+00
2329.96	5	3	5.3E+00
2345.54	9	7	2.2E+00
2346.63	7	5	5.5E-01
2347.51	9	9	2.2E-01
2348.73	7	7	2.2E-01
2419.31	7	5	2.0E-01
2943.91	7	5	1.1E-01
2981.65	5	3	2.8E-01
3002.48	7	7	8.0E-01
3003.62	5	5	6.9E-01
3012.00	5	5	1.3E+00
3037.93	7	7	2.8E-01
3050.82	7	9	6.0E-01
3054.31	5	5	4.0E-01
3057.64	3	3	1.0E+00
3064.62	5	7	1.1E-01
3101.56	5	7	6.3E-01
3101.88	5	7	4.9E-01
3134.11	3	5	7.3E-01
3225.02	5	3	9.3E-02
3369.56	9	7	1.8E-01
3380.57	5	3	1.3E+00
3392.98	7	7	2.4E-01
3414.76	7	9	5.5E-01
3423.71	3	3	3.3E-01
3433.56	7	7	1.7E-01
3446.26	5	5	4.4E-01
3452.88	5	7	9.8E-02
3458.46	3	5	6.1E-01
3461.66	7	9	2.7E-01
3472.55	5	7	1.2E-01
3483.77	5	3	1.4E-01
3492.96	5	3	9.8E-01
3510.33	3	1	1.2E+00
3515.05	5	7	4.2E-01
3524.54	7	5	1.0E+00
3566.37	5	5	5.6E-01
3597.70	3	3	1.4E-01
3619.39	5	7	6.6E-01
4027.67	5	7	1.3E-01
4295.88	9	7	1.7E-01
4401.54	9	11	3.8E-01
4462.46	3	5	1.7E-01
4470.48	5	7	1.9E-01
4600.37	5	3	2.6E-01
4604.99	9	7	2.3E-01
4606.23	5	3	1.0E-01
4648.66	11	9	2.4E-01
4686.22	5	5	1.4E-01
4701.54	9	9	1.4E-01
4714.42	13	11	4.6E-01
4715.78	7	7	2.0E-01
4732.47	7	9	9.3E-02
4752.43	3	3	2.0E-01
4756.52	9	9	1.5E-01
4786.54	11	11	1.8E-01
4812.00	3	1	9.5E-02
4829.03	5	7	1.9E-01
4831.18	9	7	1.6E-01
4838.64	9	7	2.2E-01
4855.41	5	5	5.7E-01
4904.41	5	3	6.2E-01
4912.03	3	3	1.5E-01
4913.97	1	3	2.2E-01
4918.36	9	7	2.3E-01
4935.83	7	5	2.4E-01
4937.34	9	9	1.2E-01
4953.20	5	5	1.2E-01
4980.17	9	11	1.9E-01
5000.34	7	7	1.4E-01
5012.46	7	7	1.1E-01
5017.58	11	11	2.0E-01
5035.37	7	9	5.7E-01
5042.20	3	5	1.4E-01
5048.85	7	7	1.6E-01
5080.53	9	11	3.2E-01
5081.11	7	9	5.7E-01
5082.35	3	3	2.5E-01
5084.08	7	9	3.1E-01
5099.95	7	7	2.9E-01
5115.40	11	9	2.2E-01
5129.37	7	5	1.2E-01
5155.14	5	5	1.1E-01
5155.76	5	7	2.9E-01
5176.57	5	5	1.8E-01
5371.33	7	7	1.6E-01
5476.91	1	3	9.5E-02
5637.12	3	3	1.1E-01
5664.02	5	7	1.1E-01
5695.00	3	3	1.7E-01
6086.29	3	5	1.1E-01
6175.42	3	3	1.7E-01
7122.24	5	7	2.1E-01
7381.94	9	11	9.7E-02
7422.30	7	5	1.8E-01
7727.66	7	7	1.1E-01
Ni II			
2165.55	10	10	2.4E+00
2169.10	8	8	1.58E+00
2174.67	8	10	1.43E+00
2175.15	6	6	1.77E+00
2184.61	4	4	2.90E+00
2201.41	4	6	1.3E+00
2206.72	6	8	1.66E+00
2216.48	10	12	3.4E+00
2220.40	6	8	2.3E+00
2222.96	10	10	9.8E-01
2224.86	8	8	1.55E+00
2226.33	6	6	1.3E+00
2253.85	4	6	1.98E+00
2264.46	6	8	1.43E+00

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
2270.21	8	10	1.56E+00
2278.77	8	6	2.8E+00
2287.09	6	4	2.8E+00
2296.55	8	8	1.98E+00
2297.14	6	4	2.70E+00
2297.49	4	2	3.0E+00
2298.27	6	6	2.8E+00
2303.00	8	6	2.9E+00
2316.04	10	8	2.88E+00
2334.58	8	8	8.0E-01
2375.42	6	8	6.6E-01
2394.52	8	10	1.70E+00
2416.13	6	8	2.1E+00
2437.89	8	10	5.4E-01
2510.87	8	10	5.8E-01
Ni III			
1692.51	11	13	7.9E+00
1709.90	9	11	6.3E+00
1719.46	5	7	6.0E+00
1722.28	3	5	5.9E+00
1724.52	3	1	6.7E+00
1741.96	9	7	5.7E+00
1752.43	7	5	5.5E+00
1760.56	5	3	6.5E+00
1769.64	11	11	6.2E+00
1823.06	9	9	5.6E+00
Ni XIV			
164.13	6	8	1.2E+03
168	2	4	2.4E+02
168.12	4	2	8.5E+02
169.69	4	4	9.8E+02
170.50	4	4	7.1E+02
171.37	4	6	9.4E+02
172.16	6	6	4.7E+02
172.80	6	4	1.4E+02
177.28	4	4	5.6E+02
178	2	4	8.9E+01
181	4	6	7.4E+01
182.14	4	2	1.5E+02
196	4	2	3.8E+01
288.894	4	4	4.6E+01
292.399	6	6	3.6E+01
Ni XV			
50.249	5	7	6.8E+03
60.890	9	11	1.0E+04
64.635	7	9	9.6E+03
163.64	5	7	5.6E+01
173.73	5	7	7.6E+02
175	3	1	5.7E+02
179.28	5	7	7.5E+02
181	1	3	6.8E+02
269	3	1	5.3E+01
278.386	5	5	4.3E+01
Ni XVI			
166	4	6	3.1E+02
168	6	8	3.2E+02
182	2	2	2.5E+02
185.23	2	4	4.2E+02
187	4	6	1.2E+02
187	4	2	3.3E+02
188	2	2	4.7E+02
190	6	8	2.0E+02
192	6	8	4.54E+02
192	6	6	3.1E+02
194	4	6	2.8E+02
194	2	4	5.5E+02
194	2	2	1.1E+02
194	4	4	3.5E+02
194.04	4	6	4.6E+02
195.27	4	4	9.5E+01
196	4	6	6.7E+02
197	4	6	1.5E+02
197	4	2	1.2E+02
199	2	4	4.9E+02
206	2	2	3.7E+02
217	4	4	1.1E+02
218.391	2	4	9.5E+01
223.119	2	2	1.3E+02
231	4	4	1.6E+02
232.475	4	4	4.07E+02
233	6	4	2.4E+02
235	4	2	3.8E+02
235	6	6	2.5E+02
236	4	4	1.2E+02
237.875	4	2	2.6E+02
238	6	4	1.3E+02
239.550	2	2	2.6E+02
245	4	4	1.4E+02
245	4	6	3.2E+02
249	6	8	3.3E+02
249	6	4	1.2E+02
250	4	2	1.6E+02
254	6	4	1.8E+02
Ni XVII			
30.919	1	3	2.77E+03
42.855	1	3	4.75E+03
54.451	9	11	1.5E+04
55.361	1	3	6.7E+03
57.348	7	9	1.4E+04
197.39	1	3	1.6E+02
199.87	3	5	2.1E+02
204	3	3	1.8E+02
205	3	1	2.4E+02
206	1	3	3.0E+02
207.50	5	7	2.5E+02
215.89	3	5	4.8E+02
216	1	3	2.7E+02
217	5	7	2.4E+02
227	5	5	1.6E+02
249.180	1	3	2.75E+02
281.50	3	1	2.1E+02
282	3	1	2.4E+02
284	5	3	1.5E+02
292	5	7	2.2E+02
Ni XVIII			
24.881	2	4	8.6E+02
25.070	4	6	9.9E+02
26.02	2	4	1.26E+03
26.020	2	4	1.1E+03
26.046	2	2	1.1E+03
26.218	4	6	1.5E+03
27.98	4	6	1.0E+03
27.982	2	4	2.0E+03
28.018	6	8	1.1E+03
28.220	4	6	2.33E+03
29.383	4	6	1.58E+03
29.422	6	8	1.69E+03
29.779	2	4	1.9E+03
29.829	2	2	1.9E+03
31.845	4	6	2.7E+03
31.890	6	8	3.0E+03
32.034	2	4	3.4E+03
32.340	4	6	4.0E+03
36.990	4	6	5.5E+03
37.049	6	8	5.9E+03
41.015	2	4	2.97E+03
41.218	2	2	3.2E+03
43.814	2	4	5.5E+03
44.365	4	6	6.8E+03
44.405	4	4	1.14E+03
52.615	4	6	1.5E+04
52.720	6	8	1.6E+04
52.745	6	6	1.06E+03
59.950	6	4	9.6E+02
60.212	4	2	1.1E+03
63.512	4	6	7.9E+02
63.589	6	8	8.5E+02
69.075	4	6	8.0E+02
76.254	4	6	1.38E+03
76.359	6	8	1.47E+03
99.275	2	4	1.0E+03
100.4	4	6	1.2E+03
114.46	4	6	2.5E+03
114.74	6	8	2.7E+03
Ni XIX			
9.140	1	3	3.1E+04
9.153	1	3	5.2E+03
9.977	1	3	1.1E+05
10.110	1	3	9.4E+04
10.283	1	3	4.7E+03
10.433	1	3	5.1E+03
11.539	1	3	4.8E+04
11.599	1	3	6.3E+03
12.435	1	3	3.66E+05
12.656	1	3	1.0E+05
13.779	1	3	1.23E+04
14.043	1	3	1.31E+04
40.7	3	3	6.4E+03
40.7	3	1	8.4E+03
41.132	7	9	9.4E+03

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
Ni XXI			
11.13	3	3	1.7E+04
11.23	5	3	1.7E+04
11.239	5	7	5.7E+04
11.28	3	1	2.2E+05
11.318	5	7	2.8E+05
11.48	3	1	1.1E+05
11.48	1	3	4.0E+05
11.517	5	7	1.4E+05
11.539	5	7	1.2E+05
11.67	1	3	8.0E+04
11.72	3	3	2.3E+04
12.454	5	3	3.3E+04
12.472	3	3	1.8E+04
12.502	5	5	2.8E+04
Ni XXII			
72.52	4	2	2.84E+02
84.06	6	4	1.2E+03
84.24	4	2	5.6E+02
85.86	4	2	4.9E+02
88.00	4	2	1.2E+03
95.95	2	2	4.4E+02
98.16	4	4	5.2E+02
98.58	4	4	2.45E+02
100.60	6	6	3.9E+02
101.31	6	4	4.83E+02
103.31	4	2	2.66E+02
106.04	4	4	2.36E+02
106.16	4	2	5.1E+02
124.31	2	2	3.7E+02
126.32	4	4	3.3E+02
Ni XXIII			
87.66	3	3	2.8E+02
88.11	5	3	8.3E+02
90.49	3	3	1.77E+02
90.96	5	3	2.5E+02
91.83	5	3	7.5E+02
92.32	3	1	4.39E+02
100.42	1	3	2.1E+02
102.08	5	5	5.3E+02
103.23	3	3	2.4E+02
103.67	5	5	1.78E+02
104.70	3	1	2.94E+02
106.02	5	5	2.87E+02
108.27	7	5	3.32E+02
111.23	3	1	2.26E+02
111.78	5	3	2.19E+02
111.86	1	3	1.7E+02
112.55	3	1	1.0E+03
128.87	5	5	4.02E+02
133.54	3	3	1.86E+02
137.55	3	1	2.53E+02
Ni XXIV			
101.13	6	4	1.63E+02
102.11	4	4	5.4E+02
103.43	2	4	1.3E+02
103.53	4	2	4.17E+02
104.64	2	2	4.7E+02
106.68	4	2	3.67E+02
113.14	4	4	1.65E+02
118.52	2	4	1.5E+02
122.72	6	4	2.17E+02
134.73	6	6	1.44E+02
135.47	4	4	8.0E+01
137.01	4	4	2.6E+02
138.80	4	6	7.2E+01
153.47	2	2	1.27E+02
159.69	2	4	8.9E+01
Ni XXV			
9.30	3	1	9.3E+04
9.31	5	7	8.2E+04
9.32	3	5	7.8E+04
9.34	1	3	1.1E+05
9.42	3	1	9.0E+04
9.49	3	5	8.9E+04
9.60	1	3	1.8E+05
9.63	3	5	2.4E+05
9.64	3	3	1.3E+05
9.71	3	1	2.3E+05
9.71	3	3	1.8E+05
9.74	5	7	3.0E+05
9.75	3	5	1.3E+05
9.76	1	3	3.03E+05
9.76	5	3	7.5E+04
9.78	5	7	2.9E+05
9.86	5	7	4.8E+05
9.87	3	5	2.03E+05
9.92	5	5	1.3E+05
9.94	5	7	1.29E+05
9.97	3	5	2.5E+05
10.08	1	3	2.80E+05
Ni XXVI			
1.5930	4	2	3.4E+06
1.5935	2	2	4.0E+06
1.5973	4	4	8.1E+06
1.5977	2	4	4.4E+06
1.5982	2	2	7.3E+06
1.5996	2	2	2.7E+06
1.6005	4	6	2.7E+06
1.6036	4	2	2.1E+06
9.390	2	4	2.59E+05
9.535	4	6	2.96E+05
Ni XXVII			
1.2534	1	3	3.35E+05
1.2824	1	3	6.38E+05
1.3500	1	3	1.63E+06
1.3516	1	3	2.4E+05
1.531	3	3	2.0E+05
1.534	3	1	6.9E+06
1.537	5	5	2.3E+06
1.537	1	3	3.7E+06
1.538	3	5	3.9E+06
1.539	1	3	2.6E+06
1.539	3	5	2.6E+06
1.540	3	3	1.7E+06
1.541	3	5	5.5E+06
1.542	3	3	3.6E+06
1.542	5	5	3.5E+06
1.544	5	3	3.2E+06
1.546	3	5	1.6E+06
1.547	3	3	2.1E+05
1.549	1	3	2.0E+05
1.551	3	1	8.2E+05
1.558	3	1	6.5E+05
1.5883	1	3	6.02E+06
1.5963	1	3	7.70E+05
Nitrogen			
N I			
1163.88	6	6	7.52E-01
1164.00	4	6	1.27E-02
1164.21	6	4	5.17E-02
1164.32	4	4	6.94E-01
1167.45	6	8	1.29E+00
1168.42	6	6	4.24E-02
1168.54	4	6	1.24E+00
1176.51	6	4	9.22E-01
1176.63	4	4	1.02E-01
1177.69	4	2	1.02E+00
1199.55	4	6	4.01E+00
1200.22	4	4	3.99E+00
1200.71	4	2	3.98E+00
1310.54	4	6	8.42E-01
1316.29	4	6	1.42E-02
1492.63	6	4	3.13E+00
1492.82	4	4	3.51E-01
1494.68	4	2	3.72E+00
3822.03	2	2	3.70E-02
3830.43	4	4	4.67E-02
3834.22	4	2	1.89E-02
4099.94	2	4	3.48E-02
4109.95	4	6	3.90E-02
4113.97	4	4	6.62E-03
4137.64	2	4	2.80E-03
4143.43	4	4	6.09E-03
4151.48	6	4	1.01E-02
4249.87	4	2	2.59E-02
4264.00	6	4	2.26E-02
4356.29	6	8	5.10E-02
4385.54	2	2	8.84E-03
4392.41	4	2	1.76E-02
4435.43	2	4	7.51E-03
4442.45	4	4	3.81E-02
4669.89	4	4	7.49E-03
4914.94	2	2	8.08E-03
4935.12	4	2	1.76E-02
5199.84	2	2	1.87E-02
5201.61	2	4	1.87E-02
5281.20	6	6	2.45E-03
5344.05	6	6	6.10E-04
5356.62	4	6	1.41E-03

λ	Weights		A
Å	g_i	g_k	$10^8\ s^{-1}$
5367.01	4	4	1.07E-03
5372.61	2	4	8.34E-04
5378.27	2	2	1.66E-03
6606.18	4	6	8.87E-04
6622.54	6	6	7.93E-03
6626.99	2	4	2.20E-03
6636.94	4	4	1.40E-02
6644.96	8	6	3.49E-02
6646.50	2	2	2.18E-02
6653.46	6	4	2.74E-02
6656.51	4	2	2.17E-02
6926.67	4	6	7.75E-03
6945.18	6	6	1.83E-02
6951.60	2	4	1.03E-02
6960.50	4	4	4.67E-03
6973.07	2	2	3.83E-03
6979.18	6	4	9.83E-03
6982.03	4	2	2.04E-02
7423.64	2	4	5.95E-02
7442.30	4	4	1.24E-01
7468.31	6	4	1.93E-01
7898.98	6	4	2.82E-01
7899.28	4	4	3.28E-02
7915.42	4	2	3.13E-01
8184.86	4	6	8.58E-02
8188.01	2	4	1.27E-01
8200.36	2	2	4.95E-02
8210.72	4	4	4.84E-02
8216.34	6	6	2.23E-01
8223.13	4	2	2.64E-01
8242.39	6	4	1.36E-01
8567.74	2	4	4.92E-02
8594.00	2	2	2.09E-01
8629.24	4	4	2.66E-01
8655.88	4	2	1.05E-01
8680.28	6	8	2.46E-01
8683.40	4	6	1.80E-01
8686.15	2	4	1.09E-01
8703.25	2	2	2.10E-01
8711.70	4	4	1.28E-01
8718.84	6	6	6.75E-02
8728.90	4	2	3.76E-02
8747.37	6	4	1.04E-02
9028.92	2	2	3.02E-01
9045.88	6	8	2.80E-01
9049.49	6	6	1.88E-02
9049.89	4	6	2.60E-01
9060.48	2	4	2.95E-01
9187.45	6	6	2.44E-01
9187.86	4	6	1.76E-02
9207.59	6	4	2.70E-02
9208.00	4	4	2.33E-01
9386.81	2	4	2.24E-01
9392.79	4	6	2.63E-01
9460.68	4	4	3.98E-02
9776.90	2	4	1.18E-02
9786.78	4	6	1.13E-02
9788.29	2	2	2.99E-02
9798.56	4	4	2.75E-02
9810.01	4	2	5.30E-02
9814.02	6	8	6.56E-03
9822.75	6	6	4.95E-02
9834.61	6	4	4.50E-02
9863.33	8	8	9.62E-02
9872.15	8	6	2.97E-02
9883.38	2	2	2.93E-02
9905.52	4	2	3.11E-03
9909.22	2	4	7.58E-03
9931.47	4	4	3.64E-02
9947.07	6	8	1.08E-02
9965.75	4	6	7.60E-03
9968.51	6	4	4.50E-03
9980.42	4	6	8.10E-03
9997.73	8	8	9.20E-03

N II

λ	Weights		A
Å	g_i	g_k	$10^8\ s^{-1}$
474.891	5	5	9.66E+00
475.647	1	3	1.17E+01
475.698	3	5	1.58E+01
475.757	3	3	8.75E+00
475.803	5	7	2.10E+01
475.884	5	5	5.25E+00
508.697	5	5	1.91E+00
510.758	5	7	1.87E+01
513.849	5	5	1.24E+01
529.355	1	3	7.23E+00
529.413	3	1	2.43E+01
529.491	3	3	6.75E+00
529.637	3	5	4.92E+00
529.722	5	3	1.03E+01
529.867	5	5	1.94E+01
533.511	1	3	2.39E+01
533.581	3	5	3.20E+01
533.650	3	3	1.66E+01
533.729	5	7	4.13E+01
533.815	5	5	9.19E+00
547.818	5	3	2.16E+00
559.762	1	3	1.14E+01
574.650	5	7	3.60E+01
582.156	5	5	2.85E+01
635.197	1	3	2.33E+01
644.634	1	3	1.21E+01
644.837	3	3	3.64E+01
645.178	5	3	6.07E+01
660.286	5	3	3.69E+01
671.016	3	5	2.47E+00
671.386	5	5	7.40E+00
671.411	1	3	3.04E+00
671.630	3	3	2.27E+00
671.773	3	1	9.85E+00
672.001	5	3	3.87E+00
745.841	1	3	1.25E+01
746.984	5	3	3.85E+01
748.369	5	3	3.83E+00
775.965	5	5	3.08E+01
915.612	1	3	4.38E+00
915.962	3	1	1.32E+01
1083.99	1	3	2.18E+00
1085.55	5	5	9.47E-01
1085.70	5	7	3.87E+00
3408.13	3	1	2.19E-01
3437.14	3	1	2.07E+00
3593.60	3	5	1.21E-01
3609.10	3	3	1.41E-01
3615.86	3	1	1.53E-01
3829.80	3	5	2.42E-01
3838.37	5	5	6.98E-01
3842.19	1	3	3.06E-01
3847.40	3	3	2.22E-01
3855.10	3	1	8.82E-01
3856.06	5	3	3.71E-01
3919.00	3	3	6.76E-01
3955.85	3	5	1.31E-01
3995.00	3	5	1.35E+00
4114.33	3	3	1.42E-03
4124.08	3	5	3.20E-01
4133.67	5	5	5.30E-01
4145.77	7	5	7.36E-01
4374.99	3	5	5.55E-03
4447.03	3	5	1.14E+00
4459.94	3	1	1.12E-01
4465.53	3	3	2.36E-02
4477.68	5	3	8.85E-02
4488.09	5	5	1.30E-02
4507.56	7	5	1.00E-01
4564.76	3	5	1.41E-02
4601.48	3	5	2.35E-01
4607.15	1	3	3.26E-01
4613.87	3	3	2.26E-01
4621.39	3	1	9.55E-01
4630.54	5	5	7.72E-01
4643.09	5	3	4.51E-01
4654.53	3	5	2.43E-02
4667.21	3	3	2.99E-02
4674.91	3	1	1.05E-01
4694.27	1	3	1.23E-01
4695.90	3	5	1.29E-01
4697.64	3	3	3.06E-02
4698.55	3	1	3.67E-01
4700.03	5	7	1.05E-01
4702.50	5	5	9.15E-02
4704.25	5	3	2.13E-01
4706.40	7	9	6.09E-02
4709.58	7	7	1.82E-01
4712.07	7	5	1.46E-01
4718.38	9	9	3.02E-01
4721.58	9	7	7.75E-02
4774.24	3	5	3.24E-02
4779.72	3	3	2.52E-01
4781.19	5	7	2.05E-02
4788.14	5	5	2.52E-01
4793.65	5	3	7.77E-02
4803.29	7	7	3.18E-01
4810.30	7	5	4.75E-02
4860.17	3	5	1.61E-02
4987.38	3	1	7.48E-01
4991.24	3	5	3.54E-01

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$	λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$	λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
4994.36	5	7	2.62E-01	5551.92	7	7	2.00E-01	2978.84	2	4	1.66E-01
4994.37	3	3	7.60E-01	5552.68	5	3	1.50E-01	2983.64	4	4	8.24E-01
4997.22	3	3	1.96E-01	5565.26	7	5	3.97E-02	3342.76	2	2	3.80E-01
5001.13	3	5	9.76E-01	5666.63	3	5	3.74E-01	3353.98	2	4	7.66E-01
5001.47	5	7	1.05E+00	5676.02	1	3	2.96E-01	3354.32	4	6	5.51E-01
5002.70	1	3	8.45E-02	5679.56	5	7	5.25E-01	3355.46	4	2	7.51E-01
5005.15	7	9	1.16E+00	5686.21	3	3	1.94E-01	3358.78	2	2	3.05E-01
5005.30	5	5	6.51E-02	5710.77	5	5	1.24E-01	3360.98	4	4	2.44E-01
5007.33	3	5	7.89E-01	5730.66	5	3	1.34E-02	3365.80	4	2	1.52E+00
5010.62	3	3	2.19E-01	5747.30	3	5	3.40E-02	3367.36	6	6	1.27E+00
5011.31	5	3	5.84E-01	5767.45	3	3	2.44E-02	3374.07	6	4	8.13E-01
5012.04	7	7	5.19E-01	5893.15	5	7	2.88E-01	3745.95	2	4	1.90E-01
5016.38	5	5	1.62E-01	5897.25	3	5	2.16E-01	3752.63	2	2	6.67E-02
5023.05	7	5	3.61E-01	5899.83	1	3	1.60E-01	3754.69	4	4	3.78E-01
5025.66	7	7	1.07E-01	5927.81	1	3	3.22E-01	3762.60	4	4	4.24E-02
5040.71	7	5	3.78E-03	5931.78	3	5	4.27E-01	3771.03	6	4	5.59E-01
5045.10	5	3	3.42E-01	5940.24	3	3	2.26E-01	3771.36	6	4	8.28E-02
5073.59	3	3	2.59E-02	5941.65	5	7	5.54E-01	3792.97	8	6	1.03E-01
5168.05	3	5	3.06E-01	5952.39	5	5	1.27E-01	3934.50	2	4	7.49E-01
5170.16	3	3	6.54E-01	5960.91	5	3	1.34E-02	3938.51	4	6	8.96E-01
5171.27	3	1	8.71E-01	6065.00	3	5	2.21E-03	3942.88	4	4	1.49E-01
5171.47	5	7	5.81E-01	6284.32	5	3	7.74E-02	4097.36	2	4	8.70E-01
5172.34	3	5	6.01E-01	6379.62	3	3	6.11E-02	4103.39	2	2	8.67E-01
5172.97	1	3	5.01E-01	6482.05	3	3	3.01E-01	4195.74	2	4	9.37E-01
5173.39	5	7	7.36E-01	6610.56	5	7	6.34E-01	4200.07	4	6	1.12E+00
5174.46	5	5	5.07E-01	6857.03	5	3	2.53E-01	4215.77	4	4	1.85E-01
5175.89	7	9	8.93E-01	6869.58	5	5	2.51E-01	4318.78	2	4	5.40E-02
5176.57	5	3	2.17E-01	6887.83	5	7	2.49E-01	4321.22	2	2	1.08E-01
5177.06	3	3	5.00E-01	7762.24	5	5	8.74E-02	4321.39	4	6	5.03E-02
5179.34	7	9	8.67E-01	8438.74	1	3	2.24E-01	4325.43	4	4	8.60E-02
5179.52	9	11	1.07E+00	8831.75	1	3	8.42E-03	4327.69	6	8	3.06E-02
5180.36	5	5	4.28E-01	8855.30	3	3	2.51E-02	4327.88	4	2	1.07E-01
5183.20	7	7	2.88E-01	8893.29	5	3	4.12E-02	4332.95	6	6	1.23E-01
5184.96	7	7	3.20E-01					4337.01	6	4	7.47E-02
5185.09	5	3	7.11E-02	**N III**				4345.81	8	8	1.82E-01
5186.21	7	5	5.76E-02	374.198	2	4	9.89E+01	4351.11	8	6	4.01E-02
5190.38	9	9	1.77E-01	451.871	2	2	1.03E+01	4510.88	2	4	2.84E-01
5191.96	7	5	4.25E-02	452.227	4	2	2.05E+01	4510.96	4	6	4.77E-01
5199.50	9	7	1.51E-02	684.998	2	4	9.63E+00	4514.85	6	8	6.80E-01
5313.42	3	3	1.41E-01	685.515	2	2	3.83E+01	4518.14	2	2	5.65E-01
5320.20	5	3	4.20E-01	685.817	4	4	4.54E+01	4523.56	4	4	3.61E-01
5320.96	3	5	2.52E-01	686.336	4	2	1.95E+01	4530.86	4	2	1.12E-01
5327.76	5	5	4.65E-02	763.334	2	2	9.58E+00	4534.58	6	6	2.01E-01
5338.73	5	7	1.85E-01	764.351	4	2	1.85E+01	4547.30	6	4	3.33E-02
5340.21	7	5	2.59E-01	771.545	2	4	8.19E+00	4634.13	2	4	6.36E-01
5351.23	7	7	3.67E-01	771.901	4	4	1.64E+01	4640.64	4	6	7.60E-01
5383.72	3	5	3.31E-03	772.384	6	4	2.45E+01	4641.85	4	4	1.26E-01
5452.07	1	3	8.89E-02	772.889	6	4	2.09E+01	4858.70	2	4	4.35E-01
5454.22	3	1	3.34E-01	772.955	4	2	2.34E+01	4858.98	4	6	4.66E-01
5462.58	3	3	1.00E-01	979.832	4	4	8.84E+00	4861.27	6	8	5.32E-01
5478.09	3	5	4.75E-02	979.905	6	6	9.21E+00	4867.12	4	4	1.73E-01
5480.05	5	3	1.30E-01	989.799	2	4	4.18E+00	4867.17	8	10	6.18E-01
5495.65	5	5	2.40E-01	991.511	4	4	8.17E-01	4873.60	6	6	1.50E-01
5526.23	3	5	2.13E-01	991.577	4	6	4.97E+00	4881.78	6	4	1.22E-02
5530.24	5	7	4.04E-01	1747.85	2	4	1.28E+00	4884.14	8	8	8.71E-02
5535.35	7	9	6.04E-01	1751.22	4	4	2.48E-01	4896.58	8	6	5.86E-03
5535.38	3	3	4.53E-01	1751.66	4	6	1.51E+00	5260.86	2	2	2.80E-02
5540.06	3	1	6.03E-01	2972.55	2	2	6.67E-01	5270.57	2	4	6.95E-02
5543.47	5	5	3.51E-01	2977.33	4	2	3.32E-01	5272.68	4	2	1.39E-01

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
5282.43	4	4	2.21E-02
5297.75	4	6	4.93E-02
5298.95	6	4	7.38E-02
5314.36	6	6	1.14E-01
5320.87	6	8	5.68E-01
5327.19	4	6	5.29E-01
5352.46	6	6	3.72E-02
6365.84	2	2	2.18E-01
6394.75	2	4	2.15E-01
6445.34	2	4	8.89E-02
6450.79	2	2	1.77E-01
6454.08	4	6	1.49E-01
6463.09	4	4	1.13E-01
6467.02	6	8	2.11E-01
6468.57	4	2	3.52E-02
6478.76	6	6	6.31E-02
6487.84	6	4	1.05E-02
7371.51	4	4	3.53E-02
7404.54	6	6	3.61E-02
8307.51	2	4	1.65E-02
8344.95	2	2	6.52E-02
8386.39	4	4	8.03E-02
8424.56	4	2	3.17E-02

N IV

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
247.205	1	3	1.19E+02
*283.52	9	15	3.05E+02
*322.64	9	3	8.99E+01
335.047	3	5	1.845E+02
387.356	3	1	2.55E+01
765.147	1	3	2.320E+01
*923.16	9	9	1.759E+01
955.334	3	1	2.919E+01
1718.55	3	5	2.321E+00
2649.88	3	3	1.07E+00
3052.20	1	3	1.33E-01
3059.60	3	3	3.95E-01
3075.19	5	3	6.48E-01
3443.61	3	5	3.46E-01
3445.22	1	3	4.60E-01
3454.65	3	3	3.42E-01
3461.36	3	1	1.36E+00
3463.36	5	5	1.02E+00
3474.53	5	3	5.61E-01
3478.72	3	5	1.06E+00
*3480.8	3	9	1.06E+00
3483.00	3	3	1.06E+00
3484.93	3	1	1.06E+00
3689.94	3	1	9.10E-02
3694.14	3	3	2.27E-02
3707.39	5	3	6.73E-02
3714.43	5	5	1.34E-02
3735.43	7	5	7.37E-02
3747.54	3	5	9.92E-01
4057.76	3	5	6.62E-01
4740.26	3	5	1.53E-02
4747.96	3	3	7.60E-02
4752.49	5	7	1.13E-02
4762.09	5	5	6.99E-02
4769.86	5	3	2.50E-02
4786.92	7	7	8.79E-02
4796.66	7	5	1.53E-02
5200.41	3	5	2.67E-01
5204.28	5	7	3.55E-01
5205.15	1	3	1.97E-01
5226.70	3	3	1.46E-01
5245.60	5	5	8.66E-02
5272.35	5	3	9.48E-03
5288.25	5	3	3.22E-02
5736.93	3	5	1.84E-01
5776.31	1	3	1.85E-02
5784.76	3	1	5.51E-02
5795.09	3	3	1.37E-02
5812.31	3	5	1.36E-02
5826.43	5	3	2.25E-02
5843.84	5	5	4.01E-02
6380.75	1	3	1.42E-01
7103.24	1	3	6.28E-02
7109.35	3	5	8.46E-02
7111.28	3	3	4.70E-02
*7116.8	9	15	1.12E-01
7122.98	5	7	1.12E-01
7127.25	5	5	2.80E-02
7127.25	5	3	3.11E-03
9165.07	3	5	4.23E-02
9182.16	5	7	4.45E-02
9222.99	7	9	4.95E-02
9247.04	5	5	7.66E-03
9311.55	7	7	5.36E-03

N V

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
*209.29	2	6	1.21E+02
*247.66	6	10	4.26E+02
1238.82	2	4	3.40E+00
1242.80	2	2	3.37E+00
4603.74	2	4	4.14E-01
4619.97	2	2	4.10E-01

N VI

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
24.8980	1	3	5.158E+03
28.7870	1	3	1.809E+04
*161.220	3	9	2.859E+02
173.275	1	3	2.697E+02
*173.93	9	15	8.756E+02
185.192	3	5	8.205E+02
*1901	3	9	6.780E-01
2896.4	1	3	2.079E-01
*6991.1	3	9	8.384E-02
9622.0	1	3	3.276E-02

Oxygen

O I

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
791.973	5	5	4.94E+00
792.938	1	3	2.19E+00
792.967	3	5	1.64E+00
877.798	5	3	2.85E+00
877.879	5	5	5.12E+00
922.008	5	7	1.23E+00
935.193	5	5	1.33E+00
1028.16	1	3	4.22E-01
1152.15	5	5	5.28E+00
1217.65	1	3	2.06E+00
1302.17	5	3	3.41E+00
1304.86	3	3	2.03E+00
1306.03	1	3	6.76E-01
3823.41	7	7	6.63E-03
3823.87	5	3	1.87E-03
3824.35	5	5	5.19E-03
3825.02	3	3	5.59E-03
3825.19	5	7	8.31E-04
3855.01	5	5	1.63E-02
3947.29	5	7	4.91E-03
3947.48	5	5	4.88E-03
3947.59	5	3	4.87E-03
3951.93	3	1	3.10E-03
3952.98	5	3	1.29E-03
3953.00	1	3	1.03E-03
3954.52	3	5	7.73E-04
3954.61	5	5	2.32E-03
3997.95	5	3	2.41E-02
4217.09	3	1	5.44E-03
4222.77	5	3	2.26E-03
4222.82	1	3	1.81E-03
4233.27	5	5	4.04E-03
4368.19	3	1	7.56E-03
4368.24	3	5	7.59E-03
4967.38	3	5	4.43E-03
4967.88	5	7	8.44E-03
4968.79	7	9	1.27E-02
5019.29	5	5	7.13E-03
5020.22	7	5	9.98E-03
5329.11	3	5	9.48E-03
5329.69	5	7	1.81E-02
5330.74	7	9	2.71E-02
5435.18	3	5	7.74E-03
5435.77	5	5	1.29E-02
5436.86	7	5	1.80E-02
5512.60	3	5	2.69E-03
5512.77	5	7	3.58E-03
5554.83	3	3	5.83E-03
5555.00	5	3	9.71E-03
5958.39	3	5	6.80E-03
5958.58	5	7	9.06E-03
6046.23	3	3	1.05E-02
6046.44	5	3	1.75E-02
6046.49	1	3	3.50E-03
6155.99	3	5	2.67E-02
6156.78	5	7	5.08E-02
6158.19	7	9	7.62E-02
6324.84	7	5	3.76E-05
6453.60	3	5	1.65E-02
6454.44	5	5	2.75E-02
6455.98	7	5	3.85E-02
6726.28	5	5	1.18E-05
6726.54	5	3	6.44E-06
7001.92	3	5	2.65E-02
7002.23	5	7	3.53E-02

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
7254.15	3	3	2.24E-02
7254.45	5	3	3.73E-02
7254.53	1	3	7.45E-03
7771.94	5	7	3.69E-01
7774.17	5	5	3.69E-01
7775.39	5	3	3.69E-01
7981.94	3	3	2.33E-04
7982.40	1	3	3.09E-04
7986.98	3	5	4.19E-04
7987.33	5	5	1.41E-04
7995.07	5	7	5.63E-04
8221.82	7	7	2.89E-01
8227.65	5	3	8.13E-02
8230.00	5	5	2.26E-01
8233.00	3	3	2.43E-01
8235.35	3	5	4.86E-02
8446.25	3	1	3.22E-01
8446.36	3	5	3.22E-01
8446.76	3	3	3.22E-01
8820.42	5	7	2.93E-01
9260.81	3	1	4.46E-01
9260.85	3	3	3.34E-01
9260.94	3	5	1.56E-01
9262.58	5	3	1.11E-01
9262.67	5	5	2.60E-01
9262.78	5	7	2.97E-01
9265.83	7	5	2.97E-02
9265.93	7	7	1.48E-01
9266.01	7	9	4.45E-01
9482.89	5	3	2.34E-01
9622.11	5	3	5.22E-04
9622.16	3	3	1.57E-03
9625.26	7	5	3.25E-04
9625.30	7	7	1.85E-03
9694.66	5	7	4.54E-04
9694.91	5	5	4.54E-04
9695.06	5	3	4.54E-04
O II			
429.918	4	2	4.25E+01
430.041	4	4	4.13E+01
430.176	4	6	4.36E+01
483.760	4	2	2.05E+01
483.980	6	4	1.80E+01
484.027	4	4	3.22E+00
485.087	6	8	2.60E+01
485.470	6	6	1.20E+00
485.518	4	6	1.93E+01
2290.85	2	4	7.41E-02
2293.30	2	2	3.25E-01
2300.33	4	4	4.17E-01
2302.81	4	2	1.67E-01
2365.14	4	2	1.52E-01
2375.72	6	4	1.35E-01
2406.38	6	4	1.85E-01
2407.48	4	4	2.25E-01
2411.60	4	2	2.05E-01
2411.64	2	2	1.10E-01
2415.13	4	2	2.20E-01

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
2418.46	6	6	2.30E-01
2425.57	6	6	1.77E-01
2433.54	2	4	4.21E-01
2436.06	4	4	1.69E-01
2444.25	4	4	7.56E-02
2445.53	4	6	4.98E-01
2517.96	4	6	7.72E-02
2523.21	2	2	9.63E-02
2526.87	4	4	1.20E-01
2530.28	6	8	8.16E-02
2571.46	2	4	1.15E-01
2575.28	4	6	1.37E-01
3134.73	8	6	1.23E+00
3273.43	8	6	9.99E-01
3377.15	2	2	1.27E+00
3390.21	2	4	1.22E+00
3407.28	6	6	1.02E+00
3712.74	2	4	2.84E-01
3727.32	4	4	5.81E-01
3749.48	6	4	9.31E-01
3833.07	6	8	1.02E-02
3842.81	2	4	7.45E-02
3843.58	4	6	3.55E-02
3847.89	2	2	1.95E-01
3850.80	4	6	6.00E-03
3851.03	4	4	1.59E-01
3851.47	8	8	2.72E-02
3856.13	4	2	2.28E-01
3857.16	6	6	6.59E-02
3863.50	6	8	6.49E-02
3864.13	2	2	9.12E-02
3864.43	6	6	2.15E-01
3864.67	6	4	1.80E-01
3874.09	2	4	3.26E-02
3875.80	8	6	3.38E-02
3882.19	8	8	5.50E-01
3882.45	4	4	8.94E-02
3883.14	8	6	1.13E-01
3893.52	4	6	1.89E-02
3907.45	6	6	8.64E-02
3911.96	6	4	1.09E+00
3912.12	4	4	1.41E-01
3919.27	4	2	1.22E+00
3945.04	2	4	2.05E-01
3954.36	2	2	8.57E-01
3973.26	4	4	1.04E+00
3982.71	4	2	4.27E-01
4069.62	2	4	1.52E+00
4069.88	4	6	1.53E+00
4072.15	6	8	1.98E+00
4075.86	8	10	2.11E+00
4078.84	4	4	5.52E-01
4084.65	6	8	7.28E-02
4085.11	6	6	4.55E-01
4092.93	8	8	2.65E-01
4094.14	6	4	4.70E-02
4096.53	4	6	1.73E-01
4097.22	2	4	3.62E-01
4103.00	2	2	5.09E-01

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
4104.72	4	6	3.14E-01
4104.99	4	4	9.14E-01
4106.02	8	6	1.70E-02
4109.84	6	6	1.21E-02
4110.19	6	4	2.54E-01
4110.79	4	2	7.70E-01
4112.02	6	6	1.81E-01
4113.83	8	6	2.41E-01
4119.22	6	8	1.33E+00
4120.28	6	6	2.15E-01
4120.55	6	4	2.60E-01
4121.46	2	2	5.60E-01
4129.32	4	2	1.79E-01
4132.80	2	4	9.13E-01
4140.70	4	4	4.09E-02
4153.30	4	6	7.91E-01
4156.53	6	4	2.11E-01
4169.22	6	6	2.71E-01
4185.44	6	8	1.91E+00
4189.58	8	8	7.06E-02
4189.79	8	10	1.98E+00
4192.51	6	4	3.21E-01
4196.27	4	4	3.56E-02
4196.70	4	2	3.56E-01
4317.14	2	4	3.70E-01
4319.63	4	6	2.55E-01
4319.87	2	2	5.62E-01
4325.76	2	2	1.47E-01
4327.46	6	6	6.76E-01
4327.85	6	4	7.24E-02
4328.59	4	2	1.12E+00
4331.47	4	6	4.82E-02
4331.86	4	4	6.50E-01
4336.86	4	4	1.57E-01
4345.56	4	2	8.31E-01
4347.22	6	4	1.19E-01
4347.41	4	4	9.32E-01
4349.43	6	6	6.91E-01
4351.26	6	6	9.89E-01
4351.46	4	6	5.82E-02
4359.40	4	6	1.44E-02
4366.89	6	4	3.98E-01
4369.27	4	4	3.57E-01
4395.93	6	6	3.91E-01
4405.98	6	4	4.30E-02
4414.90	4	6	8.34E-01
4416.97	2	4	7.13E-01
4443.01	6	6	5.05E-01
4443.52	6	8	1.89E-02
4447.68	8	6	2.52E-02
4448.19	8	8	5.10E-01
4452.38	4	4	1.37E-01
4466.24	2	4	9.00E-01
4467.46	2	2	9.00E-01
4563.18	4	4	7.18E-03
4590.97	6	8	8.85E-01
4595.96	6	6	4.87E-02
4596.18	4	6	8.34E-01
4638.86	2	4	3.71E-01

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
4641.81	4	6	5.96E-01
4649.13	6	8	7.81E-01
4650.84	2	2	6.86E-01
4661.63	4	4	4.10E-01
4673.73	4	2	1.35E-01
4676.23	6	6	2.05E-01
4690.89	2	4	1.86E-01
4691.42	2	2	7.43E-01
4696.35	6	4	3.25E-02
4698.44	6	6	6.59E-02
4699.01	6	8	9.88E-01
4699.22	4	6	9.36E-01
4701.18	4	4	9.23E-01
4701.71	4	2	3.69E-01
4703.16	4	6	9.20E-01
4705.35	6	8	1.10E+00
4710.01	4	6	2.98E-01
4741.70	6	6	4.71E-02
4751.28	6	8	6.39E-02
4752.69	6	6	1.45E-02
4844.92	4	6	1.02E-02
4856.39	4	6	5.58E-02
4856.76	4	4	1.00E-01
4860.97	2	4	4.70E-01
4864.88	4	2	8.07E-02
4871.52	4	6	5.60E-01
4872.02	4	4	9.34E-02
4890.86	4	2	4.80E-01
4906.83	4	4	4.54E-01
4924.53	4	6	5.43E-01
4941.07	2	4	5.87E-01
4943.01	4	6	7.78E-01
4955.71	4	4	1.82E-01
5159.94	2	2	3.29E-01
5175.90	4	2	1.49E-01
5190.50	2	4	1.26E-01
5206.65	4	4	3.58E-01
5583.22	2	4	2.17E-02
5611.07	2	2	2.14E-02
6627.37	4	4	1.73E-01
6641.03	2	2	9.88E-02
6666.66	4	2	6.78E-02
6677.87	2	4	3.37E-02
6717.75	2	2	1.33E-01
6721.39	4	2	1.81E-01
6810.48	6	8	1.64E-03
6844.10	4	6	2.97E-03
6846.80	8	8	3.17E-02
6869.48	6	6	5.35E-02
6884.88	4	4	6.12E-02
6895.10	10	8	2.72E-01
6906.44	8	6	2.48E-01
6907.87	4	2	3.03E-01
6910.56	6	4	2.43E-01
O III			
263.694	1	3	3.32E+01
263.727	3	5	4.48E+01
263.773	3	3	2.49E+01
263.817	5	7	5.97E+01
263.861	5	5	1.49E+01
277.386	5	7	9.43E+01
279.788	5	5	4.25E+01
295.942	1	3	5.56E+01
303.413	1	3	4.29E+01
303.461	3	1	1.29E+02
303.517	3	3	3.21E+01
303.622	3	5	3.21E+01
303.695	5	3	5.34E+01
303.800	5	5	9.61E+01
305.596	1	3	1.20E+02
305.656	3	5	1.62E+02
305.702	3	3	9.01E+01
305.767	5	7	2.16E+02
305.836	5	5	5.40E+01
320.978	5	7	2.17E+02
328.448	5	5	1.04E+02
345.312	1	3	1.35E+02
374.073	5	5	2.85E+01
395.557	5	3	2.80E+01
507.388	1	3	1.61E+01
507.680	3	3	4.82E+01
508.178	5	3	8.04E+01
525.794	5	3	9.60E+01
597.814	1	3	1.49E+01
599.590	5	5	5.41E+01
702.337	1	3	6.06E+00
702.838	3	1	1.83E+01
832.929	1	3	3.41E+00
835.092	5	5	1.44E+00
835.289	5	7	5.99E+00
1679.03	3	5	6.57E-01
1686.73	3	3	6.48E-01
1760.41	3	5	8.38E-01
1764.46	5	5	2.50E+00
1766.63	1	3	1.11E+00
1772.28	3	1	3.29E+00
1772.97	5	3	1.37E+00
2390.43	3	3	1.62E+00
2454.97	3	1	3.43E+00
2665.68	3	5	6.75E-01
2674.58	5	5	1.11E+00
2683.66	3	1	1.85E+00
2686.15	7	5	1.54E+00
2687.55	3	3	1.84E+00
2695.48	3	5	1.82E+00
2794.14	3	1	1.82E-01
2798.93	3	3	4.52E-02
2809.66	5	3	1.34E-01
2818.70	5	5	2.66E-02
2836.31	7	5	1.46E-01
2959.69	3	5	1.83E+00
2983.78	3	5	2.15E+00
2992.08	3	5	9.32E-02
2996.48	3	3	4.64E-01
2997.69	5	7	6.88E-02
3004.34	5	5	4.27E-01
3008.78	5	3	1.53E-01
3017.62	7	7	5.38E-01
3023.43	3	5	4.79E-01
3024.36	7	5	9.39E-02
3024.54	1	3	6.16E-01
3035.41	3	3	4.59E-01
3042.07	3	1	1.94E+00
3047.10	5	5	1.49E+00
3059.28	5	3	8.72E-01
3064.98	1	3	2.17E-01
3068.13	3	1	6.49E-01
3068.26	3	3	5.41E-02
3068.67	3	5	2.27E-01
3074.14	5	7	1.84E-01
3074.72	5	3	3.76E-01
3075.13	5	5	1.61E-01
3075.95	7	9	1.07E-01
3083.65	7	7	3.20E-01
3084.64	7	5	2.55E-01
3088.04	9	9	5.30E-01
3095.79	9	7	1.35E-01
3115.67	3	1	1.39E+00
3121.63	3	3	1.38E+00
3132.79	3	5	1.37E+00
3198.18	3	5	9.57E-02
3201.14	3	3	4.77E-01
3202.51	5	7	7.08E-02
3207.61	5	5	4.40E-01
3210.58	5	3	1.58E-01
3216.07	7	7	5.58E-01
3221.21	7	5	9.75E-02
3260.86	5	7	1.68E+00
3265.33	7	9	1.88E+00
3267.20	3	5	1.58E+00
3281.83	5	5	2.89E-01
3284.45	7	7	2.06E-01
3299.39	1	3	1.64E-01
3312.33	3	3	4.60E-01
3326.06	3	3	2.65E-01
3330.30	3	5	6.81E-01
3330.32	3	5	4.76E-01
3332.41	5	3	7.92E-01
3332.93	5	7	5.04E-01
3336.67	3	3	3.76E-01
3336.69	5	5	8.77E-02
3340.76	5	3	6.57E-01
3344.20	5	5	1.25E-01
3344.51	5	7	3.48E-01
3347.98	7	5	4.86E-01
3350.62	5	3	1.12E+00
3350.92	7	7	9.91E-01
3355.86	7	7	6.89E-01
3362.31	7	5	6.87E-01
3376.61	3	1	1.49E+00
3376.76	3	3	1.12E+00
3377.26	3	5	5.20E-01
3382.61	5	7	9.86E-01
3383.31	5	3	3.70E-01
3383.81	5	5	8.62E-01
3384.90	7	9	1.48E+00

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
3394.22	7	7	4.88E-01
3395.43	7	5	9.75E-02
3406.88	1	3	1.93E-01
3408.13	3	1	5.79E-01
3415.26	3	3	1.44E-01
3428.63	3	5	1.42E-01
3430.57	5	3	2.37E-01
3444.05	5	5	4.21E-01
3446.68	3	5	9.71E-01
3447.15	1	3	8.09E-01
3447.97	5	7	1.19E+00
3450.91	7	9	1.44E+00
3451.30	3	3	8.06E-01
3454.84	5	5	6.89E-01
3454.99	9	11	1.72E+00
3459.48	5	3	1.14E-01
3459.94	7	7	5.14E-01
3466.13	9	9	2.84E-01
3466.85	7	5	6.82E-02
3475.24	9	7	2.42E-02
3520.94	1	3	1.50E-01
3531.22	3	1	4.45E-01
3533.38	3	3	1.11E-01
3534.90	3	5	1.11E-01
3555.24	5	3	1.82E-01
3556.78	5	5	3.26E-01
3695.38	3	5	4.01E-01
3698.72	5	7	7.62E-01
3703.36	7	9	1.14E+00
3704.75	3	3	8.53E-01
3707.27	3	5	7.34E-01
3709.54	3	1	1.13E+00
3712.49	5	5	6.59E-01
3714.03	3	3	4.06E-01
3715.09	5	7	9.73E-01
3720.89	7	7	3.74E-01
3721.95	5	3	2.80E-01
3725.31	5	5	2.41E-01
3728.51	5	7	1.29E+00
3728.84	7	9	1.45E+00
3729.80	3	5	1.22E+00
3732.13	5	3	2.67E-02
3734.83	7	5	7.40E-02
3742.63	5	5	2.24E-01
3746.90	7	7	1.59E-01
3754.70	3	5	7.53E-01
3757.23	1	3	5.56E-01
3759.88	5	7	9.79E-01
3774.03	3	3	3.91E-01
3791.28	5	5	2.24E-01
3810.98	5	3	2.37E-02
3816.75	5	3	9.63E-02
3961.57	5	7	1.25E+00
4072.64	1	3	3.37E-01
4073.98	3	5	4.54E-01
4081.02	5	7	6.02E-01
4089.30	3	3	2.49E-01
4103.07	5	5	1.48E-01
4118.60	5	3	1.63E-02
4440.09	5	3	4.42E-01
4447.69	5	5	4.40E-01
4461.61	5	7	4.36E-01
4524.22	3	1	3.38E-01
4532.78	5	3	1.40E-01
4535.29	3	3	8.40E-02
4555.39	5	5	2.49E-01
4557.91	3	5	8.27E-02
5268.30	1	3	3.50E-01
5508.24	5	5	1.06E-01
5592.25	3	3	3.27E-01

O IV

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
238.360	2	4	2.96E+02
238.570	4	6	3.54E+02
238.579	4	4	5.90E+01
279.631	2	2	2.68E+01
279.933	4	2	5.34E+01
553.329	2	4	1.22E+01
554.076	2	2	4.86E+01
554.513	4	4	6.06E+01
555.263	4	2	2.41E+01
608.397	2	2	1.21E+01
609.829	4	2	2.40E+01
616.952	6	4	2.60E+01
617.005	4	4	2.89E+00
617.036	4	2	2.89E+01
624.619	2	4	1.07E+01
625.127	4	4	2.13E+01
625.853	6	4	3.19E+01
779.736	6	4	1.46E+00
779.820	4	4	1.31E+01
779.912	6	6	1.36E+01
779.997	4	6	9.70E-01
787.710	2	4	5.95E+00
790.112	4	4	1.18E+00
790.199	4	6	7.08E+00
921.296	2	4	2.21E+00
921.365	2	2	8.83E+00
923.367	4	4	1.10E+01
923.436	4	2	4.39E+00
1338.61	2	4	2.17E+00
1342.99	4	4	4.29E-01
1343.51	4	6	2.57E+00
2120.58	2	2	1.05E+00
2132.64	4	4	1.29E+00
2493.39	2	4	1.18E+00
2493.75	4	6	8.48E-01
2493.99	2	2	6.09E-01
2499.27	2	2	4.68E-01
2501.81	4	4	3.73E-01
2507.73	4	2	2.32E+00
2509.22	6	6	1.94E+00
2510.58	4	2	1.19E+00
2517.37	6	4	1.24E+00
2781.22	2	2	1.03E-01
2803.57	6	4	1.26E-01
2805.87	2	4	2.90E-01
2812.50	6	6	3.58E-02
2816.53	4	4	5.74E-01
2829.17	8	6	1.56E-01
2836.27	6	4	8.43E-01
2916.31	2	4	1.06E+00
2921.46	4	6	1.27E+00
2926.18	4	4	2.11E-01
3063.43	2	4	1.30E+00
3071.60	2	2	1.29E+00
3177.89	2	4	7.59E-02
3180.77	2	2	1.51E-01
3180.99	4	6	7.06E-02
3185.74	4	4	1.21E-01
3188.22	6	8	4.28E-02
3188.64	4	2	1.50E-01
3194.78	6	6	1.71E-01
3199.58	6	4	1.04E-01
3209.65	8	8	2.53E-01
3216.31	8	6	5.56E-02
3348.06	2	4	8.51E-01
3349.11	4	6	1.02E+00
3354.27	4	2	7.71E-01
3362.55	4	4	7.65E-01
3375.40	4	6	7.56E-01
3378.02	4	4	1.66E-01
3381.21	4	6	7.19E-01
3381.30	2	4	4.28E-01
3385.52	6	8	1.02E+00
3390.19	2	2	8.49E-01
3396.80	4	4	5.40E-01
3405.77	4	2	1.67E-01
3409.70	6	6	3.00E-01
3411.30	4	4	1.69E-01
3411.69	4	6	1.02E+00
3425.55	6	4	4.94E-02
3489.89	4	6	7.29E-01
3492.21	2	4	6.06E-01
3493.43	4	4	1.21E-01
3560.39	4	6	1.03E+00
3563.33	6	8	1.10E+00
3593.08	6	6	7.15E-02
3725.89	2	4	5.61E-01
3725.94	4	6	6.01E-01
3729.03	6	8	6.86E-01
3736.68	4	4	2.23E-01
3736.85	8	10	7.95E-01
3744.89	6	6	1.92E-01
3758.39	8	8	1.11E-01
3930.68	2	2	3.80E-02
3942.06	2	4	9.42E-02
3945.31	4	2	1.88E-01
3956.77	4	4	2.98E-02
3974.58	4	6	6.62E-02
3977.09	6	4	9.91E-02
3995.08	6	6	1.52E-01
4687.03	2	4	2.79E-01
4772.60	2	4	1.23E-01
4779.10	2	2	2.45E-01
4783.42	4	6	2.06E-01
4794.18	4	4	1.56E-01

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
4798.27	6	8	2.91E-01
4813.15	6	6	8.65E-02
5305.51	4	4	6.10E-02
5362.51	6	6	6.12E-02
6876.49	2	4	1.88E-02
6931.60	2	2	7.35E-02
7004.11	4	4	8.90E-02
7061.30	4	2	3.48E-02

O V

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
172.169	1	3	2.94E+02
*192.85	9	15	6.90E+02
*215.17	9	3	1.83E+02
220.353	3	5	4.292E+02
248.460	3	1	5.59E+01
629.732	1	3	2.872E+01
758.677	3	5	5.547E+00
759.442	1	3	7.373E+00
760.227	3	3	5.514E+00
760.446	5	5	1.652E+01
761.128	3	1	2.197E+01
762.004	5	3	9.125E+00
774.518	3	1	3.804E+01
1371.30	3	5	3.336E+00
2729.31	3	5	4.52E-01
2731.45	1	3	5.90E-01
2743.61	3	3	4.38E-01
2752.23	3	1	1.82E+00
2755.13	5	5	1.37E+00
2769.69	5	3	7.88E-01
2781.01	3	5	1.40E+00
*2784.0	3	9	1.40E+00
2786.99	3	3	1.39E+00
2789.85	3	1	1.38E+00
3058.68	3	5	1.39E+00
3144.66	3	5	8.86E-01
3219.24	3	1	1.54E-01
3222.29	1	3	1.16E-01
3227.54	3	3	3.38E-02
3239.21	3	3	3.28E-01
3248.28	5	3	1.18E-01
3263.54	5	5	1.86E-02
3275.64	5	3	4.76E-01
3297.62	7	5	1.30E-01
3690.17	3	5	1.97E-02
3698.36	3	3	1.03E-01
3702.72	5	7	1.41E-02
3717.31	5	5	9.63E-02
3725.63	5	3	2.91E-02
3746.64	7	7	1.18E-01
3761.58	7	5	1.61E-02
4119.37	3	5	3.66E-01
4120.49	3	1	3.33E-01
4123.96	5	7	4.81E-01
4125.49	1	3	2.70E-01
4134.11	3	3	3.34E-01
4153.27	3	3	1.92E-01
4158.86	3	5	3.39E-01
4178.46	5	5	1.12E-01
4213.35	5	3	1.19E-02
4522.66	5	3	1.02E-02
4554.53	3	5	2.41E-01
5114.06	1	3	1.80E-01
5339.94	1	3	1.85E-02
5349.74	3	1	7.04E-02
5372.71	3	3	1.42E-02
5414.59	3	5	9.29E-03
5428.38	5	3	2.68E-02
5471.12	5	5	4.86E-02
5571.81	1	3	8.33E-02
5580.12	3	5	1.11E-01
5583.23	3	3	6.20E-02
*5589.9	9	15	1.49E-01
5597.89	5	7	1.48E-01
5604.27	5	5	3.68E-02
5607.41	5	3	4.08E-03
6330.05	5	7	1.21E-01
6460.12	3	5	9.37E-02
6466.14	5	7	1.01E-01
6500.24	7	9	1.11E-01
6543.77	5	5	1.64E-02
6601.28	7	7	1.14E-02
6764.72	1	3	4.37E-02
6789.62	3	5	5.79E-02
6817.40	3	3	3.00E-02
6828.95	5	7	7.35E-02
6878.76	5	5	1.65E-02

O VI

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
*150.10	2	6	2.62E+02
*173.03	6	10	8.78E+02
1031.91	2	4	4.16E+00
1037.61	2	2	4.09E+00
3811.35	2	4	5.14E-01
3834.24	2	2	5.05E-01

O VII

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
18.6270	1	3	9.365E+03
21.6020	1	3	3.309E+04
*120.33	3	9	5.334E+02
128.411	1	3	8.982E+02
*128.46	9	15	1.615E+03
135.820	3	5	1.523E+03
*1630.3	3	9	7.935E-01
2448.98	1	3	2.514E-01
*5933.1	3	9	1.002E-01
8241.76	1	3	3.864E-02

Phosphorus

P I

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
1671.7	4	2	3.9E-01
1674.6	4	4	4.0E-01
1679.7	4	6	3.9E-01
1775.0	4	6	2.17E+00
1782.9	4	4	2.14E+00
1787.7	4	2	2.13E+00
2135.5	4	4	2.11E-01
2136.2	6	4	2.83E+00
2149.1	4	2	3.18E+00
2152.9	2	4	4.85E-01
2154.1	4	4	1.73E-01
2154.1	4	6	5.8E-01
2534.0	2	4	2.00E-01
2535.6	4	4	9.5E-01
2553.3	2	2	7.1E-01
2554.9	4	2	3.00E-01

P II

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
1301.9	1	3	5.0E-01
1304.5	3	1	1.5E+00
1304.7	3	3	3.7E-01
1305.5	3	5	3.8E-01
1309.9	5	3	6.2E-01
1310.7	5	5	1.1E+00
4475.3	5	7	1.3E+00
4499.2	5	7	1.4E+00
4530.8	3	5	1.0E+00
4554.8	3	5	9.6E-01
4588.0	5	7	1.7E+00
4589.9	3	5	1.6E+00
4602.1	7	9	1.9E+00
4943.5	7	5	6.3E-01
5253.5	3	5	1.0E+00
5425.9	5	5	6.9E-01
6024.2	3	5	5.1E-01
6043.1	5	7	6.8E-01

P III

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
1334.8	2	4	5.5E-01
1344.3	4	6	6.4E-01
1344.8	4	4	1.1E-01
4057.4	4	4	1.0E-01
4059.3	6	4	9.0E-01
4080.1	4	2	9.9E-01

Potassium

K I

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
4044.1	2	4	1.24E-02
4047.2	2	2	1.24E-02
5084.2	2	2	3.50E-03
5099.2	4	2	7.0E-03
5323.3	2	2	6.3E-03
5339.7	4	2	1.26E-02
5343.0	2	4	4.0E-03
5359.6	4	6	4.6E-03
5782.4	2	2	1.23E-02
5801.8	4	2	2.46E-02
5812.2	2	4	2.8E-03
5831.9	4	6	3.2E-03
6911.1	2	2	2.72E-02
6938.8	4	2	5.4E-02
7664.9	2	4	3.87E-01
7699.0	2	2	3.82E-01

K II

λ Å	Weights g_i	g_k	A $10^8\ s^{-1}$
607.93	1	3	1.3E-02

λ	Weights		A
Å	g_i	g_k	10^8 s^{-1}
K III			
2550.0	6	4	2.0E+00
2635.1	4	4	1.2E+00
2992.4	6	8	2.5E+00
3052.1	4	6	1.7E+00
3202.0	4	4	1.8E+00
3289.1	4	6	2.0E+00
3322.4	6	6	1.3E+00
3421.8	2	4	1.5E+00
K XVI			
206.27	1	3	9.4E+01
K XVII			
22.020	2	4	4.7E+04
22.163	4	6	5.6E+04
22.18	4	4	9.3E+03
22.60	2	2	2.5E+03
22.76	4	2	4.7E+03
Praseodymium			
Pr II			
3997.0	15	15	1.87E-01
4062.8	13	15	1.00E+00
4100.7	17	19	8.4E-01
4143.1	15	17	5.8E-01
4179.4	13	15	5.2E-01
4222.9	11	13	3.91E-01
4241.0	17	15	2.30E-01
4359.8	15	15	1.1E-01
4405.8	17	17	9.0E-02
4429.3	15	15	2.28E-01
4449.8	13	13	1.24E-01
4468.7	11	13	1.54E-01
4510.2	13	15	1.16E-01
4534.2	15	17	4.9E-02
4734.2	15	13	2.5E-02
4879.1	15	15	1.8E-02
4886.0	15	15	1.3E-02
4912.6	17	15	5.7E-02
5034.4	19	19	1.1E-01
5110.8	21	19	2.78E-01
5135.1	17	17	1.25E-01
5173.9	19	17	3.18E-01
5219.1	15	15	9.5E-02
5220.1	17	15	2.35E-01
5251.7	15	13	1.1E-02
5259.7	15	13	2.24E-01
5292.6	13	13	9.3E-02
5810.6	17	19	2.3E-02
5879.3	15	15	7.6E-02
6200.8	15	17	1.8E-02
6278.7	13	15	2.6E-02
6398.0	11	13	1.9E-02
Rhodium			
Rh I			
3083.96	8	6	4.8E-02
3114.91	6	4	4.45E-02

λ	Weights		A
Å	g_i	g_k	10^8 s^{-1}
3121.76	6	6	1.1E-01
3123.70	10	8	4.6E-02
3137.71	4	6	3.3E-02
3189.05	6	6	3.03E-01
3197.13	6	4	4.35E-02
3263.14	6	6	1.3E-01
3271.61	6	4	2.0E-01
3280.55	8	8	2.36E-01
3283.57	6	8	4.4E-01
3289.14	4	4	1.0E-01
3323.09	8	10	6.3E-01
3331.09	4	2	5.40E-02
3338.54	8	6	3.5E-02
3360.80	4	4	1.2E-01
3368.38	6	4	1.1E-01
3396.82	10	10	6.5E-01
3399.70	6	8	1.2E-01
3462.04	6	6	6.2E-01
3470.66	4	4	8.5E-01
3478.91	6	6	3.32E-01
3484.04	6	8	9.3E-03
3498.73	4	6	2.12E-01
3502.52	10	10	4.3E-01
3507.32	6	8	3.4E-01
3528.02	8	8	8.5E-01
3543.95	4	4	4.65E-01
3549.54	6	6	2.22E-01
3570.18	4	6	1.82E-01
3583.10	8	10	2.6E-01
3596.19	6	4	5.5E-01
3597.15	6	8	5.9E-01
3612.47	4	2	8.90E-01
3620.46	6	4	8.5E-02
3654.87	8	8	6.0E-02
3657.99	8	6	8.8E-01
3666.22	6	8	8.4E-02
3690.70	6	4	3.23E-01
3692.36	10	8	9.1E-01
3700.91	8	10	3.9E-01
3713.02	4	4	8.3E-02
3788.47	4	6	1.4E-01
3793.22	8	6	4.2E-01
3799.31	8	8	5.5E-01
3806.76	6	6	6.2E-02
3818.19	6	4	5.8E-01
3822.26	6	6	8.5E-01
3828.48	6	6	6.2E-01
3833.89	6	4	5.8E-01
3856.52	8	10	5.9E-01
3872.39	4	6	6.7E-03
3877.34	8	6	3.7E-02
3913.51	8	8	2.5E-03
3922.19	4	2	6.25E-02
3934.23	8	8	1.58E-01
3942.72	4	2	7.15E-01
3958.86	6	8	5.5E-01
3984.40	4	4	1.1E-01
3995.61	4	6	4.7E-02
4053.44	2	2	2.8E-02

λ	Weights		A
Å	g_i	g_k	10^8 s^{-1}
4056.34	6	4	9.5E-03
4082.78	6	4	1.4E-01
4097.52	2	4	7.0E-02
4121.68	6	6	9.8E-02
4128.87	6	8	1.73E-01
4135.27	8	8	1.0E-01
4196.50	6	8	3.9E-02
4211.14	8	10	1.62E-01
4244.44	4	4	6.5E-03
4278.60	4	6	9.2E-03
4288.71	6	8	6.1E-02
4373.04	2	4	1.8E-02
4374.80	8	10	1.64E-01
4379.92	6	6	2.48E-02
4492.47	6	6	4.5E-03
4528.72	6	8	1.35E-02
4548.73	4	6	5.5E-03
4551.64	4	4	4.00E-02
4565.19	4	4	1.1E-02
4569.00	6	8	1.0E-02
4608.12	2	2	2.1E-02
4675.03	8	8	6.4E-03
4721.00	6	4	3.43E-03
4745.11	6	6	5.2E-03
4755.58	4	4	6.0E-03
4842.43	6	8	1.6E-03
4963.71	2	2	3.0E-02
4977.75	4	4	9.8E-03
4979.18	4	6	1.0E-02
5090.63	6	6	5.0E-03
5120.69	6	8	3.1E-03
5130.76	4	4	4.35E-03
5155.54	2	4	9.8E-03
5184.19	6	8	1.6E-03
5212.73	4	2	5.95E-03
5292.14	10	10	3.7E-03
5390.44	4	6	9.5E-03
5424.72	4	4	5.0E-03
5599.42	6	8	1.3E-02
5983.60	10	10	2.1E-02
Rubidium			
Rb I			
3022.5	2	4	4.13E-05
3032.0	2	4	4.93E-05
3044.2	2	4	8.2E-05
3060.2	2	4	1.05E-04
3082.0	2	4	1.49E-04
3112.6	2	4	2.5E-04
3113.1	2	2	1.3E-04
3157.5	2	4	3.38E-04
3158.3	2	2	2.0E-04
3228.0	2	4	6.4E-04
3229.2	2	2	3.8E-04
3348.7	2	4	1.37E-03
3350.8	2	2	8.9E-04
3587.1	2	4	3.97E-03
3591.6	2	2	2.9E-03
4201.8	2	4	1.8E-02

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
4215.5	2	2	1.5E-02
7800.3	2	4	3.70E-01
7947.6	2	2	3.40E-01
Scandium			
Sc I			
2116.7	4	4	2.0E-01
2120.4	6	6	2.0E-01
2262.3	4	4	5.8E-02
2266.6	4	2	4.8E-01
2270.9	6	4	4.6E-01
2280.8	4	6	2.8E-01
2289.6	6	6	4.1E-02
2311.29	4	6	4.1E-02
2315.69	4	4	2.5E-01
2320.32	6	6	2.4E-01
2324.75	6	4	4.1E-02
2328.19	4	6	4.6E-02
2334.67	4	2	1.7E-01
2346.03	6	4	1.3E-01
2429.19	4	4	2.8E-01
2438.63	6	6	2.1E-01
2468.40	4	2	4.9E-02
2692.78	4	2	1.61E-01
2699.02	4	6	2.4E-02
2706.74	4	4	3.1E-01
2707.93	6	4	1.49E-01
2711.34	6	6	3.2E-01
2965.88	4	6	7.5E-02
2974.01	4	4	5.5E-01
2980.76	6	6	5.4E-01
2988.97	6	4	6.9E-02
3015.37	4	6	7.8E-01
3019.35	6	8	8.7E-01
3030.76	6	6	1.00E-01
3255.68	4	4	3.2E-01
3269.90	4	2	3.13E+00
3273.63	6	4	2.81E+00
3907.48	4	6	1.66E+00
3911.81	6	8	1.79E+00
3933.38	6	6	1.62E-01
3996.60	4	6	1.65E-01
4020.39	4	4	1.63E+00
4023.22	4	4	3.0E-01
4023.68	6	6	1.65E+00
4031.38	6	6	2.9E-01
4036.86	6	4	7.9E-02
4043.80	8	8	3.11E-01
4047.80	6	4	1.54E-01
4051.83	8	6	7.7E-02
4054.54	4	2	1.67E-01
4067.00	6	8	1.91E-01
4067.63	10	8	4.1E-02
4074.96	4	6	3.7E-01
4078.56	2	4	4.3E-01
4080.57	4	4	6.6E-02
4082.39	6	4	2.73E-01
4086.66	6	8	3.7E-01
4087.47	4	6	1.12E-01
4093.12	4	4	1.23E-01
4094.86	6	6	1.44E-01
4098.36	8	8	8.7E-02
4132.98	4	6	1.19E+00
4140.27	6	8	1.17E+00
4147.38	6	6	1.74E-01
4161.85	8	8	1.77E-01
4171.53	6	4	1.36E-01
4186.42	6	8	8.4E-02
4187.61	8	6	1.28E-01
4193.53	4	6	6.1E-02
4204.52	6	8	3.5E-02
4205.20	10	8	1.12E-01
4212.32	4	6	1.58E-01
4212.48	6	6	8.6E-02
4216.08	2	4	2.36E-01
4218.23	4	4	2.26E-01
4225.54	6	8	9.5E-02
4225.69	4	6	7.6E-02
4231.64	4	4	1.31E-01
4233.59	6	6	4.0E-01
4238.05	8	8	7.1E-01
4239.55	6	4	2.27E-01
4246.14	8	6	1.15E-01
4542.55	6	4	1.28E-01
4544.67	8	6	1.33E-01
4706.94	4	6	2.81E-01
4709.31	6	8	4.0E-01
4711.72	2	4	1.81E-01
4714.30	4	4	2.14E-01
4719.31	6	6	1.04E-01
4728.77	8	8	1.16E-01
4729.20	4	4	2.20E-01
4729.24	6	6	1.93E-01
4734.11	4	2	1.10E+00
4737.65	6	4	8.8E-01
4741.02	8	6	9.1E-01
4743.82	10	8	9.8E-01
4973.67	4	2	8.4E-01
4980.36	6	4	5.6E-01
4983.43	4	4	2.58E-01
4991.91	6	6	3.8E-01
4995.00	4	6	5.9E-02
5018.41	6	4	2.09E-01
5021.52	4	4	2.30E-01
5064.31	8	10	7.3E-02
5066.38	6	6	3.6E-02
5070.17	6	8	1.16E-01
5072.71	2	4	2.0E-02
5075.82	4	6	1.15E-01
5080.22	4	4	4.1E-02
5081.56	10	10	7.6E-01
5083.72	8	8	6.2E-01
5085.55	6	6	5.7E-01
5086.94	4	4	6.6E-01
5096.72	6	4	1.69E-01
5099.27	4	6	1.50E-01
5101.12	10	8	8.8E-02
5331.79	4	4	1.11E-01
5339.43	6	6	1.06E-01
5341.07	4	2	3.8E-01
5349.34	6	4	5.9E-01
5350.28	8	8	6.8E-02
5355.79	6	4	3.0E-01
5356.10	8	6	5.7E-01
5375.37	8	6	3.4E-01
5392.06	10	8	4.2E-01
5416.16	4	6	4.4E-02
5416.41	6	6	2.0E-02
5425.55	6	8	4.5E-02
5429.42	2	4	9.0E-02
5432.98	4	4	5.4E-02
5433.25	6	4	9.7E-02
5438.28	4	6	3.4E-02
5439.04	2	2	1.74E-01
5442.62	4	2	2.15E-01
5446.20	8	8	2.8E-01
5451.37	6	6	1.50E-01
5455.24	4	4	6.6E-02
5464.95	4	2	3.2E-02
5468.40	6	4	9.7E-02
5472.19	8	6	9.7E-02
5482.01	8	8	5.2E-01
5484.63	6	6	5.2E-01
5514.23	6	8	4.1E-01
5520.52	8	10	4.3E-01
5526.10	4	4	7.1E-02
5541.07	6	6	5.5E-02
5631.04	2	4	3.0E-02
5671.83	10	12	5.4E-01
5686.86	8	10	4.9E-01
5700.19	6	8	4.6E-01
5708.64	10	10	4.7E-02
5711.79	4	6	4.5E-01
5717.31	8	8	7.5E-02
5724.13	6	6	7.4E-02
5988.43	6	6	6.6E-02
6026.16	4	4	7.2E-02
6146.20	6	8	4.2E-02
6198.43	4	6	3.5E-02
6249.96	6	8	3.2E-02
6262.22	4	6	8.4E-02
6280.16	2	4	4.0E-02
6284.16	6	6	3.9E-02
6284.73	4	4	7.1E-02
6293.02	2	2	1.04E-01
7741.16	10	10	3.8E-02
7800.42	8	8	5.1E-02
Sc II			
1880.6	5	3	5.0E+00
2064.3	7	5	2.2E+00
2068.0	5	3	2.0E+00
2273.1	1	3	7.7E+00
2545.20	5	5	4.0E-01
2552.35	7	5	2.21E+00
2555.79	3	3	6.9E-01
2560.23	5	3	2.01E+00

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
2563.19	3	1	2.70E+00
2611.19	5	5	2.2E+00
2667.70	3	5	1.5E+00
2746.36	3	1	3.9E+00
2782.31	5	5	1.3E+00
2789.15	7	7	1.3E+00
2801.31	9	9	1.3E+00
2819.49	3	5	2.3E+00
2822.12	5	7	2.5E+00
2826.64	7	9	2.8E+00
2870.85	5	3	1.1E+00
2912.98	5	3	1.1E+00
2979.68	3	5	1.2E+00
2988.92	5	7	2.9E+00
3039.92	7	9	3.5E+00
3045.73	5	7	3.68E+00
3052.92	7	9	3.92E+00
3060.54	7	7	3.0E-01
3065.12	9	11	4.00E+00
3075.36	9	9	2.5E-01
3128.27	3	3	1.9E+00
3133.07	5	5	1.8E+00
3139.72	7	7	2.1E+00
3190.98	3	3	1.1E+00
3199.33	5	3	1.9E+00
3312.72	5	7	1.2E+00
3320.40	5	3	1.2E+00
3343.23	9	7	1.1E+00
3353.72	5	7	1.51E+00
3359.67	5	5	2.16E-01
3361.26	3	3	3.4E-01
3361.93	3	1	1.17E+00
3368.94	5	3	8.3E-01
3372.15	7	5	9.9E-01
3379.16	3	3	2.5E+00
3535.71	5	3	6.1E-01
3558.53	5	7	3.0E-01
3567.70	3	5	3.5E-01
3572.53	7	7	1.38E+00
3576.34	5	5	1.06E+00
3580.93	3	3	1.23E+00
3589.63	5	3	4.6E-01
3590.47	7	5	2.9E-01
3613.83	7	9	1.48E+00
3630.74	5	7	1.20E+00
3642.78	3	5	1.13E+00
3645.31	7	7	2.74E-01
3651.80	5	5	3.0E-01
3859.59	7	5	1.1E+00
4246.82	5	5	1.29E+00
4314.08	9	7	4.1E-01
4320.75	7	5	4.0E-01
4325.00	5	3	4.3E-01
4374.46	9	9	1.48E-01
4400.39	7	7	1.43E-01
4415.54	5	5	1.47E-01
4670.41	5	7	1.16E-01
5031.01	5	3	3.5E-01
5239.81	1	3	1.39E-01
5526.79	9	7	3.3E-01
5657.91	5	5	1.04E-01
5669.06	3	1	1.31E-01

Silicon

Si I

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
1977.6	1	3	1.8E-01
1979.2	3	1	5.1E-01
1980.6	3	3	1.3E-01
1983.2	3	5	1.4E-01
1986.4	5	3	2.1E-01
1989.0	5	5	4.1E-01
2208.0	1	3	3.11E-01
2210.9	3	5	4.16E-01
2211.7	3	3	2.32E-01
2216.7	5	7	5.5E-01
2218.1	5	5	1.38E-01
2506.9	3	5	4.66E-01
2514.3	1	3	6.1E-01
2516.1	5	5	1.21E+00
2519.2	3	3	4.56E-01
2524.1	3	1	1.81E+00
2528.5	5	3	7.7E-01
2532.4	1	3	2.6E-01
2631.3	1	3	9.7E-01
2881.6	5	3	1.89E+00
3905.5	1	3	1.18E-01
4738.8	3	3	1.0E-02
4783.0	5	3	1.7E-02
4792.3	5	5	1.7E-02
4818.1	5	7	1.1E-02
4821.2	3	5	8.0E-03
4947.6	3	1	4.2E-02
5006.1	3	5	2.8E-02
5622.2	3	3	1.6E-02
5690.4	3	3	1.2E-02
5708.4	5	5	1.4E-02
5754.2	5	3	1.5E-02
5772.1	3	1	3.6E-02
5948.5	3	5	2.2E-02
7226.2	3	5	7.9E-03
7405.8	3	5	3.7E-02
7409.1	5	7	2.3E-02
7680.3	3	5	4.6E-02
7918.4	3	5	5.2E-02
7932.3	5	7	5.1E-02
7944.0	7	9	5.8E-02
7970.3	5	5	7.1E-03

Si II

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
989.87	2	4	6.7E+00
992.68	4	6	8.0E+00
1020.7	2	2	1.3E+00
1190.4	2	4	6.9E+00
1193.3	2	2	2.8E+01
1194.5	4	4	3.6E+01
1197.4	4	2	1.4E+01
1248.4	4	4	1.3E+01
1251.2	6	4	1.9E+01
1260.4	2	4	2.0E+01
1264.7	4	6	2.3E+01
1304.4	2	2	3.6E+00
1309.3	4	2	7.0E+00
1526.7	2	2	3.73E+00
1533.5	4	2	7.4E+00
1808.0	2	4	3.7E-02
2904.3	4	6	6.7E-01
2905.7	6	8	7.1E-01
3210.0	4	6	4.6E-01
4128.1	4	6	1.32E+00
4130.9	6	8	1.42E+00
5041.0	2	4	9.8E-01
5056.0	4	6	1.2E+00
5957.6	2	2	4.2E-01
5978.9	4	2	8.1E-01
6347.1	2	4	7.0E-01
6371.4	2	2	6.9E-01
7848.8	4	6	3.9E-01
7849.7	6	8	4.2E-01

Si III

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
883.40	5	7	6.3E+01
994.79	3	3	7.89E+00
997.39	5	3	1.31E+01
1141.6	3	5	3.0E+01
1144.3	5	7	3.9E+01
1161.6	5	5	1.6E+01
1206.5	1	3	2.59E+01
1206.5	3	5	4.89E+01
1207.5	5	5	1.9E+01
1294.5	3	5	5.42E+00
1296.7	1	3	7.19E+00
1298.9	3	3	5.36E+00
1299.0	5	5	1.61E+01
1301.2	3	1	2.13E+01
1303.3	5	3	8.85E+00
1328.8	1	3	2.7E+01
1417.2	3	1	2.60E+01
1435.8	5	7	2.1E+01
1589.0	5	3	1.1E+01
1778.7	7	9	4.4E+00
1783.1	5	7	3.8E+00
3241.6	5	3	2.3E+00
*3486.9	15	21	1.8E+00
3590.5	3	5	3.9E+00
4552.6	3	5	1.26E+00
4554.0	5	3	7.6E-01
4567.8	3	3	1.25E+00
4683.0	5	5	9.5E-01
4716.7	5	7	2.8E+00
5451.5	3	5	6.0E-01
5473.1	5	7	7.9E-01
5716.3	9	7	1.9E-01
5739.7	1	3	4.7E-01
7462.6	5	3	4.9E-01
7466.3	7	5	5.4E-01
7612.4	3	5	1.1E+00

λ	Weights		*A*
Å	g_i	g_k	10^8 s^{-1}
Si IV			
457.82	2	4	3.6E+00
458.16	2	2	3.6E+00
515.12	2	2	4.1E+00
516.35	4	2	8.2E+00
*560.50	6	10	1.0E+00
*749.94	10	14	1.45E+01
815.05	2	2	1.23E+01
818.13	4	2	2.44E+01
*860.74	10	6	1.8E+00
*1066.6	10	14	3.91E+01
1122.5	2	4	2.05E+01
1128.3	4	4	4.03E+00
1128.3	4	6	2.42E+01
1393.8	2	4	7.73E+00
1402.8	2	2	7.58E+00
*1724.1	10	6	5.5E+00
Si V			
96.439	1	3	4.8E+02
97.143	1	3	2.0E+03
117.86	1	3	3.0E+02
Si VI			
246.00	4	2	1.7E+02
249.12	2	2	8.5E+01
Si VII			
217.83	5	3	4.3E+02
272.64	5	3	5.1E+01
274.18	3	1	1.2E+02
275.35	5	5	8.9E+01
275.67	3	3	3.0E+01
276.84	1	3	3.9E+01
278.45	3	5	2.9E+01
Si VIII			
214.76	4	2	4.1E+02
216.92	6	4	3.6E+02
232.86	2	2	8.0E+01
235.56	4	4	9.7E+01
250.45	2	2	7.7E+01
250.79	4	2	1.6E+02
314.31	4	2	5.2E+01
316.20	4	4	5.0E+01
319.83	4	6	4.9E+01
Si IX			
223.73	1	3	4.2E+01
225.03	3	3	1.2E+02
227.01	5	3	2.0E+02
227.30	5	3	2.3E+02
258.10	5	5	1.04E+02
*294.37	9	9	5.9E+01
*347.36	9	15	2.2E+01
Si X			
253.77	2	4	2.9E+01
256.57	2	2	1.1E+02
258.35	4	4	1.4E+02
261.05	4	2	5.4E+01
272.00	2	2	3.0E+01
277.26	4	2	5.7E+01
287.08	2	4	2.6E+01
289.19	4	4	5.0E+01
292.22	6	4	7.3E+01
*347.73	10	10	4.3E+01
*353.09	6	10	2.1E+01
Si XI			
43.763	1	3	6.11E+03
*49.116	9	3	2.45E+03
49.222	3	5	8.9E+03
52.296	3	1	7.6E+02
303.30	1	3	6.42E+01
358.29	3	1	1.03E+02
358.63	3	5	1.38E+01
361.41	1	3	1.80E+01
364.50	3	3	1.32E+01
365.42	5	5	3.90E+01
368.28	3	1	5.1E+01
371.48	5	3	2.07E+01
604.14	3	5	1.12E+01
2300.8	1	3	4.34E-01
Si XII			
*40.924	2	6	4.42E+03
*44.118	6	10	1.4E+04
499.43	2	4	9.56E+00
520.72	2	2	8.47E+00
1862	2	4	1.15E+00
1949	2	2	1.0E+00
4620	2	4	4.6E-02
4942	4	6	4.5E-02
Silver			
Ag I			
2061.2	2	4	3.1E-02
2069.9	2	2	1.5E-02
3280.7	2	4	1.4E+00
3382.9	2	2	1.3E+00
5209.1	2	4	7.5E-01
5465.5	4	6	8.6E-01
5471.6	4	4	1.4E-01
Sodium			
Na I			
3302.4	2	4	2.81E-02
3303.0	2	2	2.81E-02
4390.0	2	4	7.7E-03
4393.3	4	4	1.6E-03
4393.3	4	6	9.2E-03
4494.2	2	4	1.2E-02
4497.7	4	6	1.4E-02
4497.7	4	4	2.4E-03
4664.8	2	4	2.33E-02
4668.6	4	4	4.1E-03
4668.6	4	6	2.5E-02
4747.9	2	2	6.3E-03
4751.8	4	2	1.27E-02
4978.5	2	4	4.1E-02
4982.8	4	4	8.2E-03
4982.8	4	6	4.89E-02
5148.8	2	2	1.17E-02
5153.4	4	2	2.33E-02
5682.6	2	4	1.03E-01
5688.2	4	6	1.2E-01
5688.2	4	4	2.1E-02
5890.0	2	4	6.11E-01
5895.9	2	2	6.10E-01
6154.2	2	2	2.6E-02
6160.8	4	2	5.2E-02
8183.3	2	4	4.53E-01
8194.8	4	6	5.4E-01
8194.8	4	4	9.0E-02
11381	2	2	8.9E-02
11404	4	2	1.76E-01
Na II			
300.15	1	3	3.0E+01
301.44	1	3	4.9E+01
372.08	1	3	3.4E+01
Na III			
378.14	4	2	7.7E+01
380.10	2	2	3.7E+01
1991.0	4	6	8.3E+00
2004.2	2	4	4.6E+00
2011.9	6	8	8.4E+00
2151.5	2	4	4.4E+00
2174.5	4	6	5.3E+00
2230.3	6	8	3.7E+00
2232.2	4	4	3.3E+00
2246.7	4	6	2.4E+00
2459.3	4	6	3.0E+00
2468.9	2	4	2.4E+00
2497.0	6	6	1.7E+00
Na V			
*307.89	10	6	2.0E+02
*333.46	6	6	5.6E+01
*369.01	10	6	1.2E+02
*400.72	10	10	5.0E+01
*445.14	6	10	7.1E+00
459.90	4	2	2.3E+01
461.05	4	4	2.3E+01
463.26	4	6	2.2E+01
510.10	2	2	5.6E+01
511.19	4	4	6.8E+01
Na VI			
313.75	5	3	1.3E+02
361.25	5	5	7.7E+01
*416.53	9	9	3.7E+01
*492.80	9	15	1.3E+01
1550.6	5	5	4.35E+00
1567.8	5	3	2.68E+00

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
1608.5	3	1	2.6E+00
1649.4	5	5	2.05E+00
1741.5	3	5	2.59E+00
1747.5	5	7	3.1E+00
Na VII			
*94.409	6	10	2.7E+03
*105.27	6	2	4.5E+02
353.29	4	4	1.0E+02
381.30	4	2	4.0E+01
397.49	4	4	3.5E+01
399.18	6	4	5.2E+01
*483.28	10	10	2.9E+01
486.74	2	4	1.1E+01
491.95	4	6	1.3E+01
555.80	4	4	2.3E+01
777.83	4	6	6.8E+00
Na VIII			
*83.34	9	15	3.94E+03
*89.88	9	3	8.09E+02
90.536	3	5	2.86E+03
411.15	1	3	4.42E+01
1239.4	3	3	3.02E+00
1802.7	3	1	2.70E+00
1867.7	3	5	2.01E+00
2059.1	3	5	1.80E+00
2558.2	5	3	2.26E-02
2772.0	3	5	4.19E-01
3021.0	5	7	4.90E-01
3108.9	1	3	2.58E-01
3182.3	1	3	2.92E-01
Na IX			
70.615	2	4	1.35E+03
70.653	2	2	1.35E+03
77.764	2	4	3.6E+03
77.911	4	6	4.3E+03
681.72	2	4	6.63E+00
694.17	2	2	6.30E+00
2487.7	2	4	8.32E-01
2535.8	2	2	7.89E-01
6841.8	2	4	2.59E-02
7103.4	4	6	2.78E-02
Strontium			
Sr I			
2206.2	1	3	6.6E-03
2211.3	1	3	8.5E-03
2217.8	1	3	1.2E-02
2226.3	1	3	1.6E-02
2237.7	1	3	2.3E-02
2253.3	1	3	3.7E-02
2275.3	1	3	6.7E-02
2307.3	1	3	1.2E-01
2354.3	1	3	1.8E-01
2428.1	1	3	1.7E-01
2569.5	1	3	5.3E-02
2931.8	1	3	1.9E-02
4607.3	1	3	2.01E+00
Sr II			
2018.7	2	2	1.2E-01
2051.9	4	2	2.4E-01
2282.0	2	4	8.3E-01
2322.4	4	6	9.1E-01
2324.5	4	4	1.5E-01
2423.5	2	2	2.4E-01
2471.6	4	2	4.8E-01
3464.5	4	6	3.1E+00
3474.9	4	4	5.1E-01
4077.7	2	4	1.42E+00
4161.8	2	2	6.5E-01
4215.5	2	2	1.27E+00
4305.5	4	2	1.4E+00
4414.8	4	6	1.1E-01
4417.5	4	4	1.8E-02
4585.9	4	2	7.0E-02
5303.1	2	4	1.9E-01
5379.1	4	6	2.2E-01
5385.5	4	4	3.7E-02
5723.7	2	2	7.1E-02
5819.0	4	2	1.4E-01
8688.9	4	6	5.5E-01
8719.6	4	4	9.7E-02
Sulfur			
S I			
1295.7	5	5	4.9E+00
1296.2	5	3	2.7E+00
1302.3	3	5	1.8E+00
1302.9	3	3	1.6E+00
1303.1	3	1	6.6E+00
1303.4	5	3	1.9E+00
1305.9	1	3	2.4E+00
1401.5	5	3	9.1E-01
1409.3	3	3	5.0E-01
1412.9	1	3	1.6E-01
1425.0	5	7	4.5E+00
1425.2	5	5	1.2E+00
1433.3	3	5	3.3E+00
1433.3	3	3	1.9E+00
1437.0	1	3	2.4E+00
1448.2	5	3	7.3E+00
1473.0	5	7	4.2E-01
1474.0	5	7	1.6E+00
1474.4	5	5	5.0E-01
1474.6	5	3	6.2E-02
1481.7	3	5	1.7E-01
1483.0	3	5	1.2E+00
1483.2	3	3	7.5E-01
1487.2	1	3	8.7E-01
1666.7	5	5	6.3E+00
1687.5	1	3	9.4E-01
1782.3	1	3	1.9E+00
1807.3	5	3	3.8E+00
1820.3	3	3	2.2E+00
1826.2	1	3	7.2E-01
4694.1	5	7	6.7E-03
4695.4	5	5	6.7E-03
4696.2	5	3	6.5E-03
6403.6	3	5	5.7E-03
6408.1	5	5	9.5E-03
6415.5	7	5	1.3E-02
*6751.2	15	25	7.9E-02
7679.6	3	5	1.2E-02
7686.1	5	5	2.0E-02
7696.7	7	5	2.8E-02
S II			
1124.4	2	4	1.0E+00
1125.0	4	4	4.6E+00
1131.0	2	2	3.5E+00
1131.6	4	2	1.4E+00
1250.5	4	2	4.6E-01
1253.8	4	4	4.2E-01
1259.5	4	6	3.4E-01
4463.6	8	6	5.3E-01
4483.4	6	4	3.1E-01
4486.7	4	2	6.6E-01
4524.7	4	4	9.3E-02
4525.0	6	4	1.2E+00
4552.4	4	2	1.2E+00
4656.7	2	4	9.0E-02
4716.2	4	4	2.9E-01
4815.5	6	4	8.8E-01
4885.6	2	4	1.7E-01
4917.2	2	2	6.6E-01
4924.1	4	6	2.2E-01
4925.3	2	4	2.4E-01
4942.5	2	2	1.5E-01
4991.9	4	4	1.5E-01
5009.5	4	2	7.0E-01
5014.0	4	4	8.4E-01
5027.2	4	2	2.6E-01
5032.4	6	6	8.1E-01
5047.3	4	2	3.6E-01
5103.3	6	4	5.0E-01
5142.3	2	2	1.9E-01
5201.0	4	4	7.5E-01
5201.3	6	4	6.5E-02
5212.6	4	6	9.8E-02
5212.6	6	6	8.5E-01
5320.7	6	8	9.2E-01
5345.7	4	6	8.8E-01
5345.7	6	6	1.1E-01
5428.6	2	4	4.2E-01
5432.8	4	6	6.8E-01
5453.8	6	8	8.5E-01
5473.6	2	2	7.3E-01
5509.7	4	4	4.0E-01
5526.2	8	8	8.1E-02
5536.8	4	6	6.6E-02
5556.0	4	2	1.1E-01
5564.9	6	6	1.7E-01
5578.8	6	6	1.1E-01
5606.1	10	8	5.4E-01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
5616.6	4	4	1.2E-01
5640.0	4	6	6.6E-01
5645.6	6	4	1.8E-02
5647.0	2	4	5.7E-01
5659.9	6	4	4.6E-01
5664.7	4	2	5.8E-01
5819.2	4	4	8.5E-02
6305.5	8	6	1.8E-01
6312.7	6	4	3.0E-01
S III			
2496.2	7	5	2.5E+00
2508.2	5	3	2.3E+00
2636.9	3	5	4.5E-01
2665.4	5	5	1.4E+00
2680.5	1	3	6.2E-01
2691.8	3	3	4.6E-01
2702.8	3	1	1.9E+00
2718.9	3	3	1.2E+00
2721.4	5	3	7.7E-01
2726.8	3	5	6.0E-01
2731.1	5	5	1.1E+00
2756.9	7	7	1.4E+00
2785.5	3	3	6.1E-01
2856.0	5	7	5.1E+00
2863.5	7	9	5.7E+00
2872.0	3	5	4.7E+00
2950.2	3	5	3.0E+00
2964.8	5	7	4.0E+00
3662.0	3	3	6.4E-01
3717.8	5	3	1.0E+00
3778.9	3	5	4.4E-01
3831.8	1	3	5.6E-01
3837.8	3	3	4.2E-01
3838.3	5	5	1.3E+00
3860.6	3	1	1.6E+00
3899.1	5	3	6.7E-01
4253.6	5	7	1.2E+00
4285.0	3	5	9.0E-01
S IV			
551.17	2	2	2.06E+01
554.07	4	2	4.08E+01
3097.5	2	4	2.6E+00
3117.7	2	2	2.5E+00
S V			
437.37	1	3	1.12E+01
438.19	3	3	3.33E+01
439.65	5	3	5.5E+01
*661.52	9	15	6.44E+01
*679.01	9	15	8.6E+01
*690.75	9	9	5.0E+01
786.48	1	3	5.25E+01
*854.85	9	9	4.18E+01
S VI			
248.99	2	4	3.1E+01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
249.27	2	2	3.1E+01
388.94	2	2	4.5E+01
390.86	4	2	8.8E+01
706.48	2	4	4.17E+01
712.68	4	6	4.85E+01
712.84	4	4	8.1E+00
933.38	2	4	1.7E+01
944.52	2	2	1.6E+01
S VII			
60.161	1	3	9.46E+03
60.804	1	3	5.1E+02
72.029	1	3	8.61E+02
S VIII			
198.55	4	2	2.5E+02
202.61	2	2	1.2E+02
S XI			
*189.90	9	3	4.3E+02
190.37	5	3	2.8E+02
215.95	5	5	1.4E+02
217.63	1	3	7.2E+01
239.81	1	3	2.6E+01
242.57	3	5	1.9E+01
242.82	3	3	1.9E+01
246.90	5	5	5.4E+01
247.12	5	3	3.0E+01
*288.49	9	15	2.9E+01
S XII			
212.14	2	4	3.7E+01
215.18	2	2	1.4E+02
218.20	4	4	1.7E+02
221.44	4	2	6.4E+01
227.50	2	2	3.7E+01
234.48	4	2	6.8E+01
S XIII			
32.236	1	3	1.09E+04
37.600	3	1	1.3E+03
256.66	1	3	8.7E+01
299.89	3	5	1.78E+01
303.37	1	3	2.28E+01
307.36	3	3	1.64E+01
308.91	5	5	4.82E+01
312.68	3	1	6.3E+01
316.84	5	3	2.50E+01
500.42	3	5	1.43E+01
S XIV			
*30.434	2	6	8.28E+03
*32.517	6	10	2.6E+04
417.67	2	4	1.2E+01
445.71	2	2	1.0E+01
1550	2	4	1.4E+00
1663	2	2	1.2E+00
3967	2	4	5.4E-02

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
4153	4	6	5.7E-02
Tantalum			
Ta I			
3127.9	4	6	5.7E-03
3168.3	4	4	6.0E-03
3170.3	8	10	8.5E-02
3205.5	6	8	5.6E-03
3260.2	4	4	5.8E-03
3337.8	6	6	1.3E-02
3383.9	6	4	5.3E-03
3406.9	4	6	6.8E-02
3419.7	8	8	1.91E-02
3463.8	4	6	2.62E-02
3484.6	4	4	8.5E-03
3488.8	6	4	7.3E-03
3497.9	6	8	4.9E-02
3505.0	8	6	2.72E-02
3553.4	4	6	3.3E-03
3607.4	6	8	4.6E-02
3625.2	10	8	1.0E-02
3626.6	8	10	7.1E-02
3642.1	10	12	5.5E-02
3657.5	6	6	4.3E-03
3731.0	4	6	5.3E-03
3754.5	8	8	6.5E-03
3784.3	4	6	4.3E-02
3792.1	4	4	9.0E-03
3826.9	6	6	5.2E-03
3836.6	8	10	4.0E-03
3848.1	10	8	1.30E-02
3858.6	10	10	2.5E-03
3918.5	4	2	2.5E-02
3922.8	4	4	3.98E-02
3996.2	2	4	3.35E-02
3999.3	4	4	1.8E-02
4003.7	10	8	3.1E-03
4006.8	6	8	7.6E-03
4026.9	4	4	3.60E-02
4029.9	10	10	2.8E-02
4030.7	8	10	2.3E-03
4040.9	10	12	7.3E-03
4061.4	2	4	6.5E-02
4064.6	4	4	3.83E-02
4067.2	6	4	6.8E-03
4067.9	6	8	8.4E-03
4097.2	10	10	2.1E-03
4105.0	6	4	1.1E-02
4136.2	8	6	1.82E-02
4147.9	10	8	1.79E-02
4175.2	6	8	2.8E-02
4205.9	8	10	8.9E-03
4303.0	6	6	2.08E-02
4378.8	8	6	4.8E-03
4386.1	4	6	1.0E-02
4402.5	6	6	2.28E-02
4415.7	2	4	2.53E-02
4441.0	4	6	7.5E-03

λ	Weights		A
Å	g_i	g_k	10^8 s^{-1}
4441.7	10	8	9.0E-03
4473.5	6	8	1.36E-02
4511.0	10	12	1.56E-02
4511.5	10	8	3.6E-03
4514.2	10	10	3.1E-03
4521.1	10	10	2.3E-03
4530.9	4	6	2.42E-02
4547.2	4	6	5.3E-03
4553.7	6	8	9.5E-03
4565.9	8	8	2.5E-02
4574.3	4	4	1.2E-02
4580.7	8	10	2.1E-03
4619.5	6	4	5.3E-02
4633.1	4	4	1.2E-02
4669.1	6	4	2.85E-02
4681.9	6	6	1.5E-02
4684.9	10	8	2.8E-03
4685.3	6	8	3.4E-03
4691.9	2	4	4.08E-02
4706.1	6	6	1.4E-02
4740.2	4	4	5.0E-02
4758.0	4	6	7.5E-03
4769.0	8	8	2.8E-02
4780.9	10	8	2.16E-02
4812.8	4	4	1.2E-02
4825.4	6	6	2.63E-02
4832.2	4	4	1.7E-02
4852.2	4	4	1.7E-02
4884.0	6	8	1.1E-02
4904.6	12	10	1.95E-02
4920.9	8	10	2.1E-03
4921.3	2	4	1.2E-02
4926.0	4	4	1.5E-02
4936.4	8	6	4.5E-02
4969.7	4	4	1.0E-02
5012.5	4	4	1.9E-02
5037.4	10	8	4.4E-02
5043.3	6	4	2.73E-02
5067.9	8	6	2.92E-02
5069.9	10	12	1.7E-03
5082.3	10	12	1.9E-03
5087.4	6	4	1.5E-02
5090.7	8	6	9.5E-03
5095.3	6	6	5.0E-03
5136.5	2	2	4.5E-02
5141.6	4	2	1.2E-02
5143.7	6	4	1.7E-02
5147.6	6	4	9.0E-03
5161.8	4	6	6.3E-03
5218.7	8	6	8.2E-03
5235.4	6	6	4.7E-03
5295.0	6	6	7.5E-03
5336.1	6	8	5.5E-03
5349.6	6	4	2.2E-02
5354.7	4	4	6.5E-03
5396.0	6	8	2.5E-03
5402.5	4	2	1.4E-02
5435.3	4	6	1.1E-02
5499.4	10	10	6.1E-03
5518.9	8	10	3.8E-02
5620.7	8	10	6.0E-03
5640.2	6	8	4.9E-03
5645.9	6	8	1.43E-02
5699.2	6	6	4.2E-03
5767.9	6	8	2.6E-03
5780.7	4	6	3.3E-03
5811.1	8	6	5.7E-03
5849.7	10	8	2.8E-03
5877.4	10	12	2.3E-02
5939.8	2	4	1.6E-02
5944.0	4	6	2.13E-02
5997.2	10	10	2.4E-02
6020.7	2	4	1.0E-02
6045.4	6	8	2.6E-02
6047.3	8	10	9.0E-03
6249.8	6	6	3.5E-03
6258.7	6	8	3.3E-03
6309.6	4	6	1.83E-02
6360.8	6	8	4.6E-03
6428.6	6	6	6.0E-03
6430.8	8	8	2.9E-02
6450.4	8	10	2.2E-02
6485.4	10	10	5.8E-02
6514.4	6	4	2.2E-02
6516.1	6	8	1.25E-02
6612.0	6	4	1.9E-02
6673.7	2	4	9.0E-03
6771.7	4	4	5.8E-03
6866.2	8	6	2.58E-02
6927.4	10	12	1.01E-02
6928.5	10	8	1.69E-02
6951.3	10	10	3.7E-03
6953.9	6	8	8.3E-03
6966.1	8	8	1.2E-02
6969.5	10	10	2.9E-03
7407.9	6	4	2.0E-02

Thallium

Tl I

λ Å	g_i	g_k	A 10^8 s^{-1}
2104.6	2	4	4.0E-02
2118.9	2	2	2.0E-02
2129.3	2	4	5.8E-02
2151.9	2	2	3.1E-02
2168.6	2	4	9.8E-02
2237.8	2	4	1.9E-01
2316.0	2	2	7.8E-02
2379.7	2	4	4.4E-01
2507.9	4	2	1.1E-02
2538.2	4	2	1.6E-02
2580.1	2	2	1.8E-01
2609.0	4	6	1.0E-01
2609.8	4	4	1.9E-02
2665.6	4	2	5.7E-02
2709.2	4	6	1.7E-01
2710.7	4	4	3.7E-02
2767.9	2	4	1.26E+00
2826.2	4	2	8.0E-02
2918.3	4	6	4.2E-01
2921.5	4	4	7.6E-02
3229.8	4	2	1.73E-01
3519.2	4	6	1.24E+00
3529.4	4	4	2.20E-01
3775.7	2	2	6.25E-01
5350.5	4	2	7.05E-01

Thulium

Tm I

λ Å	g_i	g_k	A 10^8 s^{-1}
2513.8	8	10	6.9E-02
2527.0	8	8	1.7E-01
2596.5	8	10	1.6E-01
2601.1	8	6	1.7E-01
2622.5	8	10	6.1E-02
2841.1	6	6	2.0E-01
2854.2	8	6	2.7E-01
2914.8	8	8	7.7E-02
2933.0	8	6	1.0E-01
2973.2	8	8	2.3E-01
3046.9	8	8	1.8E-01
3081.1	8	8	1.9E-01
3122.5	6	6	5.2E-01
3142.4	6	6	8.8E-02
3172.7	8	8	1.8E-01
3233.7	8	10	5.1E-02
3247.0	6	8	3.0E-01
3251.8	6	4	5.2E-01
3380.7	6	8	2.0E-01
3406.0	6	8	1.5E-01
3410.1	8	10	1.0E-01
3416.6	8	8	5.7E-02
3418.6	6	6	1.1E-01
3563.9	8	6	9.8E-02
3567.4	8	10	4.2E-02
3744.1	8	8	9.5E-01
3751.8	8	10	1.9E-01
3798.5	6	4	1.2E+00
3807.7	6	6	3.9E-01
3883.1	8	6	1.0E+00
3887.4	8	8	3.8E-01
3916.5	6	8	1.5E+00
3949.3	6	6	1.0E+00
4022.6	6	8	4.0E-02
4044.5	6	4	2.9E-01
4094.2	8	6	9.0E-01
4105.8	8	10	6.0E-01
4138.3	6	4	7.0E-01
4158.6	6	8	5.5E-02
4187.6	8	8	6.1E-01
4203.7	8	10	2.5E-01
4222.7	6	8	1.5E-01
4271.7	6	6	1.1E-01
4359.9	8	6	1.3E-01
4386.4	8	8	4.2E-02
4394.4	6	4	1.1E-01
4643.1	6	6	3.4E-02
4681.9	6	8	3.9E-02
4691.1	6	6	3.9E-02
5307.1	8	10	2.3E-02

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
5658.3	6	8	1.0E-02
5675.8	8	10	1.3E-02
5760.2	6	6	1.3E-02
Tin			
Sn I			
2073.1	1	3	3.6E-02
2199.3	3	5	2.9E-01
2209.7	5	5	5.6E-01
2246.1	1	3	1.6E+00
2268.9	5	7	1.2E+00
2286.7	5	5	3.1E-01
2317.2	5	7	2.0E+00
2334.8	3	3	6.6E-01
2354.8	3	5	1.7E+00
2380.7	3	5	3.1E-02
2408.2	5	3	1.8E-01
2421.7	5	7	2.5E+00
2429.5	5	7	1.5E+00
2433.5	5	3	8.0E-03
2455.2	5	5	1.1E-02
2476.4	5	3	1.1E-02
2483.4	5	5	2.1E-01
2491.8	1	3	1.7E-01
2495.7	5	5	6.2E-01
2523.9	5	3	7.4E-02
2546.6	1	3	2.1E-01
2558.0	1	3	3.4E-01
2571.6	5	7	4.5E-01
2594.4	5	5	3.0E-01
2636.9	1	3	1.1E-01
2661.2	3	3	1.1E-01
2706.5	3	5	6.6E-01
2761.8	5	5	3.7E-03
2779.8	5	7	1.8E-01
2785.0	5	3	1.4E-01
2788.0	1	3	1.4E-01
2812.6	1	3	2.3E-01
2813.6	5	5	1.2E-01
2840.0	5	5	1.7E+00
2850.6	5	5	3.3E-01
2863.3	1	3	5.4E-01
2913.5	1	3	8.3E-01
3009.1	3	3	3.8E-01
3032.8	1	3	6.2E-01
3034.1	3	1	2.0E+00
3141.8	1	3	1.9E-01
3175.1	5	3	1.0E+00
3218.7	1	3	4.7E-02
3223.6	5	5	1.2E-03
3262.3	5	3	2.7E+00
3330.6	5	5	2.0E-01
3655.8	1	3	4.1E-02
3801.0	5	3	2.8E-01
4524.7	1	3	2.6E-01
5631.7	1	3	2.4E-02
5970.3	5	3	9.6E-02
6037.7	5	5	5.0E-02
6069.0	1	3	4.6E-02
6073.5	3	1	6.3E-02
6171.5	3	3	4.9E-02
Sn II			
2368.3	4	2	4.4E-03
2449.0	4	6	3.7E-01
2487.0	6	8	5.5E-01
3283.2	4	6	1.0E+00
3352.0	6	8	1.0E+00
3472.5	2	4	1.6E-01
3575.5	4	6	1.3E-01
5332.4	2	4	8.6E-01
5562.0	4	6	1.2E+00
5588.9	4	6	8.5E-01
5596.2	4	4	1.5E-01
5797.2	6	6	2.8E-01
5799.2	6	8	8.1E-01
6453.5	2	4	1.2E+00
6761.5	2	2	3.2E-01
6844.1	2	2	6.6E-01
Titanium			
Ti I			
2276.75	7	5	1.3E+00
2280.00	9	7	9.4E-01
2299.86	5	5	6.9E-01
2302.75	7	7	5.7E-01
2305.69	9	9	5.2E-01
2424.26	9	9	1.7E-01
2520.54	5	3	3.8E-01
2529.87	7	5	3.8E-01
2541.92	9	7	4.3E-01
2599.91	5	5	6.7E-01
2605.16	7	7	6.4E-01
2611.29	9	9	6.4E-01
2611.47	7	5	3.3E-01
2619.94	9	7	2.1E-01
2631.55	7	7	1.7E-01
2632.42	5	5	2.7E-01
2641.12	5	3	1.8E+00
2644.28	7	5	1.4E+00
2646.65	9	7	1.5E+00
2733.27	5	5	1.9E+00
2735.30	3	1	4.1E+00
2912.07	5	7	1.3E+00
2942.00	5	5	1.0E+00
2948.26	7	7	9.3E-01
2956.13	9	9	9.7E-01
2956.80	7	5	1.8E-01
3186.45	5	7	8.0E-01
3191.99	7	9	8.5E-01
3199.92	9	11	9.4E-01
3341.88	5	7	6.5E-01
3354.63	7	9	6.9E-01
3370.44	5	3	7.6E-01
3371.45	9	11	7.2E-01
3377.58	7	5	6.9E-01
3385.94	9	7	5.0E-01
3635.46	5	7	8.04E-01
3642.68	7	9	7.74E-01
3653.50	9	11	7.54E-01
3724.57	9	9	9.1E-01
3725.16	5	3	7.3E-01
3729.81	5	5	4.27E-01
3741.06	7	7	4.17E-01
3752.86	9	9	5.04E-01
3786.04	5	3	1.4E+00
3948.67	5	3	4.85E-01
3956.34	7	5	3.00E-01
3958.21	9	7	4.05E-01
3981.76	5	5	3.76E-01
3989.76	7	7	3.79E-01
3998.64	9	9	4.08E-01
4013.24	7	5	2.0E-01
4055.01	1	3	2.8E-01
4060.26	3	5	2.4E-01
4064.20	3	3	2.4E-01
4065.09	3	1	7.0E-01
4186.12	9	9	2.10E-01
4266.23	5	5	3.1E-01
4284.99	5	5	3.2E-01
4289.07	5	5	3.0E-01
4290.93	3	3	4.5E-01
4295.75	3	1	1.3E+00
4393.93	9	11	3.3E-01
4417.27	11	9	3.6E-01
4449.14	11	11	9.7E-01
4450.90	9	9	9.6E-01
4453.31	5	5	5.98E-01
4453.71	7	7	4.7E-01
4455.32	7	7	4.8E-01
4457.43	9	9	5.6E-01
4465.81	5	7	3.28E-01
4481.26	7	7	5.7E-01
4496.15	7	5	4.4E-01
4518.02	7	9	1.72E-01
4522.80	5	7	1.9E-01
4527.31	3	5	2.2E-01
4533.24	11	11	8.83E-01
4534.78	9	9	6.87E-01
4544.69	5	3	3.3E-01
4548.76	7	5	2.85E-01
4552.45	9	7	2.1E-01
4563.43	9	11	2.1E-01
4617.27	7	9	8.51E-01
4623.10	5	7	5.74E-01
4639.94	3	3	6.64E-01
4640.43	3	1	5.0E-01
4645.19	3	1	8.57E-01
4650.02	5	3	2.6E-01
4742.79	9	9	5.3E-01
4758.12	11	11	7.13E-01
4759.27	13	13	7.40E-01
4778.26	9	9	2.0E-01
4805.42	5	7	5.8E-01
4840.87	5	5	1.76E-01
4856.01	13	15	5.2E-01
4885.08	11	13	4.90E-01

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
4913.62	7	9	4.44E-01
4928.34	3	5	6.2E-01
4981.73	11	13	6.60E-01
4989.14	7	5	3.25E-01
4991.07	9	11	5.84E-01
4999.50	7	9	5.27E-01
5000.99	9	7	3.52E-01
5007.21	5	7	4.92E-01
5014.28	3	5	6.8E-01
5036.47	7	9	3.94E-01
5038.40	5	7	3.87E-01
5062.11	5	3	2.98E-01
5210.39	9	9	3.57E-02
5222.69	3	3	1.95E-01
5224.30	11	11	3.6E-01
5259.98	5	7	2.3E-01
5351.07	7	7	3.4E-01
5503.90	11	9	2.6E-01
5774.04	9	11	5.5E-01
5785.98	11	13	6.1E-01
5804.27	13	15	6.8E-01
6098.66	9	7	2.5E-01
6220.46	9	7	1.8E-01
Ti II			
2440.91	4	4	5.1E-01
2451.18	6	6	4.5E-01
2525.59	10	8	5.6E-01
2531.28	8	6	4.9E-01
2534.63	6	4	5.4E-01
2535.89	4	2	6.8E-01
2555.99	6	8	3.2E-01
2635.44	4	4	1.9E+00
2638.56	6	6	1.7E+00
2642.02	8	8	1.9E+00
2645.86	10	10	2.7E+00
2746.54	6	8	2.6E+00
2751.59	8	10	3.7E+00
2752.68	8	10	1.1E+00
2757.62	6	8	7.2E-01
2758.35	4	6	9.9E-01
2758.79	2	4	4.4E-01
2764.28	4	4	7.4E-01
2804.82	6	8	4.6E+00
2810.30	8	10	5.1E+00
2817.83	10	12	3.8E+00
2819.87	8	8	6.5E-01
2821.26	6	8	7.9E-01
2827.12	8	10	1.0E+00
2828.06	12	14	4.4E+00
2828.64	6	6	1.2E+00
2828.83	10	10	9.1E-01
2834.02	10	12	7.9E-01
2836.47	8	8	1.2E+00
2839.64	12	12	8.3E-01
2845.93	10	10	1.2E+00
2851.11	2	4	4.1E-01
2856.10	12	12	1.5E+00
2862.33	4	6	4.0E-01
2877.47	8	8	5.7E-01
2884.13	10	10	5.2E-01
2910.65	8	8	4.6E-01
2926.64	10	8	8.9E-01
2931.10	6	6	3.2E+00
2936.02	4	6	2.7E+00
2938.57	6	8	2.4E+00
2941.90	8	10	1.8E+00
2942.97	8	8	1.1E+00
2945.30	10	12	2.7E+00
2952.00	8	8	3.0E-01
2954.59	10	12	4.0E+00
2958.80	8	10	4.0E+00
2979.06	4	6	1.2E+00
2990.06	6	8	5.6E-01
3017.17	12	12	3.6E-01
3022.64	10	10	1.2E+00
3023.67	8	8	1.0E+00
3029.76	10	10	3.5E-01
3056.75	2	4	3.2E-01
3058.08	6	6	5.0E-01
3066.34	4	4	3.3E-01
3071.25	6	4	3.6E-01
3072.99	4	2	1.6E+00
3075.23	6	4	1.13E+00
3078.65	8	6	1.09E+00
3081.52	10	8	1.1E+00
3088.04	10	8	1.25E+00
3089.44	8	6	1.3E+00
3097.20	4	6	4.4E-01
3103.81	10	8	1.1E+00
3105.10	2	4	6.3E-01
3106.26	6	6	7.8E-01
3117.67	4	2	1.1E+00
3119.83	6	4	5.9E-01
3127.86	6	6	1.6E+00
3128.50	8	8	1.1E+00
3161.23	4	2	5.9E-01
3161.80	6	4	4.6E-01
3162.59	8	6	3.9E-01
3168.55	10	8	4.1E-01
3181.73	6	8	4.6E-01
3182.54	4	6	4.3E-01
3189.49	4	4	9.2E-01
3190.91	6	8	1.3E+00
3202.56	4	6	1.1E+00
3224.25	12	10	7.0E-01
3228.62	4	2	2.0E+00
3232.29	8	6	6.0E-01
3234.51	10	10	1.38E+00
3236.13	4	4	7.0E-01
3236.58	8	8	1.11E+00
3239.04	6	6	9.87E-01
3239.66	6	4	9.4E-01
3241.99	4	4	1.16E+00
3251.91	6	4	3.38E-01
3252.92	8	6	3.9E-01
3272.07	2	4	3.2E-01
3278.28	4	4	9.6E-01
3278.91	6	4	1.0E+00
3282.32	2	2	1.6E+00
3287.66	8	10	1.4E+00
3315.32	2	4	3.8E-01
3321.70	4	4	7.2E-01
3322.94	10	10	3.96E-01
3329.46	8	8	3.25E-01
3332.11	6	4	1.1E+00
3340.34	4	4	3.6E-01
3361.23	8	10	1.1E+00
3372.80	6	8	1.11E+00
3383.77	4	6	1.09E+00
3452.49	2	2	7.7E-01
3456.40	4	4	8.2E-01
3465.56	4	2	4.1E-01
3483.63	10	8	9.7E-01
3492.37	8	6	9.8E-01
3504.90	10	10	8.2E-01
3510.86	8	8	9.3E-01
3520.27	2	4	4.8E-01
3535.41	4	6	5.5E-01
3641.33	4	2	4.9E-01
3706.23	4	4	3.1E-01
3741.64	6	6	6.2E-01
3757.70	4	4	4.1E-01
3759.30	8	8	9.4E-01
3761.33	6	6	9.9E-01
4911.18	6	4	3.2E-01
Ti III			
865.79	5	3	6.6E+01
1002.37	5	5	7.6E+00
1004.67	7	5	4.3E+01
1005.80	3	3	1.3E+01
1007.16	5	3	3.8E+01
1008.12	3	1	5.1E+01
1286.37	9	9	2.0E+00
1289.30	7	7	2.2E+00
1291.62	5	5	2.4E+00
1293.23	9	7	1.0E+00
1298.97	7	5	4.9E+00
1327.59	5	3	3.2E+00
1420.44	1	3	1.2E+00
1421.63	3	1	4.0E+00
1422.41	5	5	3.0E+00
1424.14	5	3	1.6E+00
1455.19	9	7	6.4E+00
1498.70	5	5	2.8E+00
2007.36	3	3	3.4E+00
2007.60	1	3	1.2E+00
2010.80	5	3	5.4E+00
2097.30	5	7	3.3E+00
2099.86	3	5	2.5E+00
2104.86	3	3	1.1E+00
2105.09	1	3	1.7E+00
2199.22	3	3	5.7E+00
2237.77	7	7	2.4E+00
2331.35	3	1	4.3E+00
2331.66	3	3	1.2E+00

λ Å	Weights g_i	g_k	*A* 10^8 s^{-1}
2339.00	5	3	3.0E+00
2346.79	7	5	3.3E+00
2374.99	5	3	4.0E+00
2413.99	5	7	3.8E+00
2516.05	7	9	3.4E+00
2567.56	3	3	2.3E+00
2984.75	5	5	1.9E+00
3066.51	3	3	2.5E+00
3228.89	3	3	1.5E+00
3278.31	7	9	3.4E+00
3320.94	3	5	2.8E+00
3340.20	7	9	3.7E+00
3346.18	9	11	3.7E+00
3354.71	11	13	4.4E+00
3397.24	3	1	1.8E+00
3404.46	3	3	1.8E+00
3417.62	3	5	1.9E+00
3915.47	9	11	2.1E+00
4119.14	5	5	9.9E-01
4213.26	9	11	2.2E+00
4215.53	9	11	2.2E+00
4247.62	11	13	1.1E+00
4248.54	5	7	2.3E+00
4250.09	3	5	9.5E-01
4259.01	11	13	9.4E-01
4269.84	9	11	1.7E+00
4285.61	13	15	3.0E+00
4288.66	11	13	1.1E+00
4296.70	11	13	1.6E+00
4319.56	9	11	1.1E+00
4343.25	3	1	1.0E+00
4378.94	3	5	1.6E+00
4433.91	11	13	1.8E+00
4440.66	1	3	1.2E+00
4533.26	3	5	1.5E+00
4576.53	9	7	1.3E+00
4628.07	3	1	1.5E+00
4652.86	7	9	2.6E+00
4874.00	5	7	1.5E+00
4914.32	3	3	1.1E+00
4971.19	9	11	2.1E+00
5083.80	5	3	9.7E-01
5278.33	3	3	9.4E-01
7506.87	11	13	1.1E+00
Ti IV			
423.49	4	6	4.9E+01
424.16	6	8	5.3E+01
433.63	4	2	5.5E+00
433.76	6	4	5.0E+00
729.36	4	2	5.7E+00
1183.64	2	2	6.9E+00
1195.21	4	2	1.4E+01
1451.74	2	4	1.8E+01
1467.34	4	6	2.1E+01
2067.56	2	4	5.1E+00
2103.16	2	2	5.0E+00
2541.79	4	6	6.9E+00
2546.88	6	8	7.4E+00

λ Å	Weights g_i	g_k	*A* 10^8 s^{-1}
2862.60	4	2	4.1E+00
3576.44	4	6	4.6E+00
Ti VIII			
249	6	4	1.0E+01
258.610	6	8	7.5E+02
269.533	4	6	6.0E+02
272.037	4	4	4.3E+02
272.843	6	4	6.2E+01
276.701	2	4	9.3E+01
277.813	4	4	3.8E+02
289.375	2	4	3.6E+01
478.971	4	4	1.7E+01
480.376	6	6	1.5E+01
Ti IX			
267.941	5	7	5.1E+02
278.713	5	7	4.7E+02
281.446	3	1	3.2E+02
285.128	1	3	4.1E+02
433.567	1	3	6.9E+00
439.513	3	3	7.5E+00
439.745	3	1	2.1E+01
447.484	5	5	1.6E+01
447.701	5	3	6.5E+00
507.174	3	5	6.5E+00
516.215	5	7	6.9E+00
Ti X			
253	4	6	2.1E+02
254	6	8	2.3E+02
281	2	2	1.1E+02
289.579	2	4	2.5E+02
290.294	4	6	1.1E+02
291	4	2	1.8E+02
291	2	2	2.3E+02
292	6	8	1.1E+02
293.684	6	8	2.97E+02
293.798	6	6	1.7E+02
295.584	4	6	2.9E+02
296	4	6	1.4E+02
297	4	6	9.9E+01
298	4	6	4.3E+02
302	2	2	1.6E+02
305	2	4	2.5E+02
317	2	2	1.5E+02
355.815	2	2	1.3E+02
360.133	4	4	2.19E+02
363	4	2	2.1E+02
363	6	6	1.3E+02
365.628	4	2	1.2E+02
382	4	6	1.8E+02
385	6	8	1.8E+02
389.99	6	4	1.1E+02
Ti XI			
65.403	1	3	5.1E+02
87.725	1	3	8.5E+02
266	5	7	1.8E+02

λ Å	Weights g_i	g_k	*A* 10^8 s^{-1}
308.250	3	5	1.3E+02
313.229	5	7	1.6E+02
318	3	1	1.4E+02
322.75	5	7	1.99E+02
323	1	3	1.8E+02
327.192	3	5	2.9E+02
332	3	1	3.25E+02
386.140	1	3	1.48E+02
408	7	9	1.37E+02
425.74	3	1	1.2E+02
446.69	3	1	1.2E+02
453	5	7	1.3E+02
Ti XII			
52.896	2	4	1.61E+02
53.140	4	6	1.9E+02
53.433	2	4	2.1E+02
53.457	2	2	2.1E+02
55.181	2	4	2.4E+02
55.443	4	6	2.81E+02
59.133	2	4	3.72E+02
59.435	4	6	4.41E+02
60.701	2	4	3.4E+02
60.762	2	2	3.5E+02
61.286	4	2	1.8E+02
62.433	4	6	2.08E+02
62.470	6	8	2.22E+02
65.540	4	6	3.2E+02
65.577	6	8	3.5E+02
67.171	2	4	6.2E+02
67.555	4	6	7.2E+02
70.986	4	6	5.7E+02
71.031	6	8	6.1E+02
71.545	2	2	1.8E+02
71.987	4	2	3.48E+02
82.121	2	4	5.9E+02
82.307	4	6	1.13E+03
82.344	2	2	5.8E+02
82.368	6	8	1.2E+03
89.844	2	4	9.9E+02
90.512	4	6	1.16E+03
90.547	4	4	1.9E+02
116.497	4	6	3.0E+03
116.597	6	8	3.2E+03
116.62	6	6	2.1E+02
139.884	6	4	2.6E+02
140.361	4	2	2.9E+02
141.6	4	6	1.7E+02
141.7	6	8	1.7E+02
169.7	4	6	2.8E+02
169.8	6	8	2.9E+02
207.2	2	4	1.5E+02
208.5	4	6	1.8E+02
252.8	4	6	4.8E+02
253.1	6	8	5.2E+02
257.5	4	2	2.4E+02
Ti XIII			
23.356	1	3	1.02E+05

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
23.698	1	3	1.2E+04
23.991	1	3	3.4E+02
26.641	1	3	4.06E+03
26.960	1	3	3.06E+03
117.1	3	3	1.3E+02
117.3	3	1	2.8E+02
120.2	5	3	5.4E+02
120.2	7	5	4.4E+02
128.7	3	3	1.2E+02
Ti XIV			
21.341	4	6	9.8E+03
21.522	2	4	4.5E+04
21.657	4	4	1.3E+04
21.733	4	4	8.8E+04
21.82	4	2	6.4E+04
21.883	2	4	7.0E+04
21.958	2	4	1.2E+04
22.05	2	2	1.4E+04
24.592	4	2	6.1E+03
24.891	2	2	7.5E+03
Ti XV			
20.19	5	7	6.9E+03
20.234	5	7	1.9E+04
20.234	3	3	4.9E+04
20.246	1	3	4.2E+04
20.250	5	3	6.5E+03
20.29	3	3	1.1E+04
20.30	1	3	3.4E+04
20.30	1	1	5.8E+04
20.313	5	3	7.5E+04
20.418	5	7	8.0E+04
20.538	3	3	3.8E+04
20.54	3	1	4.1E+04
20.551	1	3	1.3E+04
20.689	5	7	4.3E+04
20.698	1	3	1.1E+05
20.771	5	3	1.1E+04
20.897	5	7	2.85E+04
20.928	5	5	8.4E+03
21.065	3	3	1.1E+04
21.079	1	3	1.58E+04
21.102	3	5	1.3E+04
22.482	5	3	6.4E+03
22.936	5	5	1.1E+04
22.966	5	3	1.1E+04
23.034	1	3	6.3E+03
Ti XVI			
110.561	4	2	3.36E+02
116.198	4	4	1.45E+02
118.215	6	4	7.4E+02
121.382	4	2	2.4E+02
124.805	4	2	6.1E+02
129.075	4	2	3.81E+02
134.724	2	2	2.6E+02
138.800	6	4	3.5E+02
143.459	4	4	2.8E+02

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
145.665	6	6	2.3E+02
157.812	4	2	1.32E+02
161.168	4	4	1.2E+02
163.610	4	2	1.92E+02
169.740	4	6	1.0E+02
176.267	2	2	2.45E+02
178.240	4	4	2.52E+02
Ti XVII			
18.05	3	3	4.5E+04
18.13	5	3	2.4E+04
18.13	1	3	8.1E+04
18.176	5	7	9.2E+04
123.654	3	3	2.3E+02
124.553	5	3	5.2E+02
127.782	5	3	4.6E+02
135.202	3	1	2.93E+02
136.160	5	3	1.95E+02
136.393	3	3	1.14E+02
141.948	5	5	3.87E+02
142.589	1	3	1.35E+02
144.405	5	5	9.4E+01
146.067	7	5	2.6E+02
154.133	3	1	1.63E+02
156.54	3	1	1.44E+02
158.469	5	5	1.4E+02
159.62	5	3	1.03E+02
163.049	3	1	6.2E+02
186.863	5	5	2.66E+02
207.73	3	1	1.07E+02
Ti XVIII			
17.22	2	4	7.3E+04
17.365	4	6	8.6E+04
17.39	4	4	1.4E+04
133.852	2	4	5.2E+01
144.759	4	4	3.2E+02
150.15	6	4	1.15E+02
153.15	4	2	1.97E+02
153.23	2	4	6.7E+01
159.00	4	4	1.16E+02
166.225	6	4	1.54E+02
179.902	2	4	6.3E+01
189.663	6	6	9.6E+01
191.23	4	4	6.6E+01
197.838	4	6	4.56E+01
208.07	4	4	1.2E+02
Ti XIX			
15.67	3	1	3.3E+04
15.68	5	5	2.7E+04
15.74	5	7	2.7E+04
15.75	3	5	2.4E+04
15.83	1	3	3.2E+04
15.86	1	3	2.9E+04
16.02	3	1	3.1E+04
16.18	3	5	3.8E+04
16.41	1	3	6.1E+04
16.43	3	5	8.2E+04

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
16.46	3	3	4.4E+04
16.51	5	7	1.0E+05
16.55	5	5	2.7E+04
16.61	3	1	8.0E+04
16.64	3	3	5.3E+04
16.69	1	3	1.02E+05
16.71	3	5	7.3E+04
16.72	5	3	3.3E+04
16.72	5	5	7.3E+04
16.74	5	7	1.2E+05
16.77	3	3	2.6E+04
16.80	5	7	1.81E+05
16.85	3	5	4.4E+04
17.08	3	5	8.3E+04
17.36	1	3	9.5E+04
Ti XX			
2.629	2	4	4.9E+04
2.6295	4	4	3.2E+06
2.631	2	2	6.1E+05
2.6319	2	4	1.5E+06
2.632	2	2	2.7E+06
2.6355	4	6	1.2E+06
8.621	4	2	1.1E+06
9.788	4	6	5.26E+03
10.046	2	4	7.29E+03
10.109	4	6	8.6E+03
*10.278	2	6	8.4E+03
10.620	2	4	1.34E+04
10.690	4	6	1.58E+04
*11.452	2	6	1.7E+04
11.872	2	4	2.8E+04
11.958	4	6	3.4E+04
11.958	4	4	5.6E+03
15.211	2	4	3.50E+04
15.253	2	2	3.58E+04
15.907	2	4	8.84E+04
16.049	4	6	1.05E+05
16.067	4	4	1.8E+04
31.586	4	6	5.49E+03
45.650	2	4	9.6E+03
45.996	4	6	1.1E+04
Ti XXI			
2.0633	1	3	1.32E+05
2.1108	1	3	2.60E+05
2.2211	1	3	6.35E+05
2.497	3	1	2.4E+06
2.505	5	5	3.5E+05
2.505	1	3	1.4E+06
2.507	3	5	1.4E+06
2.508	3	5	7.9E+05
2.510	3	3	6.9E+05
2.510	1	3	9.6E+05
2.511	3	3	1.4E+06
2.512	5	5	1.8E+06
2.512	3	1	1.4E+06
2.513	3	1	2.7E+06
2.513	3	5	2.4E+06

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
2.514	5	3	1.2E+06
2.520	3	5	2.6E+05
2.527	3	1	1.2E+05
2.539	3	1	4.1E+05
2.6102	1	3	2.40E+06
2.6227	1	3	1.12E+05

Tungsten

W I

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
2879.4	1	3	2.4E-01
2911.0	1	3	7.7E-02
2923.5	7	9	1.54E-02
2935.0	3	5	1.5E-01
3013.8	7	9	6.4E-02
3016.5	9	11	9.27E-02
3017.4	7	9	1.21E-01
3024.9	3	3	1.4E-01
3046.4	3	5	5.8E-02
3049.7	7	5	1.7E-01
3064.9	5	7	1.1E-02
3084.9	5	5	1.3E-02
3093.5	7	9	4.4E-02
3107.2	5	7	2.33E-02
3108.0	7	9	1.58E-02
3145.5	9	9	4.8E-03
3170.2	7	5	6.0E-03
3176.6	3	5	2.12E-02
3183.5	7	7	2.64E-03
3184.4	5	3	2.3E-02
3191.6	1	3	3.2E-02
3198.8	7	9	4.6E-02
3207.3	7	9	3.0E-02
3208.3	5	5	4.4E-02
3215.6	9	11	2.1E-01
3221.9	5	7	1.61E-02
3223.1	5	3	3.53E-03
3232.5	9	9	2.4E-02
3235.1	7	5	2.68E-03
3259.7	7	7	1.3E-02
3300.8	7	9	8.1E-02
3311.4	7	5	5.6E-02
3363.3	9	7	6.6E-03
3371.0	7	5	1.0E-02
3371.4	3	3	6.7E-03
3386.1	7	7	2.64E-03
3413.0	7	9	9.7E-03
3459.5	9	9	2.04E-03
3510.0	7	9	5.2E-03
3545.2	1	3	3.2E-02
3570.6	5	3	6.7E-03
3606.1	3	5	9.6E-03
3617.5	7	7	1.1E-01
3631.9	3	5	1.3E-02
3675.6	9	11	1.20E-02
3682.1	9	11	2.0E-02
3707.9	7	7	2.9E-02
3757.9	7	9	1.38E-02
3760.1	5	7	1.99E-02
3768.5	3	3	3.47E-02
3780.8	7	5	4.2E-02
3809.2	7	5	9.0E-03
3817.5	7	7	3.1E-02
3829.1	3	3	3.83E-03
3835.1	5	5	5.2E-02
3846.3	3	5	2.14E-02
3847.5	1	3	8.3E-03
3864.3	5	5	5.6E-03
3868.0	7	9	4.6E-02
3881.4	7	7	3.6E-02
3968.5	1	3	5.07E-03
3975.5	9	11	4.1E-03
4001.4	9	9	5.6E-03
4008.8	7	9	1.63E-01
4019.3	5	3	6.7E-03
4028.8	1	3	2.0E-02
4045.6	7	5	2.88E-02
4055.2	7	9	1.79E-03
4070.0	7	5	3.60E-02
4070.6	3	5	5.6E-03
4074.4	7	7	1.0E-01
4088.3	5	3	4.13E-03
4102.7	9	7	4.9E-02
4115.6	11	11	4.8E-03
4137.5	5	7	8.4E-03
4171.2	7	9	8.6E-03
4203.8	9	7	4.9E-03
4219.4	9	7	6.1E-03
4244.4	9	11	1.38E-02
4269.4	7	5	3.04E-02
4283.8	9	7	1.69E-03
4294.6	7	5	1.2E-01
4302.1	7	7	3.6E-02
4355.2	9	9	5.1E-03
4361.8	9	7	1.64E-03
4378.5	7	5	3.48E-03
4458.1	3	5	4.2E-03
4466.3	7	5	1.5E-02
4472.5	13	11	1.55E-03
4484.2	3	5	5.6E-03
4492.3	9	11	3.6E-03
4495.3	11	11	3.3E-03
4504.8	9	7	7.0E-03
4552.5	9	9	1.42E-03
4586.8	1	3	4.20E-03
4592.6	7	9	3.4E-03
4609.9	7	9	1.42E-02
4613.3	9	9	2.9E-03
4634.8	9	9	8.8E-03
4659.9	1	3	1.0E-02
4680.5	7	7	1.4E-02
4720.4	3	5	3.22E-03
4729.6	7	5	7.8E-03
4752.6	3	3	5.20E-03
4757.5	7	5	2.72E-03
4757.8	11	9	4.1E-03
4788.4	9	11	2.6E-03
4843.8	5	5	1.9E-02
4886.9	9	11	8.1E-03
4924.6	13	11	1.75E-03
4931.6	7	5	1.0E-02
4948.6	9	11	1.36E-03
4972.6	9	11	3.9E-03
4982.6	1	3	4.17E-03
4986.9	11	9	6.3E-03
5006.2	9	7	1.2E-02
5015.3	7	9	5.4E-03
5040.4	3	5	5.2E-03
5053.3	3	3	1.9E-02
5071.5	13	11	3.4E-03
5117.6	11	11	1.61E-03
5124.2	5	5	4.0E-03
5141.2	7	9	1.12E-03
5224.7	7	5	1.2E-02
5243.0	9	7	1.1E-02
5254.5	7	5	3.86E-03
5268.6	9	9	1.4E-03
5500.5	11	9	6.9E-03
5514.7	5	3	7.3E-03
5537.7	9	11	2.2E-03
5617.1	7	7	1.47E-03
5631.9	9	7	1.43E-03
5660.7	13	11	6.8E-03
5675.4	5	5	2.20E-03
5796.5	9	7	2.21E-03
5891.6	7	7	1.47E-03
5947.6	5	7	2.40E-03
5965.9	7	5	1.0E-02
6021.5	5	3	8.7E-03
6081.4	5	3	4.7E-03
6203.5	7	7	3.0E-03
6285.9	7	5	6.6E-03
6292.0	3	5	2.26E-03
6303.2	9	9	1.84E-03
6404.2	5	7	1.50E-03
6439.7	9	9	1.29E-03
6445.1	7	5	6.4E-03
6532.4	3	5	4.6E-03
6538.1	11	9	2.7E-03
6563.2	5	5	2.04E-03
6814.9	9	9	1.46E-03
7285.8	13	11	1.47E-03
7569.9	5	3	3.73E-03
7664.9	5	3	3.80E-03
8017.2	5	7	1.6E-03
8358.7	5	7	1.89E-03
9381.4	9	7	1.53E-03

Uranium

U I

λ Å	Weights g_i	Weights g_k	A $10^8\ s^{-1}$
3553.0	13	13	2.0E-02
3553.0	9	7	1.4E-02
3553.4	15	13	2.2E-02
3554.5	11	9	8.4E-03
3554.9	15	17	7.9E-03
3555.3	13	15	2.7E-02
3555.8	13	11	4.1E-03
3556.9	13	11	7.5E-03

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
3557.8	13	13	2.9E-02
3558.0	11	13	1.6E-02
3558.6	9	7	3.9E-02
3559.4	7	9	1.5E-02
3560.3	9	7	6.4E-02
3561.4	15	13	5.5E-02
3561.5	9	9	2.5E-02
3561.8	13	11	5.7E-02
3563.7	13	13	2.9E-02
3563.8	7	7	1.1E-02
3565.0	13	11	2.9E-02
3566.0	13	15	1.7E-02
3566.6	11	11	2.4E-01
3568.8	13	13	3.8E-02
3569.1	17	15	1.1E-01
3569.4	9	9	1.5E-02
3570.1	13	11	1.3E-02
3570.2	11	9	5.3E-03
3570.6	13	15	2.7E-02
3570.7	15	15	1.2E-02
3571.2	11	11	6.3E-03
3571.6	17	15	1.3E-01
3572.9	13	15	1.5E-02
3573.9	13	11	4.0E-02
3574.1	13	15	3.5E-02
3574.8	13	15	1.9E-02
3577.1	17	15	4.3E-02
3577.5	15	13	7.8E-03
3577.8	11	11	8.3E-03
3577.9	13	13	2.3E-02
3578.3	13	11	2.0E-02
3580.0	9	9	1.2E-02
3580.2	11	9	2.9E-02
3580.4	11	13	7.5E-03
3580.9	13	13	2.1E-02
3582.6	13	13	2.9E-02
3584.6	7	5	2.4E-02
3584.9	13	15	1.8E-01
3585.4	11	11	1.9E-02
3585.8	11	9	2.8E-02
3587.8	9	11	1.3E-02
3588.3	7	9	1.8E-02
3589.7	11	13	2.1E-02
3589.8	15	13	5.9E-02
3590.7	9	7	2.2E-02
3591.7	11	9	5.3E-02
3593.0	11	11	1.4E-02
3593.2	13	15	4.2E-02
3593.7	11	11	7.2E-02

Vanadium
V I

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
3043.12	6	8	2.3E-01
3050.39	10	8	5.3E-01
3053.65	4	4	1.3E+00
3056.33	6	6	1.3E+00
3060.46	8	8	1.4E+00
3066.37	10	10	2.1E+00
3066.53	6	4	3.2E-01
3075.93	4	6	2.8E-01
3080.33	2	4	2.7E-01
3083.54	6	8	2.5E-01
3087.06	2	2	9.2E-01
3088.11	4	6	4.9E-01
3089.13	4	4	5.3E-01
3093.79	6	6	4.1E-01
3094.69	2	4	4.3E-01
3112.92	4	2	5.0E-01
3183.41	6	8	2.4E+00
3183.96	8	10	2.5E+00
3183.98	4	6	2.4E+00
3185.38	10	12	2.7E+00
3198.01	6	6	3.9E-01
3202.39	8	8	4.0E-01
3205.58	8	10	1.3E+00
3207.41	10	10	2.6E-01
3212.43	10	12	1.4E+00
3218.87	8	6	3.5E-01
3233.19	10	8	3.2E-01
3273.03	8	8	2.7E-01
3284.36	10	10	2.8E-01
3309.18	4	4	3.2E-01
3329.85	6	4	7.7E-01
3356.35	4	6	3.1E-01
3365.55	2	4	4.8E-01
3376.05	4	4	3.2E-01
3377.39	4	2	9.0E-01
3377.62	6	6	6.0E-01
3397.58	6	4	2.3E-01
3400.39	8	8	2.5E-01
3529.73	4	6	4.1E-01
3533.68	6	8	5.2E-01
3533.76	2	4	3.7E-01
3543.49	2	2	6.7E-01
3545.33	4	4	3.7E-01
3553.27	6	6	2.2E-01
3555.14	4	2	2.6E-01
3663.60	4	6	3.1E+00
3667.74	6	8	2.7E+00
3672.41	12	12	9.2E-01
3673.41	8	10	2.7E+00
3676.70	14	14	1.3E+00
3680.12	10	12	2.2E+00
3686.26	10	12	2.3E-01
3687.50	12	14	2.9E+00
3688.07	8	8	3.5E-01
3690.28	2	4	4.5E-01
3692.22	6	6	5.4E-01
3695.34	14	16	2.8E+00
3695.86	4	4	6.6E-01
3703.57	10	8	9.2E-01
3704.70	8	6	6.6E-01
3705.04	6	4	3.6E-01
3706.03	10	10	5.2E-01
3708.71	12	12	4.4E-01
3790.46	10	8	2.3E-01
3794.96	10	10	2.3E-01
3806.79	10	10	2.5E-01
3818.24	4	2	6.73E-01
3828.56	6	4	5.33E-01
3840.75	8	6	5.48E-01
3855.36	4	4	3.30E-01
3855.85	10	8	5.78E-01
3863.86	8	6	3.1E-01
3864.86	6	6	2.70E-01
3871.07	10	8	2.8E-01
3875.07	8	8	2.36E-01
3902.26	10	10	2.68E-01
3921.86	4	2	2.7E-01
3922.43	6	6	2.6E-01
3930.02	10	10	3.3E-01
3934.01	8	8	6.2E-01
3992.80	12	10	1.2E+00
3998.73	14	12	1.0E+00
4050.96	10	10	1.4E+00
4051.35	12	12	1.3E+00
4090.57	8	10	8.5E-01
4092.68	8	10	2.30E-01
4095.48	6	8	7.2E-01
4099.78	6	8	4.10E-01
4102.15	4	6	7.1E-01
4104.77	10	8	2.1E+00
4105.16	4	6	4.9E-01
4109.78	2	4	5.00E-01
4111.78	10	10	1.01E+00
4115.18	8	8	5.80E-01
4116.47	6	6	3.2E-01
4116.59	2	2	2.90E-01
4123.50	4	2	1.00E+00
4128.06	6	4	7.70E-01
4131.99	8	6	5.5E-01
4134.49	10	8	2.90E-01
4232.46	10	10	9.8E-01
4232.95	8	8	7.7E-01
4268.64	14	14	1.2E+00
4271.55	12	12	9.6E-01
4276.95	10	10	9.4E-01
4284.05	8	8	1.2E+00
4291.82	12	14	8.8E-01
4296.10	10	12	7.7E-01
4297.67	8	10	7.0E-01
4298.03	6	8	7.8E-01
4379.23	10	12	1.1E+00
4384.71	8	10	1.1E+00
4389.98	6	8	6.9E-01
4395.22	4	6	5.5E-01
4400.57	2	4	3.4E-01
4406.64	10	10	2.2E-01
4407.63	8	8	4.4E-01
4408.20	6	6	6.0E-01
4416.47	4	2	2.6E-01
4452.01	14	16	9.2E-01
4457.75	10	12	2.7E-01
4460.33	10	8	3.0E-01
4462.36	12	14	7.6E-01
4468.00	8	10	2.3E-01
4469.71	10	12	6.2E-01

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
4474.04	10	8	4.7E-01
4496.06	8	6	4.0E-01
4514.18	6	4	3.3E-01
4524.21	12	10	3.0E-01
4525.17	4	2	4.1E-01
4529.58	10	8	2.4E-01
4545.40	10	12	7.6E-01
4560.72	8	10	7.0E-01
4571.79	6	8	6.0E-01
4578.73	4	6	6.8E-01
4706.16	6	4	2.4E-01
4757.47	4	2	7.6E-01
4766.62	6	4	5.6E-01
4776.36	8	6	5.1E-01
4786.50	10	8	4.7E-01
4796.92	12	10	4.8E-01
4807.52	14	12	5.8E-01
5193.00	12	12	4.0E-01
5195.39	8	8	2.3E-01
5234.08	10	10	4.9E-01
5240.87	12	12	4.3E-01
5415.25	12	14	3.1E-01
5487.91	12	10	2.9E-01
5507.75	10	8	3.5E-01
6090.21	8	6	2.60E-01

V II

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
2527.90	13	13	6.1E-01
2528.47	9	9	5.2E-01
2528.83	11	11	5.3E-01
2554.04	9	9	5.4E-01
2589.10	9	9	7.7E-01
2640.86	5	7	1.2E+00
2677.80	3	5	3.4E-01
2679.33	7	7	3.4E-01
2683.09	1	3	3.4E-01
2687.96	9	9	7.6E-01
2689.88	3	1	9.2E-01
2690.25	7	5	3.4E-01
2690.79	5	3	5.2E-01
2700.94	9	11	3.5E-01
2706.17	7	9	3.4E-01
2734.22	9	7	6.2E-01
2753.41	13	11	4.2E-01
2784.20	9	9	1.3E+00
2787.91	7	9	5.0E-01
2825.86	9	7	1.2E+00
2843.82	7	5	9.9E-01
2847.57	9	7	4.6E-01
2854.34	11	9	5.0E-01
2862.31	11	11	3.6E-01
2868.11	5	3	2.1E+00
2869.13	13	11	4.8E-01
2882.49	5	5	4.2E-01
2884.78	3	3	5.6E-01
2889.61	3	1	1.9E+00
2891.64	5	3	1.4E+00
2892.43	9	9	3.6E-01
2892.65	7	5	1.3E+00
2893.31	9	7	1.2E+00
2903.07	3	5	3.4E-01
2906.45	7	7	7.8E-01
2908.81	11	9	1.6E+00
2910.01	5	5	1.1E+00
2910.38	3	3	1.2E+00
2911.05	7	9	3.7E-01
2912.46	11	9	5.0E-01
2915.88	9	7	4.9E-01
2924.02	11	11	1.7E+00
2924.63	9	9	1.2E+00
2930.80	7	7	5.8E-01
2941.37	11	9	3.5E-01
2944.57	9	7	7.6E-01
2948.08	9	11	4.0E-01
2952.07	7	5	7.2E-01
2955.58	7	9	3.3E-01
2968.37	7	9	7.0E-01
2972.26	5	7	5.2E-01
2973.98	9	11	3.5E-01
2985.18	7	9	4.4E-01
3001.20	7	7	7.5E-01
3014.82	5	3	8.9E-01
3016.78	7	5	5.0E-01
3020.21	9	7	5.0E-01
3048.21	11	13	7.0E-01
3063.25	9	11	1.0E+00
3100.94	7	7	5.8E-01
3113.56	11	11	5.0E-01
3122.89	11	13	7.6E-01
3134.93	13	13	5.9E-01
3136.50	11	11	5.3E-01
3139.73	9	9	5.2E-01
3151.32	3	5	4.4E-01
3190.69	9	9	3.3E-01
3250.78	11	9	5.2E-01
3251.87	5	7	3.5E-01
3271.12	7	9	6.9E-01
3276.12	9	11	5.2E-01
3279.84	9	11	5.8E-01
3287.71	5	7	7.5E-01
3337.85	5	7	5.3E-01
3517.30	9	7	3.8E-01
3530.77	5	3	4.5E-01
3545.19	7	5	4.3E-01
3556.80	9	7	5.1E-01
3592.01	7	5	4.4E-01
3618.92	3	5	3.3E-01

V III

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
2318.06	8	10	4.6E+00
2323.82	6	8	3.8E+00
2330.42	10	10	3.2E+00
2331.75	8	8	2.5E+00
2334.21	6	6	2.2E+00
2337.13	4	4	2.7E+00
2343.10	6	8	3.6E+00
2358.73	6	8	4.2E+00
2366.31	8	10	4.2E+00
2371.06	10	12	5.2E+00
2373.06	4	6	2.9E+00
2382.46	8	10	5.0E+00
2393.58	6	8	4.3E+00
2404.18	4	6	2.5E+00
2516.14	10	10	3.7E+00
2521.55	8	8	3.5E+00
2548.21	6	4	2.0E+00
2554.22	8	6	1.2E+00
2593.05	6	6	2.8E+00
2595.10	8	8	2.8E+00

V IV

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
677.345	9	9	6.7E+00
680.632	9	7	1.2E+01
681.145	7	5	1.1E+01
682.455	7	7	6.5E+00
682.923	5	5	6.9E+00
684.450	7	5	7.7E+00
691.530	5	3	1.1E+01
723.537	3	1	1.5E+01
724.068	5	5	1.1E+01
724.809	5	3	5.6E+00
737.854	9	7	2.4E+01
750.110	5	5	1.0E+01
884.146	1	3	4.7E+00
1071.05	5	5	6.1E+00
1110.72	3	3	5.0E+00
1112.20	7	7	6.3E+00
1112.44	5	5	5.0E+00
1127.84	7	5	8.9E+00
1131.26	9	7	9.4E+00
1194.46	7	5	1.0E+01
1226.52	5	5	1.5E+01
1243.72	3	1	9.4E+00
1247.07	5	3	4.7E+00
1272.97	3	1	2.7E+01
1304.17	3	5	1.5E+01
1305.42	5	7	7.0E+00
1308.06	7	9	7.9E+00
1309.50	5	5	8.7E+00
1312.72	7	7	8.6E+00
1317.57	5	7	8.7E+00
1321.92	7	9	9.9E+00
1326.81	3	5	4.0E+00
1329.29	5	5	1.5E+01
1329.97	3	3	4.8E+00
1330.36	1	3	6.0E+00
1331.67	3	1	1.7E+01
1332.46	5	3	7.5E+00
1334.49	9	9	8.3E+00
1355.13	7	9	2.5E+01
1356.53	5	3	4.9E+00
1395.00	5	7	1.4E+01
1400.42	5	7	7.5E+00
1403.62	7	9	8.4E+00
1412.69	3	3	1.1E+01
1414.41	5	7	1.2E+01
1414.84	5	5	4.6E+00

λ Å	Weights g_i	Weights g_k	A 10^8 s^{-1}
1418.53	7	7	5.2E+00
1419.58	7	9	1.3E+01
1423.72	3	5	7.1E+00
1426.65	9	11	2.2E+01
1429.11	5	5	5.0E+00
1434.84	7	7	5.4E+00
1451.04	3	3	7.0E+00
1454.00	5	3	1.1E+01
1520.14	5	7	7.2E+00
1522.49	3	5	5.5E+00
1601.92	3	3	1.2E+01
1611.88	7	7	5.2E+00
1806.18	5	3	7.3E+00
1809.85	3	1	7.2E+00
1817.68	5	3	4.8E+00
1825.84	7	5	5.3E+00
1861.56	5	7	6.6E+00
1939.07	7	9	5.8E+00
1951.43	5	7	5.0E+00
1963.10	3	5	4.8E+00
1997.72	7	7	4.7E+00
2084.43	5	5	4.0E+00
2120.05	7	9	8.1E+00
2141.20	3	5	7.0E+00
2146.83	7	9	6.6E+00
2149.85	5	7	5.1E+00
2151.09	7	9	4.3E+00
2155.34	11	13	1.2E+01
2446.80	9	11	5.3E+00
2570.72	9	11	7.6E+00
3284.56	7	9	5.3E+00
3496.42	7	9	4.4E+00
3514.25	9	11	4.7E+00
Xenon			
Xe I			
1043.8	1	3	5.9E-01
1047.1	1	3	1.3E+00
1050.1	1	3	8.5E-02
1056.1	1	3	2.45E+00
1061.2	1	3	1.9E-01
1068.2	1	3	3.99E+00
1085.4	1	3	4.10E-01
1099.7	1	3	4.34E-01
1110.7	1	3	1.5E+00
1129.3	1	3	4.4E-02
1170.4	1	3	1.6E+00
1192.0	1	3	6.2E+00
1250.2	1	3	1.4E-01
1295.6	1	3	2.46E+00
1469.6	1	3	2.81E+00
4501.0	5	3	6.2E-03
4524.7	5	5	2.1E-03
4624.3	5	5	7.2E-03
4671.2	5	7	1.0E-02
4807.0	3	1	2.4E-02
7119.6	7	9	6.6E-02
7967.3	1	3	3.0E-03
8409.2	5	3	1.0E-02
Xe II			
4180.1	4	4	2.2E+00
4330.5	6	8	1.4E+00
4414.8	6	6	1.0E+00
4603.0	4	4	8.2E-01
4844.3	6	8	1.1E+00
4876.5	6	8	6.3E-01
5260.4	2	4	2.2E-01
5262.0	4	4	8.5E-01
5292.2	6	6	8.9E-01
5372.4	4	2	7.1E-01
5419.2	4	6	6.2E-01
5439.0	4	2	7.4E-01
5472.6	8	8	9.9E-02
5531.1	8	6	8.8E-02
5719.6	4	6	6.1E-02
5976.5	4	4	2.8E-01
6036.2	6	6	7.5E-02
6051.2	8	6	1.7E-01
6097.6	6	4	2.6E-01
6270.8	4	6	1.8E-01
6277.5	4	6	3.6E-02
6805.7	8	6	6.1E-02
6990.9	10	8	2.7E-01
Ytterbium			
Yb I			
2464.5	1	3	9.1E-01
2672.0	1	3	1.18E-01
3464.4	1	3	6.2E-01
3988.0	1	3	1.76E+00
5556.5	1	3	1.14E-02
Yb II			
3289.4	2	4	1.8E+00
3694.2	2	2	1.4E+00
Yttrium			
Y I			
2948.41	4	4	3.5E-01
2974.59	4	6	3.5E-01
2984.25	6	8	4.8E-01
2995.26	6	4	5.1E-02
2996.94	4	6	8.4E-02
3005.26	4	4	4.8E-02
3022.28	6	6	6.6E-02
3045.36	6	6	1.07E-01
3053.95	6	4	1.9E-03
3155.65	4	6	2.7E-03
3172.84	4	4	9.9E-03
3185.96	6	8	1.2E-03
3209.38	6	6	3.0E-03
3227.16	6	4	1.10E-03
3484.05	4	6	1.2E-02
3549.66	6	6	1.0E-03
3552.69	4	4	2.3E-01
4077.36	4	6	1.1E+00
4083.71	4	4	2.5E-01
4102.36	6	8	1.3E+00
4128.30	6	6	1.6E+00
4142.84	4	4	1.6E+00
4167.51	6	6	2.38E-01
4235.93	6	4	3.0E-01
4352.40	4	4	6.7E-03
4379.33	6	4	7.83E-01
4385.47	4	4	6.9E-02
4394.01	8	8	1.9E-02
4409.70	4	6	2.7E-03
4417.43	10	8	3.2E-02
4437.34	6	6	8.64E-02
4443.65	10	8	1.1E-01
4459.01	4	6	1.8E-02
4476.95	8	6	2.8E-01
4491.74	10	10	2.3E-02
4514.01	4	6	3.34E-01
4527.78	8	6	8.33E-01
4534.09	6	8	4.4E-02
4544.31	6	6	4.10E-01
4559.36	2	4	4.0E-01
4581.33	6	4	1.5E-01
4613.00	6	4	1.8E-01
4643.70	4	6	1.8E-01
4653.78	4	6	1.6E-01
4674.85	6	8	1.3E-01
4725.84	4	4	1.5E-01
4762.96	6	4	4.2E-02
4780.16	2	4	8.9E-02
4781.03	8	10	1.0E-01
4799.30	6	8	1.6E-01
4804.31	6	4	2.6E-01
4804.80	4	4	3.84E-01
4821.63	6	6	1.0E-01
4845.67	8	8	6.8E-01
4852.68	6	6	6.2E-01
4856.71	6	6	2.0E-01
4859.84	4	4	7.26E-01
4893.44	6	4	2.2E-01
4900.08	8	6	2.0E-01
4906.11	10	8	1.2E-01
4950.01	8	6	2.0E-02
4963.49	4	4	1.4E-02
4981.97	4	6	4.7E-03
5004.44	6	4	1.2E-02
5205.01	4	4	8.4E-03
5258.47	6	6	2.9E-03
5271.82	8	6	1.1E-02
5380.63	6	4	3.2E-01
5381.24	4	4	9.9E-03
5388.39	6	8	1.1E-02
5390.81	8	6	2.9E-02
5401.88	6	8	6.0E-03
5424.36	6	4	3.47E-01
5466.24	4	4	1.0E-01
5466.47	10	12	6.3E-01
5469.10	4	6	3.6E-03
5513.65	6	6	2.39E-01
5519.88	4	6	1.2E-02
5526.43	6	4	3.9E-03

λ Å	Weights g_i	g_k	A 10^8 s^{-1}
5527.56	8	10	5.4E-01
5541.63	8	8	5.2E-02
5551.00	4	4	6.9E-02
5573.03	6	4	1.8E-02
5594.12	6	8	5.0E-02
5606.34	10	10	5.84E-02
5619.96	6	4	2.0E-02
5630.14	4	6	4.9E-01
5641.78	2	4	1.9E-02
5675.27	6	6	9.3E-02
5675.64	4	6	4.3E-02
5693.63	4	4	1.1E-01
5714.94	8	6	2.0E-02
5729.25	6	6	2.2E-03
5732.09	6	6	7.5E-02
5740.22	8	6	4.0E-02
5757.59	4	6	7.6E-03
5788.36	4	4	9.4E-03
5844.13	6	4	5.6E-03
5879.93	4	2	8.5E-02
5902.91	6	8	4.0E-02
6087.94	6	4	1.1E-01
6191.72	4	4	4.7E-02
6222.58	4	6	5.9E-03
6402.01	6	4	2.7E-03
6435.02	6	6	4.0E-02
6437.17	10	8	4.8E-02
6538.57	10	10	1.5E-01
6622.48	8	6	4.5E-03
6815.15	2	4	7.18E-02
7009.89	2	4	4.4E-02
7035.15	4	4	6.3E-02
Y II			
3112.03	1	3	1.3E-02
3179.42	3	5	3.8E-02
3195.62	3	3	8.23E-01
3200.27	5	5	4.8E-01
3203.32	3	1	2.77E+00
3216.69	5	3	2.0E+00
3242.28	7	5	2.0E+00
3448.81	5	5	4.1E-02
3467.88	5	3	2.7E-02
3496.08	1	3	3.49E-01
3549.01	5	7	3.97E-01
3584.51	3	5	4.02E-01
3600.74	7	7	1.4E+00
3601.91	3	3	1.13E+00
3611.04	5	5	1.04E+00
3628.70	5	3	3.3E-01
3664.62	7	5	3.7E-01
3710.29	7	9	1.5E+00
3747.55	3	3	1.9E-01
3774.34	5	7	1.1E+00
3776.56	5	3	2.42E-01
3788.70	3	5	8.1E-01
3818.34	5	5	9.70E-02
3832.90	7	7	3.0E-01
3878.29	7	5	2.9E-02
3930.66	5	5	2.1E-02
3950.36	3	5	2.80E-01
3951.59	5	3	1.5E-02
3982.60	5	5	2.7E-01
4124.91	5	7	1.8E-02
4177.54	5	5	5.27E-01
4199.27	3	5	5.36E-03
4204.69	1	3	2.20E-02
4235.73	5	5	2.3E-02
4309.62	7	5	1.29E-01
4358.73	3	3	5.55E-02
4374.95	5	5	9.97E-01
4398.01	5	3	1.16E-01
4422.59	3	1	1.83E-01
4682.33	5	5	1.9E-02
4786.58	7	7	2.1E-02
4823.31	5	5	4.3E-02
4854.87	5	3	3.9E-01
4881.44	5	3	1.5E-03
4883.69	9	7	4.7E-01
4900.11	7	5	4.51E-01
4982.13	7	9	1.5E-02
5087.42	9	9	2.0E-01
5119.11	5	7	1.6E-02
5200.41	5	5	1.3E-01
5205.73	7	7	1.6E-01
5289.82	7	5	6.7E-03
5320.78	9	7	3.9E-03
5473.39	3	5	4.3E-02
5480.73	1	3	7.62E-02
5497.41	5	5	1.2E-01
5509.90	5	5	4.24E-02
5544.61	3	1	1.8E-01
5546.01	5	3	5.8E-02
5728.89	5	5	3.0E-02
6613.74	5	7	1.7E-02
6832.48	5	5	3.3E-03
7264.16	5	3	1.3E-02
Zinc			
Zn I			
748.29	1	3	6.0E-02
765.60	1	3	7.6E-02
792.05	1	3	5.7E-02
793.85	1	3	1.8E-01
809.92	1	3	2.6E-01
1109.1	1	3	3.05E-01
2138.6	1	3	7.09E+00
3075.9	1	3	3.29E-04
3282.3	1	3	9.0E-01
3302.6	3	5	1.2E+00
3302.9	3	3	6.7E-01
3345.0	5	7	1.7E+00
3345.6	5	5	4.0E-01
3345.9	5	3	4.5E-02
6362.3	3	5	4.74E-01
11054	3	1	2.43E-01
Zn II			
2025.5	2	4	3.3E+00
2064.2	2	4	4.6E+00
2099.9	4	6	5.6E+00
2102.2	4	4	9.3E-01
4911.6	4	6	1.6E+00

ELECTRON AFFINITIES
Thomas M. Miller

Electron affinity is defined as the energy difference between the lowest (ground) state of the neutral and the lowest state of the corresponding negative ion. The accuracy of electron affinity measurements has been greatly improved since the advent of laser photodetachment experiments with negative ions. Electron affinities can be determined with optical precision, though a detailed understanding of atomic and molecular states and splittings is required to specify the photodetachment threshold corresponding to the electron affinity.

Atomic and molecular electron affinities are discussed in two excellent articles reviewing photodetachment studies which appear in *Gas Phase Ion Chemistry*, Vol. 3, Bowers, M. T., Ed., Academic Press, Orlando, 1984: Chapter 21 by Drzaic, P. S., Marks, J., and Brauman, J. I., "Electron Photodetachment from Gas Phase Negative Ions", p. 167, and Chapter 22 by Mead, R. D., Stevens, A. E., and Lineberger, W. C., "Photodetachment in Negative Ion Beams", p. 213. Persons interested in photodetachment details should consult these articles and the critical review of Hotop, H., and Lineberger, W. C., *J. Phys. Chem. Ref. Data*, 14, 731, 1985. For simplicity in the tables below, any electron affinity which was discussed in the articles by Drzaic *et al.* or Hotop and Lineberger is referenced to these sources, where original references are given. A great many additional electron affinities have been provided here by G. B. Ellison, W. C. Lineberger, H. Hotop, D. G. Leopold, and K. H. Bowen. Electron affinities for the lanthanides and actinides have not been measured, but theoretical estimates have been made by Bratch, S. G., *Chem. Phys. Lett.*, 98, 113, 1983, and Bratch, S. G., and Lagowski, J. J., *Chem. Phys. Lett.*, 107, 136, 1984. The development of cluster-ion photodetachment apparatuses has brought an explosion of electron affinity estimates for atomic and molecular clusters. [See Arnold, S. T., Eaton, J. G., Patel-Mistra, D., Sarkas, H. W., and Bowen, K. H., in *Ion and Cluster Ion Spectroscopy and Structure*, Maier, J. P., Ed., Elsevier Science, New York, 1989, p. 417.] The policy in this tabulation is to list the electron affinities for the atoms, diatoms, and triatoms, if adiabatic electron affinities have been determined, but to refer the reader to original sources for higher-order clusters. Additional data on molecular electron affinities may be found in Lias, S. G., Bartmess, J. E., Liebman, J. F., Holmes, J. L., Levin, R. D., and Mallard, W. G., *Gas Phase Ion and Neutral Thermochemistry*, *J. Phys. Chem. Ref. Data*, 17, (Supplement No. 1), 1988.

For the present tabulation the value e/hc = 8065.5410 ± 0.0024 cm^{-1} eV^{-1} (Cohen, E. R., and Taylor, B. N., *Rev. Mod. Phys.*, 59, 1121, 1987) has been used to convert electron affinities from the units used in spectroscopic work, cm^{-1}, into eV for these tables. The uncertainties in the electron affinities given in the tables do not include the 0.3 ppm uncertainty in e/hc; only in a few cases, *e.g.*, atomic oxygen, is this additional uncertainty significant.

Abbreviations used in the tables: calc = calculated value; PT = photodetachment threshold using a lamp as a light source; LPT = laser photodetachment threshold; LPES = laser photoelectron spectroscopy; DA = dissociative attachment; e-scat = electron scattering; CT = charge transfer; and CD = collisional detachment.

Table 1
Atomic Electron Affinities

Atomic number	Atom	Electron affinity in eV	Uncertainty in eV	Method	Ref.
1	D	0.754593	0.000074	LPT	89
	H	0.754195	0.000019	LPT	89
		0.754209	0.000003	calc	1
2	He	not stable	—	calc	1
3	Li	0.6180	0.0005	LPT	1
4	Be	not stable	—	calc	1
5	B	0.277	0.010	LPES	1
6	C	1.2629	0.0003	LPT	1
7	N	not stable	—	DA	1
8	O	1.4611103	0.0000007	LPT	4
9	F	3.401190	0.000004	LPT	74
10	Ne	not stable	—	calc	1
11	Na	0.547926	0.000025	LPT	1
12	Mg	not stable	—	e-scat	1
13	Al	0.441	0.010	LPES	1
14	Si	1.385	0.005	LPES	1
15	P	0.7465	0.0003	LPT	1
16	S	2.077104	0.000001	LPT	1
17	Cl	3.61269	0.00006	LPT	52
18	Ar	not stable	—	calc	1
19	K	0.50147	0.00010	LPT	1
20	Ca	0.02455	0.00010	LPT	44
21	Sc	0.188	0.020	LPES	1
22	Ti	0.079	0.014	LPES	1
23	V	0.525	0.012	LPES	1
24	Cr	0.666	0.012	LPES	1
25	Mn	not stable	—	calc	1

Table 1
Atomic Electron Affinities (continued)

Atomic number	Atom	Electron affinity in eV	Uncertainty in eV	Method	Ref.
26	Fe	0.151	0.003	LPES	27
27	Co	0.662	0.003	LPES	27
28	Ni	1.156	0.010	LPES	1
29	Cu	1.235	0.005	LPES	37
30	Zn	not stable	—	e-scat	1
31	Ga	0.3	0.15	PT	1
32	Ge	1.233	0.003	LPES	28
33	As	0.81	0.03	PT	1
34	Se	2.020670	0.000025	LPT	1
35	Br	3.363590	0.000003	LPT	74
36	Kr	not stable	—	calc	1
37	Rb	0.48592	0.00002	LPT	1
38	Sr	0.048	0.006	LPT	122
39	Y	0.307	0.012	LPES	1
40	Zr	0.426	0.014	LPES	1
41	Nb	0.893	0.025	LPES	1
42	Mo	0.748	0.002	LPES	127
43	Tc	0.55	0.20	calc	1
44	Ru	1.05	0.15	calc	1
45	Rh	1.137	0.008	LPES	1
46	Pd	0.562	0.005	LPES	116
47	Ag	1.302	0.007	LPES	1
48	Cd	not stable	—	e-scat	1
49	In	0.3	0.2	PT	1
50	Sn	1.112	0.004	LPES	28
51	Sb	1.046	0.005	LPES	108
52	Te	1.9708	0.0003	LPT	1
53	I	3.059038	0.000010	LPT	92
54	Xe	not stable	—	calc	1
55	Cs	0.471626	0.000025	LPT	1
56	Ba	0.15	—	calc	57
57	La	0.5	0.3	calc	1
72	Hf	≈0	—	calc	1
73	Ta	0.322	0.012	LPES	1
74	W	0.815	0.002	LPES	37
75	Re	0.15	0.15	calc	1
76	Os	1.1	0.2	calc	1
77	Ir	1.5638	0.0005	LPT	141
78	Pt	2.128	0.002	LPT	1
79	Au	2.30863	0.00003	LPT	1
80	Hg	not stable	—	e-scat	1
81	Tl	0.2	0.2	PT	1
82	Pb	0.364	0.008	LPES	1
83	Bi	0.946	0.010	LPES	1
84	Po	1.9	0.3	calc	1
85	At	2.8	0.2	calc	1
86	Rn	not stable	—	calc	1
87	Fr	0.46	—	calc	82
118	ekaradon	0.056	—	calc	140

Table 2
Electron Affinities for Diatomic Molecules

Molecule	Electron affinity in eV	Uncertainty in eV	Method	Ref.
Ag_2	1.023	0.007	LPES	37
Al_2	1.10	0.15	LPES	68
AlO	2.60	0.02	LPES	143
AlS	2.60	0.03	LPES	129
As_2	0	—	PT	2
AsH	1.0	0.1	PT	2
Au_2	1.938	0.007	LPES	37
BO	3.12	0.09	PT	6
BeH	0.7	0.1	PT	2
Bi_2	1.271	0.008	LPES	119
Br_2	2.55	0.10	CT	2
BrO	2.353	0.006	LPES	88
C_2	3.269	0.006	LPES	87
CH	1.238	0.008	LPES	2
CN	3.862	0.004	LPES	111
CS	0.205	0.021	LPES	2
CaH	0.93	0.05	PT	2
Cl_2	2.38	0.10	CT	2
ClO	2.275	0.006	LPES	88
Co_2	1.110	0.008	LPES	27
CoD	0.680	0.010	LPES	29
CoH	0.671	0.010	LPES	29
Cr_2	0.505	0.005	LPES	114
CrD	0.568	0.010	LPES	29
CrH	0.563	0.010	LPES	29
CrO	1.221	0.006	LPES	5
Cs_2	0.469	0.015	LPES	104
CsCl	0.455	0.010	LPES	30
CsO	0.273	0.012	LPES	133
Cu_2	0.836	0.006	LPES	37
CuO	1.777	0.006	LPES	118
F_2	3.08	0.10	CT	2
FO	2.272	0.006	LPES	88
Fe_2	0.902	0.008	LPES	27
FeD	0.932	0.015	LPES	9
FeH	0.934	0.011	LPES	9
FeO	1.493	0.005	LPES	45
Ge_2	2.035	0.001	LPES	123
I_2	2.55	0.05	CT	2
IBr	2.55	0.10	CT	2
IO	2.378	0.006	LPES	88
InP	1.95	0.05	LPES	137
K_2	0.497	0.012	LPES	104
KBr	0.642	0.010	LPES	30
KCl	0.582	0.010	LPES	30
KCs	0.471	0.020	LPES	104
KI	0.728	0.010	LPES	30
KRb	0.486	0.020	LPES	104
LiCl	0.593	0.010	LPES	30
LiD	0.337	0.012	LPES	102
LiH	0.342	0.012	LPES	102
MgCl	1.589	0.011	LPES	31
MgH	1.05	0.06	PT	2
MgI	1.899	0.018	LPES	31
MnD	0.866	0.010	LPES	9
MnH	0.869	0.010	LPES	9
MoO	1.290	0.006	LPES	127
NH	0.370	0.004	LPT	32
NO	0.026	0.005	LPES	73
NS	1.194	0.011	LPES	2
Na_2	0.430	0.015	LPES	104
NaBr	0.788	0.010	LPES	30
NaCl	0.727	0.010	LPES	30
NaF	0.520	0.010	LPES	30
NaI	0.865	0.010	LPES	30
NaK	0.465	0.030	LPES	104
Ni_2	0.926	0.010	LPES	112
NiCu	0.889	0.010	LPES	128
NiAg	0.979	0.010	LPES	128
NiD	0.477	0.007	LPES	29
NiH	0.481	0.007	LPES	29
NiO	1.470	0.003	LPES	146
O_2	0.451	0.007	LPES	73
OD	1.825534	0.000037	LPT	142
OH	1.8276542	0.0000037	LPT	142
P_2	0.589	0.025	LPES	42
PH	1.028	0.010	LPES	2
PO	1.092	0.010	LPES	2
Pb_2	1.366	0.010	LPES	117
PbO	0.722	0.006	LPES	105
Pd_2	1.685	0.008	LPES	112
Pt_2	1.898	0.008	LPES	112
PtN	1.240	0.010	LPES	46
Rb_2	0.498	0.015	LPES	104
RbCl	0.544	0.010	LPES	30
RbCs	0.478	0.020	LPES	104
Re_2	1.571	0.008	LPES	33
S_2	1.670	0.015	LPES	53
SD	2.315	0.002	LPES	10
SF	2.285	0.006	LPES	93
SH	2.314344	0.000004	LPT	47
SO	1.125	0.005	LPES	84
Sb_2	1.282	0.008	LPES	108
Se_2	1.94	0.07	LPES	38
SeH	2.212520	0.000025	LPT	48
SeO	1.456	0.020	LPES	41
Si_2	2.201	0.010	LPES	100
SiH	1.277	0.009	LPES	2
Sn_2	1.962	0.010	LPES	117
SnPb	1.569	0.008	LPES	117
Te_2	1.92	0.07	LPES	38
TeH	2.102	0.015	LPES	39
TeO	1.697	0.022	LPES	40
ZnH	$\leq$0.95	—	PT	2

Table 3
Electron Affinities for Triatomic Molecules

Molecule	Electron affinity in eV	Uncertainty in eV	Method	Ref.
Ag_3	2.32	0.05	LPES	37
Al_3	1.4	0.15	LPES	68
AlO_2	4.23	0.02	LPES	143
Al_2S	0.80	0.12	LPES	129
AsH_2	1.27	0.03	PT	2
Au_3	3.7	0.3	LPES	37
BO_2	3.57	0.13	CT	6
BO_2	4.3	0.2	CT	98
Bi_3	1.60	0.03	LPES	119
C_3	1.981	0.020	LPES	11
CCl_2	1.591	0.010	LPES	95
CD_2	0.645	0.006	LPES	12
CDF	0.535	0.005	LPES	95
CF_2	0.165	0.010	LPES	95
CH_2	0.652	0.006	LPES	12
CHBr	1.454	0.005	LPES	95
CHCl	1.210	0.005	LPES	95
CHF	0.542	0.005	LPES	95
CHI	1.42	0.17	LPES	95
C_2H	2.969	0.006	LPES	87
C_2O	1.848	0.027	LPES	13
COS	0.46	0.20	CD	2
CS_2	0.895	0.020	LPES	11
C_2Ti	1.542	0.020	LPES	147
CoD_2	1.465	0.013	LPES	34
CoH_2	1.450	0.014	LPES	34
CrH_2	>2.5	—	LPES	34
Cr_2D	1.464	0.005	LPES	107
Cr_2H	1.474	0.005	LPES	107
CrO_2	2.413	0.008	LPES	144
Cs_3	0.864	0.030	LPES	18
Cu_3	2.11	0.05	LPES	37
DCO	0.301	0.005	LPES	35
DNO	0.330	0.015	LPES	14
DO_2	1.089	0.017	LPES	15
DS_2	1.912	0.015	LPES	53
HS_2	1.907	0.015	LPES	53
Fe_3	1.47	0.08	LPES	149
FeCO	1.157	0.005	LPES	103
FeD_2	1.038	0.013	LPES	34
FeH_2	1.049	0.014	LPES	34
FeO_2	2.358	0.030	LPES	130
Ge_3	2.23	0.01	LPES	123
GeH_2	1.097	0.015	LPES	28
HCO	0.313	0.005	LPES	35
HCl_2	4.896	0.005	LPES	69
HNO	0.338	0.015	LPES	14
HO_2	1.078	0.017	LPES	15
InP_2	1.61	0.05	LPES	137
In_2P	2.36	0.05	LPES	137
K_3	0.956	0.050	LPES	18
MnD_2	0.465	0.014	LPES	34
MnH_2	0.444	0.016	LPES	34
N_3	2.70	0.12	PT	2
NCN	2.484	0.006	LPES	154
NCND	2.622	0.005	LPES	154
NCNH	2.622	0.005	LPES	154
NCO	3.609	0.005	LPES	111
NCS	3.537	0.005	LPES	111
NH_2	0.771	0.005	LPES	58
N_2O	0.22	0.10	CT	59
NO_2	2.273	0.005	LPES	63
(NO)R	R=Ar,Kr,Xe	—	LPES	90
Na_3	1.019	0.060	LPES	18
Ni_3	1.41	0.05	LPES	55
NiCO	0.804	0.012	LPES	2
NiD_2	1.926	0.007	LPES	34
NiH_2	1.934	0.008	LPES	34
O_3	2.1028	0.0025	LPT	2
O_2Ar	0.52	0.02	LPES	75
OClO	2.140	0.008	LPES	88
OIO	2.577	0.008	LPES	88
PH_2	1.271	0.010	LPES	2
PO_2	3.42	0.01	LPES	124
Pt_3	1.87	0.02	LPES	55
Pd_3	<1.5	0.1	LPES	55
Rb_3	0.920	0.030	LPES	18
S_3	2.093	0.025	LPES	16
SO_2	1.107	0.008	LPES	16
S_2O	1.877	0.008	LPES	16
Sb_3	1.85	0.03	LPES	108
SeO_2	1.823	0.050	LPES	38
SiH_2	1.124	0.020	LPES	2
VO_2	2.3	0.2	CT	101

Table 4
Electron Affinities for Larger Polyatomic Molecules

Molecule	Electron Affinity in eV	Uncertainty in eV	Method	Ref.	Name
Ag_n	n = 1-10	—	LPES	37	
Al_n	n = 3-32	—	LPES	68	
Al_nO_m	n=1,2	m=1-5	LPES	143	
Al_3O	1.00	0.15	LPES	68	
Al_nS_m	n = 1-5	m = 1-3	LPES	129	
$Ar(H_2O)_n$	n = 2,6,7	—	LPES	77	

Table 4
Electron Affinities for Larger Polyatomic Molecules (continued)

Molecule	Electron Affinity in eV	Uncertainty in eV	Method	Ref.	Name
Au_n	*n* = 2-5	—	LPES	37	
AuF_6	7.5	estimate	CT	98	
BD_3	0.027	0.014	LPES	62	
BH_3	0.038	0.015	LPES	62	
Bi_4	1.05	0.010	LPES	119	
$Br(CO_2)$	3.582	0.017	LPES	131	
C_n	*n* = 2-84	—	LPES	70	
$(CO_2)_n$	*n* = 1,2	—	LPES	75	
$(CS)_n$	*n* = 2	—	LPES	75	
$(CS_2)_n$	*n* = 1,2	—	LPES	75	
CF_3Br	0.91	0.2	CD	2	
CF_3I	1.57	0.2	CD	2	
CDO_2	3.510	0.015	LPES	109	
CHO_2	3.498	0.015	LPES	109	
CH_2S	0.465	0.023	LPES	53	
CH_3	0.08	0.03	LPES	2	
CH_3I	0.2	0.1	CT	2	
CH_3NO_2	0.48	0.10	CT	61	
CH_3Si	0.852	0.010	LPES	97	CH_3-Si
CH_3Si	2.010	0.010	LPES	97	CH_2 = SiH
CD_3O	1.552	0.022	LPES	2	
CH_3O	1.570	0.022	LPES	2	
CD_3S	1.856	0.006	LPT	2	
CH_3S	1.861	0.004	LPT	2	
CD_3S_2	1.748	0.022	LPES	53	
CH_3S_2	1.757	0.022	LPES	53	
CH_3SiH_2	1.19	0.04	LPT	65	
CFO_2	4.277	0.030	LPES	131	
CO_3	2.69	0.14	LPES	2	
$CO_3(H_2O)$	2.1	0.2	PT	2	
C_2F_2	2.255	0.006	LPES	106	difluorovinylidene
C_2DO	2.350	0.020	LPES	13	
C_2HO	2.350	0.020	LPES	13	
C_2D_2	0.492	0.006	LPES	83	vinylidene-d_2
C_2HD	0.489	0.006	LPES	83	vinylidene-d_1
C_2HF	1.718	0.006	LPES	106	monofluorovinylidene
C_2H_2	0.490	0.006	LPES	83	vinylidene
C_2H_2FO	2.22	0.09	PT	2	acetyl fluoride enolate
C_2D_2N	1.538	0.012	LPES	21	cyanomethyl-d_2 radical
C_2D_2N	1.070	0.024	LPES	21	isocyanomethyl-d_2 radical
C_2H_2N	1.543	0.014	LPES	21	cyanomethyl radical
C_2H_2N	1.059	0.024	LPES	21	isocyanomethyl radical
C_2H_3	0.667	0.024	LPES	90	vinyl
C_2D_3O	1.81897	0.00012	LPT	22	acetaldehyde-d_3 enolate
C_2H_3O	1.82476	0.00012	LPT	22	acetaldehyde enolate
C_2H_5N	0.56	0.01	PT	2	ethyl nitrine
C_2D_5O	1.702	0.033	LPES	23	ethoxide-d_3
C_2H_5O	1.726	0.033	LPES	23	ethoxide
C_2H_5S	1.953	0.006	LPT	2	ethyl sulfide
C_2H_5S	0.868	0.051	LPES	53	CH_3SCH_2
$C_2H_7O_2$	2.26	0.08	PT	50	MeOHOMe
C_3Fe	1.69	0.08	LPES	132	
C_3H	1.858	0.023	LPES	11	
C_3HFe	1.58	0.06	LPES	132	
C_3H_2	1.794	0.008	LPES	153	
$C_3H_2F_3O$	2.625	0.010	LPT	113	1,1,1-trifluoroacetone enolate

Table 4
Electron Affinities for Larger Polyatomic Molecules (continued)

Molecule	Electron Affinity in eV	Uncertainty in eV	Method	Ref.	Name
C_3H_3	0.893	0.025	LPES	24	propargyl radical
C_3H_2D	0.88	0.15	LPES	24	propargyl-d_1 radical
C_3D_2H	0.907	0.023	LPES	24	propargyl-d_2 radical
C_3H_3N	1.247	0.012	LPES	21	CH_3CH-CN
C_3D_5	0.464	0.006	LPES	138	allyl-d_5
C_3H_5	0.481	0.008	LPES	138	allyl
C_3H_4D	0.373	0.019	LPES	25	allyl-d_1
C_3H_5O	1.758	0.019	LPT	113	acetone enolate
C_3H_5O	1.621	0.006	LPT	113	propionaldehyde enolate
$C_3H_5O_2$	1.80	0.06	PT	2	methyl acetate enolate
C_3H_7O	1.789	0.033	LPES	23	*n*-propyl oxide
C_3H_7O	1.839	0.029	LPES	23	isopropyl oxide
C_3H_7S	2.00	0.02	PT	2	*n*-propyl sulfide
C_3H_7S	2.02	0.02	PT	2	isopropyl sulfide
C_3O	1.34	0.15	LPES	11	
C_3O_2	0.85	0.15	LPES	11	
C_3Ti	1.561	0.015	LPES	147	
$C_4F_4O_3$	0.5	0.2	CD	2	tetrafluorosuccinic anhydride
C_4Fe	≤2.2	0.2	LPES	132	
C_4HFe	1.67	0.06	LPES	132	
$C_4H_2O_3$	1.44	0.10	CT	61	maleic anhydride
C_4D_4	0.909	0.015	LPES	125	vinylvinylidene-d_4
C_4H_4	0.914	0.015	LPES	125	vinylvinylidene
C_4H_4N	2.39	0.13	PT	2	pyrrolate
C_4H_5O	1.801	0.008	LPT	113	cyclobutanone enolate
C_4H_6	0.431	0.006	LPES	135	trimethylenemethane
$C_4H_6O_2$	0.69	0.10	CT	61	2,3-butanedione
C_4H_6D	0.493	0.008	LPES	138	2-methylallyl-d_7
C_4H_7	0.505	0.006	LPES	138	2-methylallyl
C_4H_7O	1.67	0.05	PT	2	butyraldehyde enolate
C_4H_5DO	1.67	0.05	PT	2	2-butanone-3-d_1 enolate
$C_4H_5D_2O$	1.75	0.06	PT	2	2-butanone-3,3-d_2 enolate
C_4H_9O	1.912	0.054	LPES	23	*t*-butoxyl
C_4H_9S	2.03	0.02	PT	2	*n*-butyl sulfide
C_4H_9S	2.07	0.02	PT	2	*t*-butyl sulfide
C_4O	2.05	0.15	LPES	11	
C_4O_2	2.0	0.2	LPES	11	
C_4Ti	1.494	0.020	LPES	147	
C_5	2.853	0.001	LPT	99	
C_5F_5N	0.68	0.11	CT	67	pentafluoropyridine
$C_5F_6O_3$	1.5	0.2	CD	2	hexafluoroglutaric anhydride
C_5D_5	1.790	0.008	LPES	11	cyclopentadienyl-d_5
C_5H_5	1.804	0.007	LPES	11	cyclopentadienyl
C_5H_7	0.91	0.03	PT	2	pentadienyl
C_5H_7O	1.598	0.007	LPT	113	cyclopentanone enolate
C_5H_9O	1.69	0.05	PT	2	3-penanone enolate
$C_5H_{11}O$	1.93	0.05	LPT	2	neopentoxyl
$C_5H_{11}S$	2.09	0.02	PT	2	*n*-pentyl sulfide
C_5O_2	1.2	0.2	LPES	11	
C_5Ti	1.748	0.050	LPES	147	
C_6	4.180	0.001	LPT	8	
$C_6Br_4O_2$	2.44	0.20	CT	2	tetrabromo-BQ
$C_6Cl_4O_2$	2.78	0.10	CT	61	tetrachloro-BQ
$C_6F_4O_2$	2.70	0.10	CT	61	tetrafluoro-BQ
C_6F_5Br	1.15	0.11	CT	67	pentafluorobromobenzene

Table 4
Electron Affinities for Larger Polyatomic Molecules (continued)

Molecule	Electron Affinity in eV	Uncertainty in eV	Method	Ref.	Name
C_6F_5Cl	0.82	0.11	CT	67	pentafluorochlorobenzene
C_6F_5I	1.41	0.11	CT	67	pentafluoroiodobenzene
$C_6F_5NO_2$	1.52	0.11	CT	67	pentafluoro-NB
C_6F_6	0.52	0.10	CT	51	hexafluorobenzene
C_6F_{10}	>1.4	0.3	CT	2	perfluorocyclohexene
$C_6H_2Cl_2O_2$	2.48	0.10	CT	61	2,6-dichloro-BQ
$C_6H_3F_2NO_2$	1.17	0.10	CT	61	2,4-difluoro-NB
C_6D_4	0.551	0.010	LPES	36	*o*-benzyne-d_4
C_6H_4	0.560	0.010	LPES	36	*o*-benzyne
$C_6H_4BrNO_2$	1.16	0.10	CT	61	*o*-bromo-NB
$C_6H_4BrNO_2$	1.32	0.10	CT	61	*m*-bromo-NB
$C_6H_4BrNO_2$	1.29	0.10	CT	61	*p*-bromo-NB
$C_6H_4ClNO_2$	1.14	0.10	CT	61	*o*-chloro-NB
$C_6H_4ClNO_2$	1.28	0.10	CT	61	*m*-chloro-NB
$C_6H_4ClNO_2$	1.26	0.10	CT	61	*p*-chloro-NB
C_6H_4ClO	≤2.58	0.08	PT	2	*o*-chloroperoxide
$C_6H_4FNO_2$	1.07	0.10	CT	61	*o*-fluoro-NB
$C_6H_4FNO_2$	1.23	0.10	CT	61	*m*-fluoro-NB
$C_6H_4FNO_2$	1.12	0.10	CT	61	*p*-fluoro-NB
$C_6H_4N_2O_4$	1.65	0.10	CT	61	*o*-diNB
$C_6H_4N_2O_4$	1.65	0.10	CT	61	*m*-diNB
$C_6H_4N_2O_4$	2.00	0.10	CT	61	*p*-diNB
$C_6H_4O_2$	1.91	0.10	CT	61	1,4-benzoquinone (BQ)
C_6D_5	1.092	0.020	LPES	26	phenyl-d_5
C_6D_5N	1.44	0.02	LPES	96	phenylnitrene-d_5
C_6H_5	1.096	0.006	LPES	26	phenyl
C_6H_5N	1.429	0.011	LPT	115	phenylnitrene
$C_6H_5NO_2$	1.01	0.10	CT	61	nitrobenzene (NB)
C_6H_5O	2.253	0.006	LPES	26	phenoxyl
C_6H_5S	≤2.47	0.06	PT	2	thiophenoxide
C_6H_5NH	1.70	0.03	PT	2	anilide
C_6H_7	<1.67	0.04	PT	2	methylchylopentadienyl
C_6H_8Si	1.435	0.004	LPT	65	$C_6H_5SiH_3$
C_6H_9O	1.526	0.010	LPT	113	cyclohexanone enolate
C_6H_{10}	0.645	0.015	LPES	126	*t*-butyl vinylidene
$C_6H_{11}O$	1.755	+0.05/-0.005	LPT	113	pinacolone enolate
$C_6H_{11}O$	1.82	0.06	PT	2	3,3-dimethylbutananl enolate
C_6N_4	2.3	0.3	PT	2	TCNE
C_7F_5N	1.11	0.11	CT	67	pentafluorobenzonitrile
C_7F_8	0.86	0.11	CT	67	octafluorotoluene
C_7F_{14}	1.08	0.10	CT	61	perfluoromethylcyclohexane
C_7HF_5O	1.10	0.11	CT	67	pentafluorobenzaldehyde
$C_7H_3N_3O_4$	2.16	0.10	CT	61	3,5-$(NO_2)_2$-benzonitrile
$C_7H_4F_3NO_2$	1.41	0.10	CT	61	*m*-trifluoromethyl-NB
$C_7H_4N_2O_2$	1.61	0.10	CT	61	*o*-cyano-NB
$C_7H_4N_2O_2$	1.56	0.10	CT	61	*m*-cyno-NB
$C_7H_4N_2O_2$	1.72	0.10	CT	61	*p*-cyano-NB
C_7H_6FO	2.218	0.010	LPT	2	*m*-fluoroacetophenone enolate
C_7H_6FO	2.176	0.010	LPT	2	*p*-fluoroacetophenone enolate
$C_7H_6FeO_3$	0.990	0.10	CT	120	η^4-1,3-butadiene-$Fe(CO)_3$
$C_7H_6N_2O_4$	1.77	0.05	PT	60	3,4-dintrotoluene
$C_7H_6N_2O_4$	1.77	0.05	PT	60	2,3-dinitrotoluene
$C_7H_6N_2O_4$	1.60	0.05	PT	60	2,4-dinitrotoluene
$C_7H_6N_2O_4$	1.55	0.05	PT	60	2,6-dinitrotoluene
C_7H_7	0.912	0.006	LPES	26	benzyl

Table 4
Electron Affinities for Larger Polyatomic Molecules (continued)

Molecule	Electron Affinity in eV	Uncertainty in eV	Method	Ref.	Name
C_7H_7	0.868	0.006	LPES	136	1-quadricyclanide
C_7H_7	0.962	0.006	LPES	136	2-quadricyclanide
C_7H_7	1.286	0.006	LPES	136	norbornadienide
C_7H_7	0.39	0.04	LPES	136	cycloheptatrienide
C_7H_7	3.046	0.006	LPES	136	1-(1,6-heptadiynide)
C_7H_7	≥1.140	0.006	LPES	136	3-(1,6-heptadiynide)
$C_7H_7NO_2$	0.92	0.10	CT	61	*o*-methyl-NB
$C_7H_7NO_2$	0.99	0.10	CT	61	*m*-methyl-NB
$C_7H_7NO_2$	0.95	0.10	CT	61	*p*-methyl-NB
$C_7H_7NO_3$	1.04	0.10	CT	61	*m*-OCH_3-NB
$C_7H_7NO_3$	0.91	0.10	CT	61	*p*-OCH_3-NB
C_7H_7O	≤2.36	0.06	PT	2	*o*-methyl phenoxide
C_7H_7O	2.14	0.02	PT	50	benzyloxide
$C_7H_7O_2$	1.85	0.10	CT	61	*o*-CH_3-BQ
C_7H_8FO	<3.05	0.06	PT	50	$PhCH_2OHF$
C_7H_9	1.27	0.03	PT	2	heptatrienyl
C_7H_9O	1.61	0.05	PT	2	2-norbornanone enolate
C_7H_9Si	1.33	0.04	LPT	65	$C_6H_5(CH_3)SiH$
$C_7H_{11}O$	1.598	0.007	LPT	113	cycloheptanone enolate
$C_7H_{11}O$	1.49	0.04	PT	2	2,5-dimethylcyclopentanone enolate
$C_7H_{13}O$	1.72	0.06	PT	2	4-heptanone enolate
$C_7H_{13}O$	1.46	0.04	PT	2	di-isopropyl ketone enolate
$C_8F_{14}N_2$	1.89	0.10	CT	51	1,4-$(CN)_2C_6F_4$
$C_8H_3F_5O$	0.88	0.11	CT	67	pentafluoroacetophenone
$C_8H_3F_6NO_2$	1.79	0.10	CT	61	3,5-$(CF_3)_2$-NB
$C_8H_4O_3$	1.21	0.10	CT	61	phthalic anhydride
C_8H_6	1.044	0.008	LPES	148	
C_8H_7	1.091	0.008	LPES	134	
C_8H_7O	2.057	0.010	PT	2	acetophenone enolate
C_8H_7O	2.10	0.08	LPT	2	phenylacetaldehyde enolate
C_8H_8	0.55	0.02	CT	134	cycooctatetraene
C_8H_8	0.65	0.04	LPES	134	cycooctatetraene
C_8H_8	0.919	0.008	LPES	139	*m*-xylylene
$C_8H_9NO_2$	1.21	0.05	PT	60	3,5-dimethyl-NB
$C_8H_9NO_2$	2.61	0.05	PT	60	2,6-dimethyl-NB
$C_8H_9NO_2$	0.86	0.10	CT	61	2,3-dimethyl-NB
$C_8H_{13}O$	1.63	0.06	PT	2	cyclooctanone enolate
$C_9H_8FeO_3$	0.76	0.10	CT	120	η^4-1,3-cyclohexadiene-$Fe(CO)_3$
C_9H_9O	2.030	0.010	LPT	2	*m*-methylacetophenone enolate
C_9H_9SiN	1.43	0.10	PT	2	trimethylsilylnitrene
$C_9H_{11}NO_2$	0.70	0.10	CT	61	2,4,6-trimethyl-NB
$C_9H_{15}O$	1.69	0.06	PT	2	cyclononanone enolate
$C_{10}H_4Cl_2O_2$	2.19	0.10	CT	61	2,3-dichloro-1,4-naphthoquinone
$C_{10}H_6N_2O_4$	1.78	0.10	CT	61	1,3-dinitronaphthalene
$C_{10}H_6N_2O_4$	1.77	0.10	CT	61	1,5-dinitronaphthalene
$C_{10}H_6O_2$	1.81	0.10	CT	61	1,4-naphthoquinone
$C_{10}H_7NO_2$	1.23	0.10	CT	61	1-nitronaphthalene
$C_{10}H_7NO_2$	1.18	0.10	CT	61	2-nitronaphthalene
$C_{10}H_8$	0.69	0.10	CT	61	azulene
$C_{10}H_8CrO_3$	0.93	0.10	CT	120	η^4-1,3,5-cycloheptatriene $Cr(CO)_3$
$C_{10}H_8FeO_3$	0.98	0.10	CT	120	η^4-1,3,5-cycloheptatriene-$Fe(CO)_3$
$C_{10}H_{17}O$	1.83	0.06	PT	2	cyclodecanone enolate
$C_{11}H_8FeO_3$	1.29	0.10	CT	120	η^4-1,3-butadiene-$Fe(CO)_3$
$C_{12}F_{10}$	0.82	0.11	CT	67	decafluorobiphenyl
$C_{12}H_4N_4$	2.8	0.3	CD	2	TCNQ

Table 4
Electron Affinities for Larger Polyatomic Molecules (continued)

Molecule	Electron Affinity in eV	Uncertainty in eV	Method	Ref.	Name
$C_{12}H_9$	1.07	0.10	PT	2	perinaphthenyl
$C_{12}H_{15}O$	2.032	0.010	LPT	2	*t*-butylacetophenone enolate
$C_{12}H_{21}O$	1.90	0.07	PT	2	cyclododecanone enolate
$C_{13}F_{10}O$	1.52	0.11	CT	67	decafluorobenzophenone
$C_{13}H_9FO$	0.64	0.10	CT	61	4-fluorobenzophenone
$C_{13}H_{10}O$	0.62	0.10	CT	61	benzophenone
$C_{14}H_9NO_2$	1.43	0.10	CT	61	9-nitroanthracene
$C_{14}H_{10}$	0.57	0.10	CT	66	anthracene
$C_{18}H_{12}$	1.04	0.10	CT	66	tetracene
$C_{20}H_{12}$	0.79	0.10	CT	66	benz[*a*]pyrene
$C_{20}H_{12}$	0.97	0.10	CT	66	perylene
$C_{22}H_{14}$	1.35	0.10	CT	66	pentacene
CeF_4	3.8	0.4	CT	98	
$Cl(CO_2)$	3.907	0.010	LPES	131	
CoF_4	6.4	0.3	CT	98	
$Cr(CO)_3$	1.349	0.006	LPES	94	
CrO_3	3.6	0.2	CT	98	
Cu_n	n = 1-41	—	LPES	37	
Fe_n	n=3-24	—	LPES	149	
$Fe(CO)_2$	1.22	0.02	LPES	2	
$Fe(CO)_3$	1.8	0.2	LPES	2	
$Fe(CO)_4$	2.4	0.3	LPES	2	
FeF_3	3.6	0.1	CT	98	
FeF_4	6.0	estimate	CT	98	
Fe_nO_m	n=1-4	m=1-6	LPES	152	
Ge_n	n = 3-15	—	LPES	71	
Ge_xAs_y	n = 5-30	$n = x + y$	LPES	72	
GeH_3	≤1.74	0.04	PT	2	
$H(NH_3)_n$	n = 1,2	—	LPES	76	
HNO_3	0.57	0.15	CD	2	
$(H_2O)_n$	n = 2-19	—	LPES	77	
$I(CO_2)$	3.225	0.001	LPES	131	
In_xP_y	n = 2-8	$n = x + y$	LPES	137	
IrF_4	4.7	0.3	CT	98	
IrF_6	6.5	0.4	CT	98	
K_n	n = 2-7	—	LPES	18	
MnF_4	5.5	0.2	CT	98	
$Mo(CO)_3$	1.337	0.006	LPES	94	
MoF_5	3.5	0.2	CT	98	
MoF_6	3.8	0.2	CT	98	
MoO_3	2.9	0.2	CT	98	
$(NH_3)_n$	n = 41-1100	—	LPES	77	
$NH_2(NH_3)_n$	n = 1,2	—	LPES	78	
$NO(H_2O)_n$	n = 1,2	—	LPES	75	
NO_3	3.937	0.014	LPES	85	
$NO(N_2O)_n$	n = 1,2	—	LPES	79	
$(NO)_2$	≥2.1	—	LPES	75	
$(N_2O)_n$	n = 1,2	—	LPES	81	
Na_n	n = 2-5	—	LPES	18	
$(NaF)_n$	n = 1-7,12	—	LPES	64	
$Na(NaF)_n$	n = 5,7-12	—	LPES	64	
$Ni(CO)_2$	0.643	0.014	LPES	2	
$Ni(CO)_3$	1.077	0.013	LPES	2	
NiO_2	3.05	0.01	LPES	145	ONiO
NiO_2	0.82	0.03	LPES	145	$Ni(O_2)$

Table 4
Electron Affinities for Larger Polyatomic Molecules (continued)

Molecule	Electron Affinity in eV	Uncertainty in eV	Method	Ref.	Name
$OH(H_2O)$	<2.95	0.15	PT	2	
OsF_4	3.9	0.3	CT	98	
OsF_6	6.0	0.3	CT	98	
PBr_3	1.59	0.15	CD	2	
PBr_2Cl	1.63	0.20	CD	2	
PCl_2Br	1.52	0.20	CD	2	
PCl_3	0.82	0.10	CD	2	
PF_5	0.75	0.15	CT	121	
PO_3	4.5	0.5	CT	98	
$POCl_2$	3.83	0.25	CD	2	
$POCl_3$	1.41	0.20	CD	2	
PtF_4	5.5	0.3	CT	98	
PtF_6	7.0	0.4	CT	98	
ReF_6	4.7	estimate	CT	98	
RhF_4	5.4	0.3	CT	98	
RuF_4	4.8	0.3	CT	98	
RuF_5	5.2	0.4	CT	98	
RuF_6	7.5	0.3	CT	98	
SF_4	1.5	0.2	CT	91	
SF_6	1.05	0.10	CT	56	
SO_3	$\geq$1.70	0.15	CD	2	
$(SO_2)_2$	0.6	0.2	LPES	80	
SeF_6	2.9	0.2	CD	2	
Si_4	2.17	0.01	LPES	110	
Si_n	n = 3-20	—	LPES	71	
SiD_3	1.386	0.022	LPES	43	
SiF_3	$\leq$2.95	0.10	PT	17	
SiH_3	1.406	0.014	LPES	43	
TeF_6	3.34	0.17	CD	2	
Ti_n	n=3-65	—	LPES	151	
UF_5	3.7	0.2	CT	98	
UF_6	5.1	0.2	CT	98	
UO_3	<2.1	—	CT	98	
V_n	n=3-65	—	LPES	150	
VF_4	3.5	0.2	CT	98	
V_4O_{10}	4.2	0.6	CT	101	
$W(CO)_3$	1.859	0.006	LPES	94	
WF_5	1.25	0.3	CD	18	
WF_6	3.36	+0.04/-0.20	CT	19	
WO_3	3.33	+0.04/-0.15	LPT	86	
WO_3	3.9	0.2	CT	98	

REFERENCES

1. Hotop, H., and Lineberger, W. C., *J. Phys. Chem. Ref. Data*, 14, 731, 1985.
2. Drzaic, P. S., Marks, J., and Brauman, J. I., in *Gas Phase Ion Chemistry*, Vol. 3, Bowers, M. T., Ed., Academic Press, Orlando, 1984, p. 167.
3. Schulz, P. A., Mead, R. D., Jones, P. L., and Lineberger, W. C., *J. Chem. Phys.*, 77, 1153, 1982.
4. Neumark, D. M., Lykke, K. R., Anderson, T., and Lineberger, W. C., *Phys. Rev. A*, 32, 1890, 1985.
5. Wenthold, P. G., Gunion, R. F., and Lineberger, W. C., *Chem. Phys. Lett.*, 258, 101, 1996.
6. Srivastava, R. D., Uy, O. M., and Farber, M., *Trans. Faraday Soc.*, 67, 2941, 1971.
7. Klein, R., McGinnis, R. P., and Leone, S. R., *Chem. Phys. Lett.*, 100, 475, 1983.
8. Arnold, C. C., Zhao, Y., Kitsopoulos, T. N., and Neumark, D. M., *J. Chem. Phys.*, 97, 6121, 1992; linear C_6^- to linear C_6.
9. Stevens, A. E., Fiegerle, C. S., and Lineberger, W. C., *J. Chem. Phys.*, 78, 5420, 1983.
10. Breyer, F., Frey, P., and Hotop, H., *Z. Phys.*, A 300, 7, 1981.
11. Oakes, J. M., and Ellison, G. B., *Tetrahedron*, 42, 6263, 1986.
12. Leopold, D. G., Murray, K. K., Miller, A. E. S., and Lineberger, W. C., *J. Chem. Phys.*, 83, 4849, 1985.

13. Oakes, J. M., Jones, M.E., Bierbaum, V. M., and Ellison, G. B., *J. Chem. Phys.*, 87, 4810, 1983.
14. Ellis, H. B., Jr. and Ellison, G. B., *J. Chem. Phys.*, 78, 6541, 1983.
15. Oakes, J. M., Harding, L. B., and Ellison, G. B., *J. Chem. Phys.*, 83, 5400, 1985.
16. Nimlos, M. E., and Ellison, G. B., *J. Chem. Phys.*, 90, 2574, 1986.
17. Richardson, L. M., Stephenson, L. M., and Brauman, J. I., *Chem. Phys. Lett.*, 30, 17, 1975.
18. McHugh, K. M., Eaton, J. G., Lee, G. H., Sarkas, H. W., Kidder, L. H., Snodgrass, J. T., Manaa, M. R., and Bowen, K. H., *J. Chem. Phys.*, 91, 3792, 1989. See also Ref. 104.
19. Viggiano, A. A., Paulson, J. F., Dale, F., Henchman, M., Adams, N. G., and Smith, D., *J. Phys. Chem.*, 89, 2264, 1985.
20. Burnett, S. M., Stevens, A. E., Fiegerle, C. S., and Lineberger, W. C., *Chem. Phys. Lett.*, 100, 124, 1983.
21. Moran, S., Ellis, H. B., DeFrees, D. J., McLean, A. D., and Ellison, G. B., *J. Am. Chem. Soc.*, 109, 5996, 1987; Moran, S., Ellis, H. B., DeFrees, D. J., McLean, A. D., Paulson, S. E., and Ellison, G. B., *J. Am. Chem. Soc.*, 109, 6004, 1987; see also Lykke, K. R., Neumark, D. M., Andersen, T., Trapa, V. J., and Lineberger, W. C., *J. Chem. Phys.*, 87, 6842, 1987.
22. Mead, R. D., Lykke, K. R., Lineberger, W. C., Marks, J., and Brauman, J. I., *J. Chem. Phys.*, 81, 4883, 1984; Lykke, K. R., Mead, R. D., and Lineberger, W. C., *Phys. Rev. Lett.*, 52, 2221, 1984. The EAs are 14717.7 ± 1.0 cm^{-1} for actaldehyde enolate and 14671.0 ± 1.0 cm^{-1} for acetaldehyde-d_3 enolate.
23. Ellison, G. B., Engelking, P. C., and Lineberger, W. C., *J. Chem. Phys.*, 86, 4873, 1982.
24. Oakes, J. M., and Ellison, G. B., *J. Am. Chem. Soc.*, 105, 2969, 1983.
25. Ellison, G. B., and Oakes, J. M., *J. Am. Chem. Soc.*, 106, 7734, 1984. EA(allyl) and EA(allyl-d_5) are 0.119 and 0.083 eV too low, respectively, in this work, according to Reference 138. Therefore, EA(allyl-d_1) is likely too low by a similar amount.
26. Gunion, R. F., Gilles, M. K., Polak, M. L., and Lineberger, W. C., *Int. J. Mass Spectrom. Ion Processes*, 117, 601, 1992; also, Miller, A. E. S., and Lineberger, W. C., unpublished. See also Reference 136.
27. Leopold, D. G., and Lineberger, W. C., *J. Chem. Phys.*, 85, 51, 1986.
28. Miller, T. M., Miller, A. E. S., and Lineberger, W. C., *Phys. Rev. A*, 33, 3558, 1986.
29. Miller, A. E. S., Fiegerle, C. S., and Lineberger, W. C., *J. Chem. Phys.*, 87, 1549, 1987.
30. Miller, T. M., Leopold, D. G., Murray, K. K., and Lineberger, W. C., *J. Chem. Phys.*,85, 2368, 1986.
31. Miller, T. M., and Lineberger, W. C., *Chem. Phys. Lett.*, 146, 364, 1988.
32. Neumark, D. M., Lykke, K. R., Andersen, T., and Lineberger, W. C., *J. Chem. Phys.*, 83, 4364, 1985.
33. Leopold, D. G., Miller, T. M., and Lineberger, W. C., *J. Am. Chem. Soc.*, 108, 178, 1986.
34. Miller, A. E. S., Fiegerle, C. S., and Lineberger, W. C., *J. Chem. Phys.*, 84, 4127, 1986.
35. Murray, K. K., Miller, T. M., Leopold, D. G., and Lineberger, W. C., *J. Chem. Phys.*, 84, 2520, 1986.
36. Leopold, D. G., Miller, A. E. S., and Lineberger, W. C., *J. Am. Chem. Soc.*, 108, 1379, 1986.
37. Ho, J., Ervin, K. M., and Lineberger, W. C., *J. Chem. Phys.*, 93, 6987, 1990; Leopold, D. G., Ho, J., and Lineberger, W. C., *J. Chem. Phys.*, 86, 1715, 1987; Pettiette, C. L., Yang, S. H., Craycraft, M. J., Conceicao, J., Laaksonen, R. T., Cheshnovsky, O., and Smalley, R. E., *J. Chem. Phys.*, 88, 5377, 1988.
38. Snodgrass, J. T., Coe, J. V., McHugh, K. M., Friedhoff, C. B., and Bowen, K. H., *J. Phys. Chem.*, 93, 1249, 1989.
39. Friedhoff, C. B., Snodgrass, J. T., Coe, J. V., McHugh, K. M., and Bowen, K. H., *J. Chem. Phys.*,84, 1051, 1986.
40. Friedhoff, C. B., Coe, J. V., Snodgrass, J. T., McHugh, K. M., and Bowen, K. H., *Chem. Phys. Lett.*, 124, 268, 1986.
41. Coe, J. V., Snodgrass, J. T., Friedhoff, C. B., McHugh, K. M., and Bowen, K. H., *J. Chem. Phys.*, 84, 619, 1986.
42. Snodgrass, J. T., Coe, J. V., Friedhoff, C. B., McHugh, K. M., and Bowen, K. H., *Chem. Phys. Lett.*, 122, 352, 1985.
43. Nimlos, M. R., and Ellison, G. B., *J. Am. Chem. Soc.*, 108, 6522, 1986.
44. Petrunin, V., Andersen, H., Balling, P., and Andersen, T., *Phys. Rev. Lett.*, 76, 744, 1996
45. Andersen, T., Lykke, K. R., Neumark, D. M., and Lineberger, W. C., *J. Chem. Phys.*, 86, 1858, 1987.
46. Murray, K. K., Lykke, K. R., and Lineberger, W. C., *Phys. Rev. A*, 36, 699, 1987.
47. Mansour, N. B., and Larson, D. J., *Abstracts of the XV Int. Conf. on the Phys. of Electronic and Atomic Collisions*, p. 70, 1987.
48. Stonemann, R. C., and Larson, D. J., *Phys. Rev. A*, 35, 2928, 1987.
49. Nimlos, M. R., Harding, L. B., and Ellison, G. B., *J. Chem. Phys.*, 87, 5116, 1987.
50. Moylan, C. R., Dodd, J. A., Han, C.-C., and Braumann, J. I., *J. Chem. Phys.*, 86, 5350, 1987.
51. Chowdhury, S., Grimsrud, E. P., Heinis, T., and Kebarle, P., *J. Am. Chem. Soc.*, 108, 3630, 1986.
52. Trainham, R., Fletcher, G. D., and Larson, D. J., *J. Phys. B: At. Mol. Phys.*, 20, L777, 1987.
53. Moran, S., and Ellison, G. B., *J. Phys. Chem.*, 92, 1794, 1988.
54. Murray, K. K., Leopold, D. G., Miller, T. M., and Lineberger, W. C., *J. Chem. Phys.*, 89, 5442, 1988.
55. Ervin, K. M., Ho, J., and Lineberger, W. C., *J. Chem. Phys.*, 89, 4514, 1988.
56. Grimsrud, E. P., Chowdhury, S., and Kebarle, P., *J. Chem. Phys.*, 85, 4989, 1985.
57. Fischer, C. F., *Phys. Rev. A*, 39, 963, 1989.
58. Wickham-Jones, C. T., Ervin, K. M., Ellision, G. B., and Lineberger, W. C., *J. Chem. Phys.*, 91, 2762, 1989.
59. Hopper, D. G., Wahl, A. C., Wu, R. L. C., and Tiernan, T. O., *J. Chem. Phys.*, 65, 5474, 1976.
60. Mock, R. S., and Grimsrud, E. P., *J. Am. Chem. Soc.*, 111, 2861, 1989.
61. Chowdhury, S., Heinis, T., Grimsrud, E. P., and Kebarle, P., *J. Phys. Chem.*, 90, 2747, 1986. The uncertainty and other results are quoted in Ref. 60.
62. Wickham-Jones, C. T., Moran, S., and Ellison, G. B., *J. Chem. Phys.*, 90, 795, 1989.
63. Ervin, K. M., Ho, J., and Lineberger, W. C., *J. Phys. Chem.*, 92, 5405, 1988.
64. Miller, T. M., and Lineberger, W. C., *Int. J. Mass Spectrom. Ion Processes*, 102, 239, 1990.
65. Wetzel, D. M., Salomon, K. E., Berger, S., and Brauman, J. I., *J. Am. Chem. Soc.*, 111, 3835, 1989.
66. Crocker, L., Wang, T., and Kebarle, P., *J. Am. Chem. Soc.*, 115, 7818, 1993.
67. Dillow, G. W., and Kebarle, P., *J. Am. Chem. Soc.*, 111, 5592, 1989.
68. Gantefor, G., Gausa, M., Meiwes-Broer, K. H., and Lutz, H. O., *Z. Phys. D*, 9, 253, 1988; Taylor, K. J., Petteitte, C. L., Craycraft, M. J., Chesnovsky, O., and Smalley, R. E., *Chem. Phys. Lett.*, 152, 347, 1988.
69. Metz, R. B., Kitsopoulos, T., Weaver, A., and Neumark, D. M., *J. Chem. Phys.*, 88, 1463, 1988.
70. Yang, S., Pettiette, C. L., Conceicao, J., Cheshnovsky, O., and Smalley, R. E., *Chem. Phys. Lett.*, 139, 233, 1987; Yang, S., Taylor, K. J., Craycraft, M. J., Conceicao, J., Pettiette, C. L., Cheshnovsky, O., and Smalley, R. E., *Chem. Phys. Lett.*, 144, 431, 1988; Arnold, D. W., Bradforth, S. E., Kitsopoulos, T. N., and Neumark, D. M., *J. Chem. Phys.*, 95, 5479, 1991.
71. Cheshnovsky, O., Yang, S., Pettiette, C. L., Craycraft, M. J., Liu, Y., and Smalley, R. E., *Chem. Phys. Lett.*, 138, 119, 1987.

73. Travers, M. J., Cowles, D. C., and Ellison, G. B., *Chem. Phys. Lett.*, 164, 449, 1989.
74. Blondel, C., Cacciani, P., Delsart, C., and Trainham, R., *Phys. Rev. A*, 40, 3698, 1989.
75. Bowen, K. H., and Eaton, J. G., in *The Structure of Small Molecules and Ions*, Naaman, R., and Vager, Z., Eds., Plenum, New York, 1988, pp. 147-169; Arnold, S. T., Eaton, J. G., Patel-Mistra, D., Sarkas, H. W., and Bowen, K. H., in *Ion and Cluster Ion Spectroscopy and Structure*, Maier, J. P., Ed., Elsevier Science, New York, 1989, p. 417.
76. Snodgrass, J. T., Coe, J. V., Friedhoff, C. B., McHugh, K. M., and Bowen, K. H., *Faraday Disc. Chem. Soc.*, 88, 1988.
77. Lee, G. H., Arnold, S. T., Eaton, J. G., Sarkas, H. W., Bowen, K. H., Ludewigt, C., and Haberland, H., *Z. Phys. D - Atoms, Mol. and Clusters*, 20, 9, 1991; Coe, J. V., Lee, G. H., Eaton, J. G., Arnold, S. T., Sarkas, H. W., Bowen, K. H., Ludewigt, C., Haberland, H., and Worsnop, D. R., *J. Chem. Phys.*, 92, 3980, 1990.
78. Snodgrass, J. T., Coe, J. V., Freidhoff, C. B., McHugh, K. M., and Bowen, K. H., to be published, quoted in Ref. 75.
79. Coe, J. V., Snodgrass, J. T., Friedhoff, C. B., McHugh, K. M., and Bowen, K. H., *J. Chem. Phys.*, 87, 4302, 1987.
80. Friedhoff, C. B., Snodgrass, J. T., and Bowen, K. H., to be published, quoted in Ref. 75.
81. Coe, J. V., Snodgrass, J. T., Friedhoff, C. B., McHugh, K. M., and Bowen, K. H., *Chem. Phys. Lett.*, 124, 274, 1986.
82. Greene, C. H., *Phys. Rev. A*, 42, 1405, 1990.
83. Ervin, K. M., Ho, J., and Lineberger, W. C., *J. Chem. Phys.*, 91, 5974, 1989.
84. Polak, M. L., Fiala, B. L., Ervin, K. M., and Lineberger, W. C., *J. Chem. Phys.*, 94, 6924, 1991.
85. Weaver, A., Arnold, D. W., Bradforth, S. E., Neumark, D. M., *J. Chem. Phys.*, 94, 1740, 1991.
86. Walter, C. W., Devynck, P., Hertzler, C. F., Bae, Y. K., Smith, G. P., and Peterson, J. R., *Bull. Am. Phys. Soc.*, 35, 1163, 1990.
87. Ervin, K. M., and Lineberger, W. C., *J. Phys. Chem.*, 95, 1167, 1991.
88. Gilles, M. K., Polak, M. L., and Lineberger, W. C., *J. Chem. Phys.*, 96, 8012, 1992.
89. Lykke, K. R., Murray, K. K., and Lineberger, W. C., *Phys. Rev. A*, 43, 6104, 1991.
90. Ervin, K. M., Gronert, S., Barlow, S. E., Gilles, M. K., Harrison, A. G., Bierbaum, V. M., DePuy, C. H., Lineberger, W. C., and Ellison, G. B., *J. Am. Chem. Soc.*, 112, 5750, 1990.
91. Viggiano, A. A., Miller, T. M., Miller, A. E. S., Morris, R. A., Van Doren, J. M., and Paulson, J. F., *Int. J. Mass Spectrom. Ion Processes*, 109, 327, 1991.
92. Hanstorp, D., and Gustafsson, M., *J. Phys. B: At. Mol. Opt. Phys.*, 25, 1773, 1992.
93. Polak, M. L., Gilles, M. K., and Lineberger, W. C., *J. Chem. Phys.*, 96, 7191, 1992.
94. Bengali, A. A., Casey, S. M., Cheng, C.-L., Dick, J. P., Fenn, P. T., Villalta, P. W., and Leopold, D. G., *J. Am. Chem. Soc.*, 114, 5257, 1992.
95. Gilles, M. K., Ervin, K. M., Ho, J., and Lineberger, W. C., *J. Phys. Chem.*, 96, 1130, 1992.
96. Travers, M. J., Cowles, D. C., Clifford, E. P., and Ellison, G. B., *J. Am. Chem. Soc.*, 114, 8699, 1992.
97. Bengali, A. A., and Leopold, D. G., *J. Am. Chem. Soc.*, 114, 9192, 1992.
98. Rudnyi, E. B., Kaibicheva, E. A., and Sidorov, L. N., *Rapid Comm. in Mass Spectrom.*, 6, 356, 1992; Sidorov, L. N., *High Temp. Sci.*, 29, 153, 1990.
99. Kitsopoulos, T. N., Chick, C. J., Zhao, Y., and Neumark, D. M., *J. Chem. Phys.*, 95, 5479, 1991.
100. Arnold, C. C., Kitsopoulos, T. N., and Neumark, D. M., *J. Chem. Phys.*, 99, 766, 1993.
101. Rudnyi, E. B., Kaibicheva, E. A., and Sidorov, L. N., *J. Chem. Thermodynamics*, 25, 929, 1993.
102. Sarkas, H. W., Hendricks, J. H., Arnold, S. T., and Bowen, K. H., *J. Chem. Phys.* 100, 1884, 1994.
103. Villalta, P. W., and Leopold, D. G., *J. Chem. Phys.* 98, 7730, 1993.
104. Eaton, J. G., Sarkas, H. W., Arnold, S. T., McHugh, K. M., and Bowen, K. H., *Chem. Phys. Lett.*, 193, 141, 1992. See also Ref. 18.
105. Polak, M. L., Gilles, M. K., Gunion, R. F., and Lineberger, W. C., *Chem. Phys. Lett.*, 210, 55, 1993.
106. Gilles, M. K., Lineberger, W. C., and Ervin, K. M., *J. Am. Chem. Soc.*, 115, 1031, 1993.
107. Casey, S. M., and Leopold, D. G., *Chem. Phys. Lett.*, 201, 205, 1993.
108. Polak, M. L., Gerber, G., Ho, J., and Lineberger, W. C., *J. Chem. Phys.*, 97, 8990, 1992.
109. Kim, E. H., Bradforth, S. E., Arnold, D. W., Metz, R. B., and Neumark, D. M., *J. Chem. Phys.*, 103, 7801, 1995.
110. Arnold, C. C., and Neumark, D. M., *J. Chem. Phys.*, 99, 3353, 1993.
111. Bradforth, S. E., Kim, E. H., Arnold, D. W., and Neumark, D. M., *J. Chem. Phys.*, 98, 800, 1993.
112. Ho, J., Polak, M. L., Ervin, K. M., and Lineberger, W. C., *J. Chem. Phys.*, 99, 8542, 1993.
113. Brinkman, E. A., Berger, S., Marks, J., and Brauman, J. I., *J. Chem. Phys.*, 99, 7586, 1993.
114. Casey, S. M., and Leopold, D. G., *J. Phys. Chem.*, 97, 816, 1993.
115. McDonald, R. N., and Davidson, S. J., *J. Am. Chem. Soc.*, 115, 10857, 1993.
116. Ho, J., Ervin, K. M., Polak, M. L., Gilles, M. K., and Lineberger, W. C., *J. Chem. Phys.*, 95, 4845, 1991.
117. Ho, J., Polak, M. L., and Lineberger, W. C., *J. Chem. Phys.*, 96, 144, 1992.
118. Polak, M. L., Gilles, M. K., Ho, J., and Lineberger, W. C., *J. Phys. Chem.*, 95, 3460, 1991.
119. Polak, M. L., Ho, J., Gerber, G., and Lineberger, W. C., *J. Chem. Phys.*, 95, 3053, 1991.
120. Sharpe, P., and Kebarle, P., *J. Am. Chem. Soc.*, 115, 782, 1993.
121. Miller, T. M., Miller, A. E. S., Viggiano, A. A., Morris, R. A., and Paulson, J. F., *J. Chem. Phys.*, 100, 7200, 1994.
122. Berkovits, D., Boaretto, E., Gehlberg, S., Heber, O., and Paul, M., *Phys. Rev. Lett.*, 75, 414, 1995.
123. Arnold, C. C., Xu, C., Burton, G. R., and Neumark, D. M., *J. Chem. Phys.*, 102, 6982, 1995. Burton, G. R., Xu, C., Arnold, C. C., and Neumark, D. M., *J. Chem. Phys.*, in press.
124. Xu, C., de Beer, E., and Neumark, D. M., *J. Chem. Phys.*, 104, 2749, 1996.
125. Gunion, R. F., Koppel, H., Leach, G. W., and Lineberger, W. C., *J. Chem. Phys.*, 103, 1250, 1995.
126. Gunion, R. F., and Lineberger, W. C., *J. Phys. Chem.*, 100, 4395, 1996.
127. Gunion, R. F., Dixon-Warren, St. J., Lineberger, W. C., and Morse, M. D., *J. Chem. Phys.*, in press.
128. Dixon-Warren, St. J., Gunion, R. F., and Lineberger, W. C., *J. Chem. Phys.*, 104, 4902, 1996.
129. Nakajima, A., Zhang, N., Kawamata, H., Hayase, T., Nakao, K., and Kaya, K., *Chem. Phys. Lett.*, 241, 295, 1995; Nakajima, A., Taguwa, T., Nakao, K., Hoshino, K., Iwata, S., and Kaya, K., *J. Chem. Phys.*, 102, 660, 1995.
130. Fan, J., and Wang, L.-S., *J. Chem. Phys.*, 102, 8714, 1995.
131. Arnold, D. W., Bradforth, S. E., Kim, E. H., and Neumark, D. M., *J. Chem. Phys.*, 102, 3493, 1995; Zhao, Y., Arnold, C. C., and Neumark, D. M., *J. Chem. Soc. Faraday Trans. 2*, 89, 1449, 1992.
132. Fan, J., Lou, L., and Wang, L.-S., *J. Chem. Phys.*, 102, 2701, 1995.

133. Sarkas, H. W., Hendricks, J. H., Arnold, S. T., Slager, V. L., and Bowen, K. H., *J. Chem. Phys*., 100, 3358, 1994.
134. Kato, S., Lee, H. S., Gareyev, R., Wenthold, P. G., Lineberger, W. C., DePuy, C. H., and Bierbaum, V. M., *J. Am. Chem. Soc.*, 119, 7863, 1997.
135. Wenthold, P. G., Hu, J., Squires, R. R., and Lineberger, W. C., *J. Am. Chem. Soc.*, 118, 475, 1996.
136. Gunion, R. F., Karney, W., Wenthold, P. G., Borden, W. T., and Lineberger, W. C., *J. Am. Chem. Soc.*, 118, 5074, 1996. The numbers in the abstract for 1,6-heptadiyne were misprinted. EA(cycloheptatrienide) quoted here derives from the LPES data combined with other thermochemical data in Reference 136.
137. Xu, C., de Beer, E., Arnold, D. W., Arnold, C. C., and Neumark, D. M., *J. Chem. Phys.*, 101, 5406, 1996.
138. Wenthold, P. G., Polak, M. L., and Lineberger, W. C., *J. Phys. Chem.*, 100, 6920, 1996.
139. Wenthold, P. G., Kim, J. B., and Lineberger, W. C., *J. Am. Chem. Soc.*, 119, 1354, 1997.
140. Eliav, E., Kaldor, U., Ishikawa, Y., and Pyykkoe, *Phys. Rev. Lett.*, 77, 5350, 1996.
141. Davies, B. J., Ingram, C. W., Larson, D. J., and Ljungblad, U., *J. Chem. Phys.* 106, 5783, 1997.
142. Smith, J. R., Kim, J. B., and Lineberger, W. C., *Phys. Rev. A.*, 55, 2036, 1997. Schulz, P.A., Mead, R. D., Jones, P. L., and Lineberger, W. C., *J. Chem. Phys.*, 77, 1153, 1982. See also Rudmin, J. D., Ratliff, L. P., Yukich, J. N., and Larson, D. J., *J. Phys. B: At. Mol. Opt. Phys.*, 29, L881, 1996.
143. Desai, S. R., Wu, H., Rohlfing, C. M., and Wantg, L.-S., *Int. J. Chem. Phys.*, 106, 1309, 1997.
144. Wenthold, P. G., Joans, K.-L., and Lineberger, W. C., *J. Chem. Phys.*, 106, 9961, 1997.
145. Wu, H. and Wang, L.-S., *J. Chem. Phys.*, 107, 16, 1997.
146. Moravec, V. D. and Jarrold, C. C., *J. Chem. Phys.*, in press.
147. Wang, X.-B., Ding, C.-F., and Wang, L.-S., *J. Phys. Chem. A*, 101, 7699, 1997.
148. Wenthold, P. G. and Lineberger, W. C., *J. Am. Chem. Soc.*, 19, 7772, 1997.
149. Wang, L.-S., Cheng, H.-S., and Fan, J., *J. Chem. Phys.*, 102, 9480, 1995.
150. Wu, H., Desai, S. R., and Wang, L.-S., *Phys. Rev. Lett.*, 77, 2436, 1996.
151. Wu, H., Desai, S. R., and Wang, L.-S., *Phys. Rev. Lett.*, 76, 212, 1996.
152. Wang, L.-S., Wu, H., and Desai, S. R., *Phys. Rev. Lett.*, 76, 4853, 1996.
153. Robinson, M. S., Polak, M. L., Bierbaum, V. M., DePuy, C. H., and Lineberger, W. C., *J. Am. Chem. Soc.*, 117, 6766, 1995.
154. Clifford, E. P., Wenthold, P. G., Lineberger, W. C., Petersson, G. A., and Ellison, G. B., *J. Phys. Chem.*, 101, 4338, 1997.
155. Wenthold, P. G., Kim, J. B., Jonas, K., and Lineberger, W. C., *J. Phys. Chem.*, in press, 1997.

ATOMIC AND MOLECULAR POLARIZABILITIES

Thomas M. Miller

The *polarizability* of an atom or molecule describes the response of the electron cloud to an external field. The atomic or molecular energy shift ΔW due to an external electric field E is proportional to E^2 for external fields which are weak compared to the internal electric fields between the nucleus and electron cloud. The *electric dipole polarizability* α is the constant of proportionality defined by $\Delta W = -\alpha E^2/2$. The induced electric dipole moment is αE. *Hyperpolarizabilities,* coefficients of higher powers of E, are less often required. Technically, the polarizability is a tensor quantity but for spherically symmetric charge distributions reduces to a single number. In any case, an *average polarizability* is usually adequate in calculations. Frequency-dependent or *dynamic polarizabilities* are needed for electric fields which vary in time, except for frequencies which are much lower than electron orbital frequencies, where *static polarizabilities* suffice.

Polarizabilities for atoms and molecules in excited states are found to be larger than for ground states and may be positive or negative. Molecular polarizabilities are very slightly temperature dependent since the size of the molecule depends on its rovibrational state. Only in the case of dihydrogen has this effect been studied enough to warrant consideration in Table 3.

Polarizabilities are normally expressed in cgs units of cm^3. Ground state polarizabilities are in the range of 10^{-24} cm^3 = 1 $Å^3$ and hence are often given in $Å^3$ units. Theorists tend to use atomic units of a_o^3 where a_o is the Bohr radius. The conversion is $\alpha(cm^3) = 0.148184 \times 10^{-24} \times \alpha(a_o^3)$. Polarizabilities are only recently encountered in SI units, $C{\cdot}m^2/V = J/(V/m)^2$. The conversion from cgs units to SI units is $\alpha(C{\cdot}m^2/V) = 4\pi\varepsilon_o \times 10^{-6} \times \alpha(cm^3)$, where ε_o is the permittivity of free space in SI units and the factor 10^{-6} simply converts cm^3 into m^3. Thus, $\alpha(C{\cdot}m^2/V) = 1.11265 \times 10^{-16} \times \alpha(cm^3)$. Persons measuring excited state polarizabilities by optical methods tend to use units of $MHz/(V/cm)^2$, where the energy shift, ΔW, is expressed in frequency units with a factor of h understood. The polarizability is $-2\,\Delta W/E^2$. The conversion into cgs units is $\alpha(cm^3) = 5.95531 \times 10^{-16} \times \alpha[MHz/(V/cm)^2]$.

The polarizability appears in many formulas for low-energy processes involving the valence electrons of atoms or molecules. These formulas are given below in cgs units: the polarizability α is in cm^3; masses m or μ are in grams; energies are in ergs; and electric charges are in esu, where $e = 4.8032 \times 10^{-10}$ esu. The symbol $\alpha(\nu)$ denotes a frequency (ν) dependent polarizability, where $\alpha(\nu)$ reduces to the static polarizability α for $\nu = 0$. For further information and references, see Miller, T. M., and Bederson, B., *Advances in Atomic and Molecular Physics*, 13, 1, 1977. Details on polarizability-related interactions, especially in regard to hyperpolarizabilities and nonlinear optical phenomena, are given by Bogaard, M. P., and Orr, B. J., in *Physical Chemistry,* Series Two, Vol. 2, *Molecular Structure and Properties*, Buckingham, A. D., Ed., Butterworths, London, 1975, pp. 149-194. A tabulation of tensor and hyperpolarizabilities is included. The gas number density, n, in Table 1 is usually taken to be that of 1 atm at 0°C in reporting experimental data.

Table 1
Formulas Involving Polarizability

Description	Formula	Remarks
Lorentz-Lorenz relation	$\alpha(\nu) = \frac{3}{4\pi n}\left[\frac{\eta^2(\nu)-1}{\eta^2(\nu)+2}\right]$	For a gas of atoms or nonpolar molecules; the index of refraction is $\eta(\nu)$
Refraction by polar molecules	$\alpha(\nu) + \frac{d^2}{3kT} = \frac{3}{4\pi n}\left[\frac{\eta^2(\nu)-1}{\eta^2(\nu)+2}\right]$	The dipole moment is d, in esu·cm (= 10^{-18} D)
Dielectric constant (dimensionless)	$\kappa(\nu) = 1 + 4\pi n\ \alpha(\nu)$	From the Lorentz-Lorenz relation for the usual case of $\kappa(\upsilon)\approx 1$
Index of refraction (dimensionless)	$\eta(\nu) = 1 + 2\pi n\ \alpha(\nu)$	From $\eta^2(\nu) = \kappa(\nu)$
Diamagnetic susceptibility	$\chi_m = e^2\left(a_o N\alpha\right)^{1/2} / 4m_e c^2$	From the approximation that the static polarizability is given by the variational formula $\alpha = (4/9a_o)\Sigma(N_i r_i^2)^2$; N is the number of electrons, m_e is the electron mass; a crude approximation is $\chi_m = (E_i/4m_e c^2)\alpha$, where E_i is the ionization energy
Long-range electron- or ion-molecule interaction energy	$V(r) = -e^2\alpha / 2r^4$	The target molecule polarizability is α
Ion mobility in a gas	$\kappa = 13.87/(\alpha\mu)^{1/2}\ \mathrm{cm^2/V \cdot s}$	This one formula is not in cgs units. Enter α in $Å^3$ or 10^{-24} cm^3 units and the reduced mass μ of the ion-molecule pair in amu. Classical limit; pure polarization potential

Table 1
Formulas Involving Polarizability (continued)

Description	Formula	Remarks
Langevin capture cross section	$\sigma(v_o) = (2\pi e/v_o)(\alpha/\mu)^{1/2}$	The relative velocity of approach for an ion-molecule pair is v_o; the target molecular polarizability is α and the reduced mass of the ion-molecule pair is μ
Langevin reaction rate coefficient	$k = 2\pi e(\alpha/\mu)^{1/2}$	Collisional rate coefficient for an ion-molecule reaction
Rate coefficient for polar molecules	$k_d = 2\pi e\left[(\alpha/\mu)^{1/2} + cd(2/\mu\pi kT)^{1/2}\right]$	The dipole moment of the neutral is d in esu·cm; the number c is a "locking factor" that depends on α and d, and is between 0 and 1
Modified effective range cross section for electron-neutral scattering	$\sigma(k) = 4\pi A^2 + 32\pi^4\mu e^2\alpha Ak/3h^2 + \ldots$	Here, k is the electron momentum divided by $h/2\pi$, where h is Planck's constant; A is called the "scattering length"; the reduced mass is μ
van der Waals constant between two systems A, B	$C_6 = \frac{3}{2}\left[\frac{\alpha^A\alpha^B E^A E^B}{E^A + E^B}\right]$	For the interaction potential term $V_6(r) = -C_6 r^6$; $E^{A,B}$ represents average dipole transition energies and $\alpha^{A,B}$ the respective polarizabilities of A, B
Dipole-quadrupole constant between two systems A, B	$C_8 = \frac{15}{4}\left[\frac{\alpha^A\alpha_q{}^B E^A E_q{}^B}{E^A + E_q{}^B}\right] + \frac{15}{4}\left[\frac{\alpha_q{}^A\alpha^B E_q{}^A E^B}{E_q{}^A + E^B}\right]$	For the interaction potential term $V_8(r) = -C_8 r^8$; $E_q{}^{A,B}$ represents average quadrupole transition energies and $\alpha_q{}^{A,B}$ are the respective quadrupole polarizabilities of A, B
van der Waals constant between an atom and a surface	$C_3 = \frac{\alpha g E^A E^S}{8(E^A + E^S)}$	For an interaction potential $V_3(r) = -C_3 r^3$; $E^{A,S}$ are characteristic energies of the atom and surface; $g = 1$ for a free-electron metal and $g = (\varepsilon_\infty - 1)/(\varepsilon_\infty + 1)$ for an ionic crystal
Relation between α(ν) and oscillator strengths	$\alpha(\nu) = \frac{e^2h^2}{4\pi^2 m_e}\Sigma\frac{f_k}{E_k^2 - (h\nu)^2}$	Here, f_k is the oscillator strength from the ground state to an excited state k, with excitation energy E_k. This formula is often used to estimate static polarizabilities ($\nu = 0$)
Dynamic polarizability	$\alpha(\nu) = \frac{\alpha E_r{}^2}{E_r{}^2 - (h\nu)^2}$	Approximate variation of the frequency-dependent polarizability α(ν) from ν = 0 up to the first dipole-allowed electronic transition, of energy E_r; the static dipole polarizability is α(0); infrared contributions ignored
Rayleigh scattering cross section	$\alpha(\nu) = \frac{8\pi}{9c^4}(2\pi\nu)^4 \times \left[3\alpha^2(\nu) + 2\gamma^2(\nu)/3\right]$	The photon frequency is ν; the polarizability anisotropy (the difference between polarizabilities parallel and perpendicular to the molecular axis) is γ(ν)
Verdet constant	$V(\nu) = \frac{\nu n}{2m_e c^2}\left[\frac{d\alpha(\nu)}{d\nu}\right]$	Defined from $\theta = V(\nu)B$, where θ is the angle of rotation of linearly polarized light through a medium of number density n, per unit length, for a longitudinal magnetic field strength B (Faraday effect)

Table 2
Static Average Electric Dipole Polarizabiilities for Ground State Atoms (in Units of 10^{-24} cm^3)

Atomic number	Atom	Polarizability	Estimated accuracy (%)	Method	Ref.
1	H	0.666793	"exact"	calc	MB77
2	He	0.204956	"exact"	calc	MB77
		0.2050	0.1	index/diel	NB65/OC67
3	Li	24.3	2	beam	MB77
4	Be	5.60	2	calc	MB77
5	B	3.03	2	calc	MB77
6	C	1.76	2	calc	MB77
7	N	1.10	2	calc/index	MB77
8	O	0.802	2	calc/index	MB77
9	F	0.557	2	calc	MB77
10	Ne	0.3956	0.1	diel	OC67
11	Na	24.08	0.4	interferom	ESCHP94
12	Mg	10.6	2	calc	MB77
13	Al	6.8	4.4	beam	MMD90
14	Si	5.38	2	calc	MB77
15	P	3.63	2	calc	MB77
16	S	2.90	2	calc	MB77
17	Cl	2.18	2	calc	MB77
18	Ar	1.6411	0.05	index/diel	NB65/OC67
19	K	43.4	2	beam	MB77
20	Ca	22.8	2	calc	MB77
		25.0	8	beam	MB77
21	Sc	17.8	25	calc	D84
22	Ti	14.6	25	calc	D84
23	V	12.4	25	calc	D84
24	Cr	11.6	25	calc	D84
25	Mn	9.4	25	calc	D84
26	Fe	8.4	25	calc	D84
27	Co	7.5	25	calc	D84
28	Ni	6.8	25	calc	D84
29	Cu	6.1	25	calc	D84
		7.31	25	calc	G84
30	Zn	7.1	25	calc	MB77
		5.6	25	calc	D84
31	Ga	8.12	2	calc	MB77
32	Ge	6.07	2	calc	MB77
33	As	4.31	2	calc	MB77
34	Se	3.77	2	calc	MB77
35	Br	3.05	2	calc	MB77
36	Kr	2.4844	0.05	diel	OC67
37	Rb	47.3	2	beam	MB77
38	Sr	27.6	8	beam	MB77
39	Y	22.7	25	calc	D84
40	Zr	17.9	25	calc	D84
41	Nb	15.7	25	calc	D84
42	Mo	12.8	25	calc	D84
43	Tc	11.4	25	calc	D84
44	Ru	9.6	25	calc	D84
45	Rh	8.6	25	calc	D84
46	Pd	4.8	25	calc	D84
47	Ag	7.2	25	calc	D84
		8.56	25	calc	G84
48	Cd	7.2	25	calc	D84
49	In	10.2	12	beam	GMBSJ84
		9.1	25	calc	D84

Table 2
Static Average Electric Dipole Polarizabiilities for Ground State Atoms (in Units of 10^{-24} cm^3) (continued)

Atomic number	Atom	Polarizability	Estimated accuracy (%)	Method	Ref.
50	Sn	7.7	25	calc	D84
51	Sb	6.6	25	calc	D84
52	Te	5.5	25	calc	D84
53	I	5.35	25	index	A56
		4.7	25	calc	D84
54	Xe	4.044	0.5	diel	MB77
55	Cs	59.6	2	beam	MB77
56	Ba	39.7	8	beam	MB77
57	La	31.1	25	calc	D84
58	Ce	29.6	25	calc	D84
59	Pr	28.2	25	calc	D84
60	Nd	31.4	25	calc	D84
61	Pm	30.1	25	calc	D84
62	Sm	28.8	25	calc	D84
63	Eu	27.7	25	calc	D84
64	Gd	23.5	25	calc	D84
65	Tb	25.5	25	calc	D84
66	Dy	24.5	25	calc	D84
67	Ho	23.6	25	calc	D84
68	Er	22.7	25	calc	D84
69	Tm	21.8	25	calc	D84
70	Yb	21.0	25	calc	D84
71	Lu	21.9	25	calc	D84
72	Hf	16.2	25	calc	D84
73	Ta	13.1	25	calc	D84
74	W	11.1	25	calc	D84
75	Re	9.7	25	calc	D84
76	Os	8.5	25	calc	D84
77	Ir	7.6	25	calc	D84
78	Pt	6.5	25	calc	D84
79	Au	5.8	25	calc	D84
		6.48	25	calc	G84
80	Hg	5.7	25	calc	D84
		5.1	15	diel	MB77
81	Tl	7.6	15	beam	NYU84
		7.5	25	calc	D84
82	Pb	6.8	25	calc	D84
83	Bi	7.4	25	calc	D84
84	Po	6.8	25	calc	D84
85	At	6.0	25	calc	D84
86	Rn	5.3	25	calc	D84
87	Fr	48.7	25	calc	D84
88	Ra	38.3	25	calc	D84
89	Ac	32.1	25	calc	D84
90	Th	32.1	25	calc	D84
91	Pa	25.4	25	calc	D84
92	U	24.9	6	beam	KB94
93	Np	24.8	25	calc	D84
94	Pu	24.5	25	calc	D84
95	Am	23.3	25	calc	D84
96	Cm	23.0	25	calc	D84
97	Bk	22.7	25	calc	D84
98	Cf	20.5	25	calc	D84
99	Es	19.7	25	calc	D84

Table 2
Static Average Electric Dipole Polarizabiilities for Ground State Atoms (in Units of 10^{-24} cm^3) (continued)

Atomic number	Atom	Polarizability	Estimated accuracy (%)	Method	Ref.
100	Fm	23.8	25	calc	D84
101	Md	18.2	25	calc	D84
102	No	17.5	25	calc	D84

Note: calc = calculated value; beam = atomic beam deflection technique; interferom = atomic beam interference; index = determination based on the measured index of refraction; diel = determination based on the measured dielectric constant.

REFERENCES

A56. Atoji, M., *J. Chem. Phys.*, 25, 174, 1956. Semiempirical method based on molecular polarizabilities and atomic radii.

D84. Doolen, G. D., Los Alamos National Laboratory, unpublished. A relativistic linear response method was used. The method is that described by Zangwill, A., and Soven, P., *Phys. Rev. A*, 21, 1561, 1980. Adjustments of less than 10% across the periodic table have been made to these results to bring them into agreement with accurate experimental values where avaialble, for the purpose of presenting "recommended" polarizabilities in Table 2.

ESCHP94. Ekstrom, C. R., Schmiedmayer, J., Chapman, M. S., Hammond, T. D., and Pritchard, D. E., *Phys. Rev. Lett.*, in press, 1994.

G84. Gollisch, H., *J. Phys. B: Atom. Mol. Phys.*, 17, 1463, 1984. Other results and useful references are contained in this paper.

GMBSJ84. Guella, T. P., Miller, T. M., Bederson, B., Stockdale, J. A. D., and Jaduszliwer, B., *Phys. Rev. A*, 29, 2977, 1984.

KB94. Kadar-Kallen, M. A., and Bonin, K. D., *Phys. Rev. Lett.*, 72, 828, 1994.

MB77. Miller, T. M., and Bederson, B., *Adv. At. Mol. Phys.*, 13, 1, 1977. For simplicity, any value in Table 2 which has not changed since this 1977 review is referenced as MB77. Persons interested in original references and further details should consult MB77.

MMD90. Milani, P., Moullet, I., and de Heer, W. A., *Phys. Rev. A*, 42, 5150, 1990.

NB65. Newell, A. C., and Baird, R. D., *J. Appl. Phys.*, 36, 3751, 1965.

NYU84. Preliminary value from the New York University group. See GMBSJ84.

OC67. Orcutt, R. H., and Cole, R. H., *J. Chem. Phys.*, 46, 697, 1967; see also the later references from this group, given following the tables.

Table 3
Average Electric Dipole Polarizabilities for Ground State Diatomic Molecules (in Units of 10^{-24} cm^3)

Molecule	Polarizability	Ref.
Al_2	19	23
BH	3.32*	1
Br_2	7.02	2
CO	1.95	3
Cl_2	4.61	3
Cs_2	104	22
CsK	89	22
D_2 (v = 0,J = 0)	0.7921*	5
D_2 (293 K)	0.7954	6
DCl	2.84	2
F_2	1.38*	7
H_2 (v = 0,J = 0)	0.8023*	5
H_2 (293 K)	0.8045*	5
H_2 (293 K)	0.8042	6
H_2 (322 K)	0.8059	8
HBr	3.61	3
HCl	2.63	3
	2.77	2
HD (v = 0,J = 0)	0.7976*	5
HF	0.80	27
HI	5.44	3
	5.35	2
HgCl	7.4*	9
ICl	12.3	2
K_2	77	22
	72	21
Li_2	34	22
LiCl	3.46*	10
LiF	10.8*	11
LiH	3.84*	12
	3.68*	13
	3.88*	14
N_2	1.7403	6,8
NO	1.70	2
Na_2	40	22
	38	21
NaK	51	22
NaLi	40	4
O_2	1.5812	6
Rb_2	79	22

Table 4
Average Electric Dipole Polarizabilities for Ground State Triatomic Molecules (in Units of 10^{-24} cm^3)

Molecule	Polarizability	Ref.	Molecule	Polarizability	Ref.	Molecule	Polarizability	Ref.
BeH_2	4.34[*]	14	HCN	2.59	3	O_3	3.21	2
CO_2	2.911	8		2.46	2	OCS	5.71	2
CS_2	8.74	3	$HgBr_2$	14.5	2		5.2	15
	8.86	2	$HgCl_2$	11.6	2	SO_2	3.72	3
D_2O	1.26	2	HgI_2	19.1	2		4.28	2
H_2O	1.45	2	N_2O	3.03	8			
H_2S	3.78	3	NO_2	3.02	2[†]			
	3.95	2	Na_3	70	21			

Table 5
Average Electric Dipole Polarizabilities for Ground State Inorganic Polyatomic Molecules (Larger than Triatomic) (in Units of 10^{-24} cm^3)

Molecule	Polarizability	Ref.	Molecule	Polarizability	Ref.
$AsCl_3$	14.9	2	$(NaBr)_2$	26.8	16
AsN_3	5.75	2	$(NaCl)_2$	23.4	16
BCl_3	9.38	20	$(NaF)_2$	20.7	16
BF_3	3.31	2	$(NaI)_2$	26.9	16
$(BN_3)_2$	5.73	2	OsO_4	8.17	2
$(BH_2N)_3$	8.0	2[†]	PCl_3	12.8	2
ClF_3	6.32	2	PF_5	6.10	2
$(CsBr)_2$	54.5	16	PH_3	4.84	2
$(CsCl)_2$	42.4	16	$(RbBr)_2$	48.2	16
$(CsF)_2$	28.4	16	$(RbCl)_2$	43.2	16
$(CsI)_2$	51.8	16	$(RbF)_2$	40.7	16
$GeCl_4$	15.1	2	$(RbI)_2$	46.3	16
GeH_3Cl	6.7	2[†]	SF_6	6.54	8
$(HgCl)_2$	14.7	9	$(SF_5)_2$	13.2	2
K_n	n = 2,5,7-9,11,20	21	SO_3	4.84	2
$(KBr)_2$	42.0	16	SO_2Cl_2	10.5	2
$(KCl)_2$	32.1	16	SeF_6	7.33	2
$(KF)_2$	21.0	16	SiF_4	5.45	2
$(KI)_2$	36.3	16	SiH_4	5.44	2
$(LiBr)_2$	18.9	16	$(SiH_3)_2$	11.1	2
$(LiCl)_2$	13.1	16	$SiHCl_3$	10.7	2
$(LiF)_2$	6.9	16	SiH_2Cl_2	8.92	2
$(LiI)_2$	23.4	16	SiH_3Cl	7.02	2
ND_3	1.70	2	$SnBr_4$	22.0	2
NF_3	3.62	2	$SnCl_4$	18.0	2
NH_3	2.81	20		13.8	15
	2.10	2	SnI_4	32.3	2
	2.26	3	TeF_6	9.00	2
$(NO_2)_2$	6.69	2	$TiCl_4$	16.4	2
Na_n	n = 1-40	21	UF_6	12.5	2

Table 6
Average Electric Dipole Polarizabilities for Ground State Hydrocarbon Molecules (in Units of 10^{-24} cm^3)

Molecule	Name	Polarizability	Ref.
CH_4	methane	2.593	8
C_2H_2	acetylene	3.33	3
		3.93	2
C_2H_4	ethylene	4.252	8
C_2H_6	ethane	4.47	3
		4.43	2
C_3H_4	propyne	6.18	2
C_3H_6	propene	6.26	2
	cyclopropane	5.66	2
C_3H_8	propane	6.29	3
		6.37	2
C_4H_6	1-butyne	7.41	2[†]
	1,3-butadiene	8.64	2
C_4H_8	1-butene	7.97	2
		8.52	2
	trans-2-butene	8.49	2
	2-methylpropene	8.29	2
C_4H_{10}	*n*-butane	8.20	2
	isobutane	8.14	27
C_5H_6	1,3-cyclopentadiene	8.64	2
C_5H_8	1-pentyne	9.12	2
	trans-1,3-pentadiene	10.0	2
	isoprene	9.99	2
C_5H_{10}	cyclopentane	9.15	18
	1-pentene	9.65	27
	2-pentene	9.84	27
C_5H_{12}	pentane	9.99	2
	neopentane	10.20	18
C_6H_6	benzene	10.0	25
		10.32	3
		10.74	2
C_6H_{10}	1-hexyne	10.9	2[†]
	2-ethyl-1,3-butadiene	11.8	2[†]
	3-methyl-1,3-pentadiene	11.8	2[†]
	2-methyl-1,3-pentadiene	12.1	2[†]
	2,3-dimethyl-1,3-butadiene	11.8	2[†]
	cyclohexene	10.7	2[†]
C_6H_{12}	cyclohexane	11.0	18
		10.87	15
	1-hexene	11.7	27
C_6H_{14}	*n*-hexane	11.9	2
C_7H_8	toluene	11.8	25
		12.26	15
		12.3	2
C_7H_{12}	1-heptyne	12.8	2[†]
C_7H_{14}	methylcyclohexane	13.1	2
	1-heptene	13.5	27
C_7H_{16}	*n*-heptane	13.7	2
C_8H_8	styrene	15.0	2
		14.4	27
C_8H_{10}	ethylbenzene	14.2	2
	o-xylene	14.9	2
		14.1	15
	p-xylene	13.7	25
		14.2	15
		14.9	2
	m-xylene	14.2	15
C_8H_{16}	ethylcyclohexane	15.9	2
C_8H_{18}	*n*-octane	15.9	2
	3-methylheptane	15.4	27
	2,2,4-trimethylpentane	15.4	27
C_9H_{10}	α-methylstyrene	16.05	27
C_9H_{12}	isopropylbenzene	16.0	2–
	mesitylene	15.5	25
		16.1	27
C_9H_{18}	isopropylcyclohexane	17.2	2
C_9H_{20}	nonane	17.4	27
$C_{10}H_8$	napthalene	16.5	17
		17.5	27
$C_{10}H_{14}$	durene	17.3	25
	t-butylbenzene	17.2	25
		17.8	2[†]
$C_{10}H_{20}$	*t*-butylcyclohexane	19.8	2
$C_{10}H_{22}$	decane	19.1	27
$C_{11}H_{10}$	α-methylnaphthalene	19.35	27
	β-methylnaphthalene	19.52	27
$C_{11}H_{14}$	α,β,β-trimethylstyrene	19.64	27
$C_{11}H_{16}$	pentamethylbenzene	19.1	25
$C_{11}H_{24}$	undecane	21.0	27
$C_{12}H_{10}$	acenaphthene	20.6	27
$C_{12}H_{12}$	α-ethylnaphthalene	21.19	27
	β-ethylnaphthalene	21.36	27
$C_{12}H_{18}$	hexamethylbenzene	20.9	25
$C_{12}H_{26}$	dodecane	22.8	27
$C_{13}H_{10}$	fluorene	21.7	27
$C_{14}H_{10}$	anthracene	25.4	17
		25.9	27
	phenanthrene	36.8[*]	17
		24.7	27
$C_{14}H_{22}$	*p*-di-*t*-butylbenzene	24.5	25
$C_{16}H_{10}$	pyrene	28.2	27
$C_{17}H_{12}$	2,3-benzfluorene	30.2	27
$C_{18}H_{12}$	napthacene	32.3	27
	1,2-benzanthracene	32.9	27
	chrysene	33.1	27
	triphenylene	31.1	27
$C_{18}H_{30}$	1,3,5-tri-*t*-butylbenzene	31.8	25
$C_{24}H_{12}$	coronene		

Table 7
Average Electric Dipole Polarizabilities for Ground State Organic Halides (in Units of 10^{-24} cm^3)

Molecule	Name	Polarizability	Ref.
CBr_2F_2	dibromodifluoromethane	9.0	2†
$CClF_3$	chlorotrifluoromethane	5.72	20
		5.59	2
CCl_2F_2	dichlorodifluoromethane	7.93	20
		7.81	2
CCl_2O	phosgene	7.29	2
CCl_2S	thiophosgene	10.2	2
CCl_3F	trichlorofluoromethane	9.47	2
CCl_3NO_2	trichloronitromethane	10.8	2†
CCl_4	carbon tetrachloride	11.2	2
		10.5	3
CF_4	carbon tetrafluoride	3.838	8
CF_2O	carbonylfluoride	1.88*	17
$CHBr_3$	bromoform	11.8	17
$CHBrF_2$	bromodifluoromethane	5.7	2†
$CHClF_2$	chlorodifluoromethane	6.38	20
		5.91	2
$CHCl_2F$	dichlorofluoromethane	6.82	2
$CHCl_3$	chloroform	9.5	8
		8.23	27
CHF_3	fluoroform	3.52	20
		3.57	8
CHFO	fluoroformaldehyde	1.76*	17
CHI_3	iodoform	18.0	17
CH_2Br_2	dibromomethane	9.32	2
		8.62	27
CH_2ClNO_2	chloronitromethane	6.9	2†
CH_2Cl_2	dichloromethane	6.48	3
		7.93	2
CH_2I_2	diiodomethane	12.90	27
CH_3Br	bromomethane	5.87	20
		6.03	2
		5.55	15
CH_3Cl	chloromethane	5.35	20
		4.72	8
CH_3F	fluoromethane	2.97	8
CH_3I	iodomethane	7.97	2
C_2ClF_5	chloropentafluoroethane	6.3	2†
$C_2Cl_2F_4$	1,2-dichlorotetrafluoroethane	8.5	2†
C_2Cl_3N	trichloroacetonitrile	6.10	18
C_2F_6	hexafluoroethane	6.82	2
C_2HBr	bromoacetylene	7.39	2
C_2HCl	chloroacetylene	6.07	2
C_2HCl_5	pentachloroethane	14.0	2
$C_2H_2Cl_2$	1,1-dichloroethylene	7.83	27
	trans-1,2-dichloroethylene	8.15	27
	cis-1,2-dichloroethylene	8.03	27
$C_2H_2Cl_2F_2$	1,1-dichloro-2,2-difluoroethane	8.4	2†
$C_2H_2Cl_2O$	chloroacetyl chloride	8.92	2
$C_2H_2Cl_3F$	1,2,2-trichloro-1-fluoroethane	10.2	2†
$C_2H_2Cl_4$	1,1,2,2-tetrachloroethane	12.1	2†
C_2H_2ClN	chloroacetonitrile	6.10	18
$C_2H_2F_2$	1,1-difluoroethylene	5.01	20
C_2H_3Br	bromoethylene	7.59	2
C_2H_3Cl	chloroethylene	6.41	2

Table 7
Average Electric Dipole Polarizabilities for Ground State Organic Halides (in Units of 10^{-24} cm^3) (continued)

Molecule	Name	Polarizability	Ref.
$C_2H_3ClF_2$	1-chloro-1,1-difluoroethane	8.05	2
C_2H_3ClO	acetyl chloride	6.62	2
$C_2H_3ClO_2$	ethyl chloroformate	7.1	2†
$C_2H_3Cl_3$	1,1,1-trichloroethane	10.7	2
$C_2H_3F_3$	1,1,1-trifluoroethane	4.4	2†
C_2H_3I	iodoethylene	9.3	2†
C_2H_4BrCl	1-bromo-2-chloroethane	9.5	2†
$C_2H_4Br_2$	1,2-dibromomethane	10.7	2†
C_2H_4ClF	1-chloro-2-fluoroethane	6.5	2†
$C_2H_4ClNO_2$	1-chloro-1-nitroethane	10.9	2
$C_2H_4Cl_2$	1,1-dichloroethane	8.64	2
	1,2-dichloroethane	8.0	2†
C_2H_5Br	bromoethane	8.05	2
		7.28	27
C_2H_5Cl	chloroethane	7.27	20
		8.29	2
		6.4	15
C_2H_5ClO	2-chloroethanol	7.1	2†
		6.88	27
	chloromethyl methyl ether	7.1	2†
C_2H_5F	fluoroethane	4.96	2
C_2H_5I	iodoethane	10.0	2
$C_3H_4Cl_2$	dichloropropene	10.1	2†
C_3H_5Cl	chloropropene	8.3	2
C_3H_5ClO	chloroacetone	8.4	2†
$C_3H_3ClO_2$	ethyl chloroformate	9.0	2†
$C_3H_6ClNO_2$	1-chloro-1-nitropropane	10.4	2†
$C_3H_6Cl_2$	dichloropropane	10.9	2†
C_3H_7Br	1-bromopropane	9.4	2†
		9.07	27
	2-bromopropane	9.6	2†
C_3H_7Cl	chloropropane	10.0	2
C_3H_7ClO	β-chloroethyl methyl ether	8.71	27
	2-chloro-1-propanol	8.89	27
	3-chloro-1-propanol	8.84	27
C_3H_7I	1-iodopropane	11.5	2†
C_4H_5Cl	4-chloro-1,2-butadiene	10.0	2†
C_4H_7Cl	1-chloro-2-methylpropene	10.8	2
$C_4H_7ClO_2$	2-chlorobutyric acid	10.7	27
	3-chlorobutyric acid	10.7	27
	4-chlorobutyric acid	10.6	27
$C_4H_8Cl_2$	1,4-dichlorobutane	12.0	2†
C_4H_9Br	bromobutane	13.9	2
		10.86	27
C_4H_9Cl	1-chlorobutane	11.3	2
	1-chloro-2-methylpropane	11.1	2
	2-chloro-2-methylpropane	12.5	2†
	2-chlorobutane	12.4	2
C_4H_9ClO	β-chloroethyl ethyl ether	10.56	27
	2-chloro-1-butanol	10.70	27
	3-chloro-1-butanol	10.38	27
C_4H_9I	1-iodobutane	13.3	2†
		12.65	27
$C_5H_9ClO_2$	2-chlorobutanoate acid	12.33	27
	3-chlorobutanoate acid	12.31	27

Table 7
Average Electric Dipole Polarizabilities for Ground State Organic Halides (in Units of 10^{-24} cm^3) (continued)

Molecule	Name	Polarizability	Ref.
	4-chlorobutanoate acid	12.27	27
	2-chloropentanoic acid	12.69	27
	3-chloropentanoic acid	12.57	27
	4-chloropentanoic acid	12.53	27
$C_5H_{11}Br$	1-bromopentane	13.1	2†
$C_5H_{11}Cl$	1-chloropentane	12.0	2†
$C_5H_{11}F$	fluoropentane	9.95	27
C_6F_6	hexafluorobenzene	9.58	27
C_6HF_5	pentafluorobenzene	9.63	27
$C_6H_2Cl_2O_2$	2,5-dichloro-1,4-benzoquinone	18.4	2
$C_6H_2F_4$	1,2,3,4-tetrafluorobenzene	9.69	27
	1,2,4,5-tetrafluorobenzene	9.69	27
$C_6H_3F_3$	1,3,5-trifluorobenzene	9.74	27
C_6H_4BrF	*p*-bromofluorobenzene	13.4	2†
$C_6H_4ClNO_2$	chloronitrobenzene	14.6	2†
$C_6H_4Cl_2$	*o*-dichlorobenzene	14.17	27
	m-dichlorobenzene	14.23	27
	p-dichlorobenzene	14.20	27
C_6H_4FI	*p*-fluoroiodobenzene	15.5	2†
$C_6H_4FNO_2$	*p*-fluoronitrobenzene	12.8	2†
$C_6H_4F_2$	*o*-difluorobenzene	9.80	27
	m-difluorobenzene	10.3	2†
	p-difluorobenzene	9.80	27
C_6H_5Br	bromobenzene	14.7	2
		13.62	27
C_6H_5Cl	chlorobenzene	14.1	2
		12.3	15
C_6H_5ClO	chlorophenol	13.0	2†
C_6H_5F	fluorobenzene	10.3	2
C_6H_5I	iodobenzene	15.5	2†
$C_6H_{11}ClO_2$	2-chlorobutanoate acid	14.16	27
	3-chlorobutanoate acid	14.13	27
	4-chlorobutanoate acid	14.11	27
$C_6H_{13}Br$	bromohexane	14.44	27
$C_6H_{13}F$	fluorohexane	11.80	27
C_7H_7Br	*p*-bromotoluene	14.80	27
C_7H_7Cl	*p*-chlorotoluene	13.70	27
C_7H_7F	*p*-fluorotoluene	11.70	27
C_7H_7I	*p*-iodotoluene	17.10	27
$C_7H_{15}Br$	1-bromoheptane	16.8	2†
		16.23	27
$C_7H_{15}F$	fluoroheptane	13.66	27
$C_8H_{17}Br$	bromooctane	18.02	27
$C_8H_{17}F$	fluorooctane	15.46	27
$C_9H_{19}Br$	bromononane	19.81	27
$C_9H_{19}F$	fluorononane	17.34	27
$C_{10}F_8$	octafluoronaphthalene	17.64	27
$C_{10}H_7Br$	α-bromonaphthalene	20.34	27
$C_{10}H_7Cl$	α-chloronaphthalene	19.30	27
	β-chloronaphthalene	19.58	27
$C_{10}H_7I$	α-iodonaphthalene	22.41	27
	β-iodonaphthalene	22.95	27
$C_{10}H_{21}Br$	bromodecane	21.60	27
$C_{10}H_{21}F$	fluorodecane	19.18	27

Table 7
Average Electric Dipole Polarizabilities for Ground State Organic Halides (in Units of 10^{-24} cm^3) (continued)

Molecule	Name	Polarizability	Ref.
$C_{11}H_{23}F$	fluoroundecane	21.00	27
$C_{12}H_{25}Br$	bromododecane	25.18	27
$C_{12}H_{25}F$	fluorododecane	22.83	27
$C_{12}H_8Br_2O$	4,4′–dibromodiphenyl ether	27.8	2†
$C_{12}H_9BrO$	4-bromodiphenyl ether	24.2	2†
$C_{13}H_{11}BrO$	*p*-bromophenyl-*p*-tolyl ether	26.6	2†
$C_{14}H_9Br$	9-bromoanthracene	28.32	27
$C_{14}H_9Cl$	9-chloroanthracene	27.35	27
$C_{14}H_9F$	fluoranthracene	28.34	27
$C_{14}H_{29}F$	fluorotetradecane	26.57	27
$C_{16}H_{33}Br$	bromohexadecane	32.34	27
$C_{18}H_{37}Br$	bromooctadecane	35.92	27

Table 8
Static Average Electric Dipole Polarizabilities for Other Ground State Organic Molecules (in Units of 10^{-24} cm^3)

Molecule	Name	Polarizability	Ref.
CN_4O_8	tetranitromethane	15.3	2
CH_2O	formaldehyde	2.8	2†
		2.45	18
CH_2O_2	formic acid	3.4	2†
CH_3NO	formamide	4.2	2†
		4.08	18
CH_3NO_2	nitromethane	7.37	2
CH_4O	methanol	3.29	2
		3.23	15
		3.32	18
CH_5N	methyl amine	4.7	2
		4.01	19
C_2N_2	cyanogen	7.99	2
C_2H_2O	ketene	4.4	2†
C_2H_3N	acetonitrile	4.40	2†
		4.48	18
C_2H_4O	acetaldehyde	4.6	2†
		4.59	18
	ethylene oxide	4.43	18
$C_2H_4O_2$	acetic acid	5.1	2†
	methyl formate	5.05	27
$C_2H_4O_4$	formic acid dimer	12.7	2
C_2H_5NO	acetamide	5.67	18
	N-methyl formamide	5.91	18
$C_2H_5NO_2$	nitroethane	9.63	2
	ethyl nitrite	7.0	15
C_2H_6O	ethanol	5.41	2
		5.11	18
	methyl ether	5.29	20
		5.84	2
		5.16	15
$C_2H_6O_2$	ethylene glycol	5.7	2†
		5.61	27
$C_2H_6O_2S$	dimethyl sulfone	7.3	2†

Table 8
Static Average Electric Dipole Polarizabilities for Other Ground State Organic Molecules (in Units of 10^{-24} cm^3) (continued)

Molecule	Name	Polarizability	Ref.
C_2H_6S	ethanethiol	7.41	2
C_2H_7N	ethyl amine	7.10	2
	dimethyl amine	6.37	2
$C_2H_8N_2$	ethylene diamine	7.2	2†
$C_3H_2N_2$	malononitrile	5.79	18
C_3H_3N	acrylonitrile	8.05	2
$C_3H_4N_2$	pyrazole	7.23	27
C_3H_4O	propenal	6.38	2†
C_3H_5N	propionitrile	6.70	2
		6.24	18
C_3H_6O	acetone	6.33	15
		6.4	2†
		6.39	18
	allyl alcohol	7.65	2
	propionaldehyde	6.50	2
$C_3H_6O_2$	propionic acid	6.9	2†
	ethyl formate	8.01	2
		6.88	27
	methyl acetate	6.94	2
		6.81	27
$C_3H_6O_3$	dimethyl carbonate	7.7	2†
C_3H_7NO	*N*-methyl acetamide	7.82	18
	N,*N*-dimethyl formamide	7.81	18
$C_3H_7NO_2$	nitropropane	8.5	2†
C_3H_8O	2-propanol	7.61	2
		6.97	18
	1-propanol	6.74	2
	ethyl methyl ether	7.93	2
$C_3H_8O_2$	dimethoxymethane	7.7	2†
	monomethylether ethylene glycol	7.44	27
C_3H_9N	*n*-propylamine	7.70	27
		9.20	2
	isopropylamine	7.77	27
	trimethylamine	8.15	2
$C_4H_2N_2$	fumaronitrile	11.8	2
$C_4H_4N_2$	succinonitrile	8.1	2†
	pyrimidene	8.53*	17
	pyridazine	9.27*	17
$C_4H_4O_2$	diketene	8.0	2†
C_4H_4S	thiophene	9.67	2
C_4H_5N	methacrylonitrile	8.0	2†
	trans-crotononitrile	8.2	2†
$C_4H_6N_2$	*N*-methylpyrazole	8.99	27
C_4H_6O	crotonaldehyde	8.5	2†
	methacrylaldehyde	8.3	2†
$C_4H_6O_2$	biacetyl	8.2	2†
$C_4H_6O_3$	acetic anhydride	8.9	2†
C_4H_6S	divinyl sulfide	10.9	2†
C_4H_7N	butyronitrile	8.4	2†
	isobutyronitrile	8.05	18
C_4H_8O	butanal	8.2	2†
	methyl ethyl ketone	8.13	15
	trans-2,3-epoxy butane	8.22*	17
$C_4H_8O_2$	ethyl acetate	9.7	2
		8.62	27

Table 8
Static Average Electric Dipole Polarizabilities for Other Ground State Organic Molecules (in Units of 10^{-24} cm^3) (continued)

Molecule	Name	Polarizability	Ref.
	1,4-dioxane	10.0	2
	p-dioxane	8.60	18
	2-methyl-1,3-dioxolane	9.44	15
	butyric acid	8.38	27
	methyl propionate	8.97	27
$C_4H_9NO_2$	1-nitrobutane	10.4	2†
	2-methyl-2-nitropropane	10.3	2†
$C_4H_{10}O$	ethyl ether	10.2	2
		8.73	15
	1-butanol	8.88	2
	2-methylpropanol	8.92	2
	n-propyl methyl ether	8.86	27
$C_4H_{10}O_2$	monoethylether ethylene glycol	9.28	27
$C_4H_{10}S$	ethyl sulfide	10.8	2
$C_4H_{11}N$	*n*-butylamine	13.5	2
	diethylamine	10.2	2
		9.61	27
C_5H_5N	pyridine	9.5	15
		9.18	27
	4-cyano-1,2-butadiene	10.5	2†
$C_5H_8N_2$	1,5-dimethylpyrazole	10.72	27
$C_5H_8O_2$	acetyl acetone	10.5	2†
C_5H_9N	valeronitrile	10.4	2
	22-DMPN	9.59	18
$C_5H_{10}O$	diethyl ketone	9.93	15
	methyl propyl ketone	9.93	15
$C_5H_{10}O_2$	ethyl propionate	10.41	27
	methyl butanoate	10.41	27
$C_5H_{10}O_3$	diethyl carbonate	11.3	2
$C_5H_{12}O$	ethyl propyl ether	10.68	27
$C_5H_{12}O_4$	tetramethyl orthocarbonate	13.0	2†
$C_6H_4N_2O_4$	*p*-dinitrobenzene	18.4	2
$C_6H_4O_2$	*p*-benzoquinone	14.5	2
$C_6H_5NO_2$	nitrobenzene	14.7	2
		12.92	15
C_6H_6O	phenol	11.1	2†
		9.94*	17
C_6H_7N	aniline	12.1	2†
$C_6H_8N_2$	phenylenediamine	13.8	2†
	phenylhydrazine	12.91	27
$C_6H_{10}N_2$	1-ethyl-5-methylpyrazole	12.50	27
$C_6H_{10}O_3$	ethyl acetoacetate	12.9	2†
$C_6H_{12}N_2$	dimethylketazine	15.6	2
$C_6H_{12}O$	cyclohexanol	11.56	18
$C_6H_{12}O_2$	amyl formate	14.2	2
$C_6H_{12}O_3$	paraldehyde	17.9	2
$C_6H_{14}O$	propyl ether	12.8	2
		12.5	15
$C_6H_{14}O_2$	1,1-diethoxyethane	13.2	2†
	1,2-diethoxyethane	11.3	2†
$C_6H_{15}N$	triethylamine	13.1	2
		13.38	27
	di-*n*-propylamine	13.29	27
$C_7H_4N_2O_2$	*p*-cyanonitrobenzene	19.0	2
C_7H_5N	benzonitrile	12.5	2†

Table 8
Static Average Electric Dipole Polarizabilities for Other Ground State Organic Molecules (in Units of 10^{-24} cm^3) (continued)

Molecule	Name	Polarizability	Ref.
$C_7H_7NO_3$	nitroanisole	15.7	2†
C_7H_7O	anisole	13.1	2†
C_7H_9NO	*o*-anisidine	14.2	2†
$C_7H_{10}N_2$	1,1-methylphenylhydrazine	14.81	27
$C_7H_{14}O$	cyclohexyl methyl ether	13.4	2†
	2,4-dimethyl-3-pentanone	13.5	15
$C_7H_{14}O_2$	pentyl acetate	14.9	2
$C_8H_4N_2$	*p*-dicyanobenzene	19.2	2
$C_8H_6N_2$	quinoxaline	15.13	27
C_8H_8O	acetophenone	15.0	2
$C_8H_8O_2$	2,5-dimethyl-1,4-benzoquinone	18.8	2
$C_8H_{10}O$	phenetole	14.9	2
$C_8H_{11}N$	*N*-dimethylaniline	16.2	2†
$C_8H_{12}N_2$	1,1-ethylphenylhydrazine	16.62	27
$C_8H_{12}O_2$	ethyl sorbate	17.2	2†
	tetramethylcyclobutane-1,3-dione	18.6	2
$C_8H_{14}O_4$	diethyl succinate	16.8	2†
$C_8H_{18}O$	*n*-butyl ether	17.2	2
C_9H_7N	quinoline	15.70	27
	isoquinoline	16.43	27
$C_9H_{10}O_2$	ethyl benzoate	16.9	2†
$C_9H_{21}N$	tri-*n*-propylamine	18.87	27
$C_{10}H_9N$	α-naphthylamine	19.50	27
	β-naphthylamine	19.73	27
	1-methylquinoline	18.65	27
	1-methylisoquinoline	18.28	27
$C_{10}H_{10}Fe$	ferrocene	17.1	26
$C_{10}H_{10}N_2$	2,3-dimethylquinoxaline	18.70	27
$C_{10}H_{14}BeO_4$	beryllium acetylacetonate	34.1	2
$C_{11}H_8O$	1-naphthaldehyde	19.75	27
	2-naphthaldehyde	20.06	27
$C_{14}H_8O_2$	anthraquinone	24.46	27
$C_{12}H_8N_2$	phenazine	23.43	27
$C_{12}H_9NO_3$	4-nitrodiphenyl ether	24.7	2†
$C_{14}H_{14}O$	di-*p*-tolyl ether	24.9	2†
$C_{15}H_{21}AlO_6$	aluminum acetylacetonate	51.9	2
$C_{15}H_{21}CrO_6$	chromium acetylacetonate	53.7	2
$C_{15}H_{21}FeO_6$	ferric acetylacetonate	58.1	2
$C_{20}H_{28}O_8Th$	thorium acetylacetonate	79.0	2
C_{60}	buckminsterfullerene	~80	24

Note: All polarizabilities in the tables are experimental values except those values marked by an asterisk (*), which indicates a calculated result. The experimental polarizabilities are mostly determined by measurements of a dielectric constant or refractive index which are quite accurate (0.5% or better). However, one should treat many of the results with several percent of caution because of the age of the data and because some of the results refer to optical frequencies rather than static. Comments given with the references are intended to allow one to judge the degree of caution required. Interested persons should consult these references. In many cases, the reference given is to a theoretical paper in which the experimental results are quoted. These papers, noted in the References, contain valuable information on polarizability calculations and experimental data which often includes the tensor components of the polarizability.

REFERENCES

1. McCullough, E. A., Jr., *J. Chem. Phys.*, 63, 5050, 1975. This calculation is for the parallel component, not the average polarizability.
2. Maryott, A. A., and Buckley, F., U. S. National Bureau of Standards Circular No. 537, 1953. A tabulation of dipole moments, dielectric constants, and molar refractions measured between 1910 and 1952, and used here to determine polarizabilities if no more recent result exists. The polarizability is $3/(4\pi N_o)$ times the molar polarization or molar refraction, where N_o is Avogadro's number. The value $3/(4\pi N_o)$ = $0.3964308 \times 10^{-24}$ cm^3 was used for this conversion. A dagger (†) following the reference number in the tables indicates that the polarizability was derived from the molar refraction and hence may not include some low-frequency contributions to the static polarizability; these "static" polarizabilities are therefore low by 1 to 30%.
3. Hirschfelder, J. O., Curtis, C. F., and Bird, R. B., *Molecular Theory of Gases and Liquids*, Wiley, New York, 1954, p. 950. Fundamental information on molecular polarizabilities.
4. Miller, T. M., and Bederson, B., *Adv. At. Mol. Phys.*, 13, 1, 1977. Review emphasizing atomic polarizabilities and measurement techniques. The data quoted in Table 3 are accurate to 8 to 12%.
5. Kolos, W., and Wolniewicz, L., *J. Chem. Phys.*, 46, 1426, 1967. Highly accurate molecular hydrogen calculations.
6. Newell, A. C., and Baird, R. C., *J. Appl. Phys.*, 36, 3751, 1965. Highly accurate refractive index measurements at 47.7 GHz (essentially static).
7. Jao, T. C., Beebe, N. H. F., Person, W. B., and Sabin, J. R., *Chem. Phys. Lett.*, 26, 47, 1974. Tensor polarizabilities, derivatives, and other results are reported.
8. Orcutt, R. H., and Cole, R. H., *J. Chem. Phys.*, 46, 697, 1967 (He, Ne, Ar, Kr, H_2, N_2); Sutter, H., and Cole, R. H., *J. Chem. Phys.*, 52, 132, 1970 (CF_3H, CFH_3, $CClF_3$, $CClH_3$); Bose, T. K., and Cole, R. H., *J. Chem. Phys.*, 52, 140, 1970 (CO_2), and 54, 3829, 1971 (C_2H_2, C_2H_4); Nelson, R. D., and Cole, R. H., *J. Chem. Phys.*, 54, 4033, 1971 (SF_6, $CClF_3$); Bose, T. K., Sochanski, J. S., and Cole, R. H., *J. Chem. Phys.*, 57, 3592, 1972 (CH_4, CF_4); Kirouac, S., and Bose, T. K., *J. Chem. Phys.*, 59, 3043, 1973 (N_2O), and 64, 1580, 1976 (He). Highly accurate dielectric constant measurements. These modern data give the most accurate polarizabilities available. A criticism of the interpretation of these data in the case of polar molecules is given in Ref. 20, p. 2905.
9. Huestis, D. L., Technical Report #MP 78-25, SRI International (project PYU 6158), Menlo Park, CA 94025. Molar refractions for mercury-chlorine compounds are analyzed.
10. Bounds, D. G., Clarke, J. H. R., and Hinchliffe, A., *Chem. Phys. Lett.*, 45, 367, 1977. Theoretical tensor polarizability for LiCl.
11. Kolker, H. J., and Karplus, M., *J. Chem. Phys.*, 39, 2011, 1963. Theoretical.
12. Cutschick, V. P., and McKoy, V., *J. Chem. Phys.*, 58, 2397, 1973. Theoretical tensor polarizabilities.
13. Gready, J. E., Bacskay, G. B., and Hush, N. S., *Chem. Phys.*, 22, 141, 1977, and 23, 9, 1977. Theoretical.
14. Amos, A. T., and Yoffe, J. A., *J. Chem. Phys.*, 63, 4723, 1975. Theoretical.
15. Stuart, H. A., *Landolt-Börnstein Zahlenwerte and Funktionen*, Vol. 1, Part 3, Eucken, A., and Hellwege, K. H., Eds., Springer-Verlag, Berlin, 1951, p. 511. Tabulation of molecular polarizabilities. Two misprints in the chemical symbols have been corrected.
16. Guella, T., Miller, T. M., Stockdale, J. A. D., Bederson, B., and Vuskovic, L., *J. Chem. Phys.*, 94, 6857, 1991. Beam measurements with accuracies between 12-24%.
17. Marchese, F. T., and Jaffé, *Theoret. Chim. Acta (Berlin)*, 45, 241, 1977. Theoretical and experimental tensor polarizabilities are tabulated in this paper.
18. Applequist, J., Carl, J. R., and Fung, K.-K., *J. Am. Chem. Soc.*, 94, 2952, 1972. Excellent reference on the calculation of molecular polarizabilities, including extensive tables of tensor polarizabilities, both theoretical and experimental, at 589.3 nm wavelength.
19. Bridge, N. J., and Buckingham, A. D., *Proc. Roy. Soc. (London)*, A295, 334, 1966. Measured tensor polarizabilities at 633 nm wavelength.
20. Barnes, A. N. M., Turner, D. J., and Sutton, L. E., *Trans. Faraday Soc.*, 67, 2902, 1971. Dielectric constants yielding polarizabilities accurate from 0.3-8%.
21. Knight, W. D., Clemenger, K., de Heer, W. A., and Saunders, W. A., *Phys. Rev. B*, 31, 2539, 1985. These data probably correspond to a very low internal temperature.
22. Tarnovsky, V., Bunimovicz, M., Vuskovic, L., Stumpf, B., and Bederson, B., *J. Chem. Phys.*, 98, 3894, 1993. These data correspond to internal temperatures 480-948 K.
23. Milani, P., Moullet, I., and de Heer, W. A., *Phys. Rev. A*, 42, 5150, 1990. Beam measurements accurate to 11%.
24. Bonin, K. D., and Kadar-Kallen, M. A., *Int. J. Mod. Phys.*, 8, 3313, 1994. Review article.
25. Aroney, M. J., and Pratten, S. J., *J. Chem. Soc., Faraday Trans. 1*, 80, 1201, 1984. Uncertainties in the range 1-3%.
26. Le Fevre, R. J. W., Murthy, D. S. N., and Saxby, J. D., *Aust. J. Chem.*, 24, 1057, 1971. Kerr effect.
27. No, K. T., Cho, K. H., Jhon, M. S., and Scheraga, H. A., *J. Am. Chem. Soc.*, 115, 2005, 1993. Theoretical; these results are quoted in numerous valuable papers on calculated polarizabilities, e.g., Miller, K. J., and Savchik, J. A., *J. Am. Chem. Soc.*, 101, 7206, 1979.

IONIZATION POTENTIALS OF ATOMS AND ATOMIC IONS

The ionization potentials of neutral and partially ionized atoms are listed in this table. Data were obtained from the compilations cited below, supplemented by results from the recent research literature. All values have been corrected to the currently recommended value of the conversion factor from wave number to energy, namely 1 eV = 8065.541 cm^{-1} (Reference 5). Values are given in eV.

Following the traditional spectroscopic notation, columns are headed I, II, III, etc. up to XXX, where I indicates the neutral atom, II the singly ionized atom, III the doubly ionized atom, etc. The first section of the table includes spectra I to VIII of all the elements; subsequent sections cover higher spectra (ionization stages) for those elements for which data are available.

REFERENCES

1. Moore, C. E., *Ionization Potentials and Ionization Limits Derived from the Analysis of Optical Spectra*, Natl. Stand. Ref. Data Ser. — Natl. Bur. Stand. (U.S.) No. 34, 1970.
2. Martin, W. C., Zalubas, R., and Hagan, L., *Atomic Energy Levels — The Rare Earth Elements*, Natl. Stand. Ref. Data Ser. — Natl. Bur. Stand. (U.S.), No. 60, 1978.
3. Sugar, J. and Corliss, C., *Atomic Energy Levels of the Iron Period Elements: Potassium through Nickel*, *J. Phys. Chem. Ref. Data*, Vol.14, Suppl. 2, 1985.
4. References to papers in *J. Phys. Chem. Ref. Data*, in the period 1973—91 covering other elements may be found in the cumulative index to that journal.
5. Cohen, E. R. and Taylor, B. N., *J. Phys. Chem. Ref. Data*, 17, 1795, 1988.
6. Martin, W.C., and Wiese, W.L., in *Atomic, Molecular, and Optical Physics Handbook*, Drake, G.W.F., Ed., AIP Press, New York, 1996.

Neutral Atoms to +7 Ions

Z	Element	I	II	III	IV	V	VI	VII	VIII
1	H	13.59844							
2	He	24.58741	54.41778						
3	Li	5.39172	75.64018	122.45429					
4	Be	9.3227	18.21116	153.89661	217.71865				
5	B	8.29803	25.15484	37.93064	259.37521	340.22580			
6	C	11.26030	24.38332	47.8878	64.4939	392.087	489.99334		
7	N	14.53414	29.6013	47.44924	77.4735	97.8902	552.0718	667.046	
8	O	13.61806	35.11730	54.9355	77.41353	113.8990	138.1197	739.29	871.4101
9	F	17.42282	34.97082	62.7084	87.1398	114.2428	157.1651	185.186	953.9112
10	Ne	21.5646	40.96328	63.45	97.12	126.21	157.93	207.2759	239.0989
11	Na	5.13908	47.2864	71.6200	98.91	138.40	172.18	208.50	264.25
12	Mg	7.64624	15.03528	80.1437	109.2655	141.27	186.76	225.02	265.96
13	Al	5.98577	18.82856	28.44765	119.992	153.825	190.49	241.76	284.66
14	Si	8.15169	16.34585	33.49302	45.14181	166.767	205.27	246.5	303.54
15	P	10.48669	19.7694	30.2027	51.4439	65.0251	220.421	263.57	309.60
16	S	10.36001	23.3379	34.79	47.222	72.5945	88.0530	280.948	328.75
17	Cl	12.96764	23.814	39.61	53.4652	67.8	97.03	114.1958	348.28
18	Ar	15.75962	27.62967	40.74	59.81	75.02	91.009	124.323	143.460
19	K	4.34066	31.63	45.806	60.91	82.66	99.4	117.56	154.88
20	Ca	6.11316	11.87172	50.9131	67.27	84.50	108.78	127.2	147.24
21	Sc	6.5615	12.79967	24.75666	73.4894	91.65	110.68	138.0	158.1
22	Ti	6.8281	13.5755	27.4917	43.2672	99.30	119.53	140.8	170.4
23	V	6.7463	14.66	29.311	46.709	65.2817	128.13	150.6	173.4
24	Cr	6.7665	16.4857	30.96	49.16	69.46	90.6349	160.18	184.7
25	Mn	7.43402	15.63999	33.668	51.2	72.4	95.6	119.203	194.5
26	Fe	7.9024	16.1878	30.652	54.8	75.0	99.1	124.98	151.06
27	Co	7.8810	17.083	33.50	51.3	79.5	102.0	128.9	157.8
28	Ni	7.6398	18.16884	35.19	54.9	76.06	108	133	162
29	Cu	7.72638	20.29240	36.841	57.38	79.8	103	139	166
30	Zn	9.3942	17.96440	39.723	59.4	82.6	108	134	174
31	Ga	5.99930	20.5142	30.71	64				
32	Ge	7.8994	15.93462	34.2241	45.7131	93.5			
33	As	9.7886	18.633	28.351	50.13	62.63	127.6		
34	Se	9.75238	21.19	30.8204	42.9450	68.3	81.7	155.4	
35	Br	11.81381	21.8	36	47.3	59.7	88.6	103.0	192.8
36	Kr	13.99961	24.35985	36.950	52.5	64.7	78.5	111.0	125.802
37	Rb	4.17713	27.285	40	52.6	71.0	84.4	99.2	136
38	Sr	5.6949	11.03013	42.89	57	71.6	90.8	106	122.3
39	Y	6.2171	12.24	20.52	60.597	77.0	93.0	116	129
40	Zr	6.63390	13.13	22.99	34.34	80.348			
41	Nb	6.75885	14.32	25.04	38.3	50.55	102.057	125	

IONIZATION POTENTIALS OF ATOMS AND ATOMIC IONS (continued)

Z	Element	I	II	III	IV	V	VI	VII	VIII
42	Mo	7.09243	16.16	27.13	46.4	54.49	68.8276	125.664	143.6
43	Tc	7.28	15.26	29.54					
44	Ru	7.36050	16.76	28.47					
45	Rh	7.45890	18.08	31.06					
46	Pd	8.3369	19.43	32.93					
47	Ag	7.5763	21.49	34.83					
48	Cd	8.9938	16.90832	37.48					
49	In	5.78636	18.8698	28.03	54				
50	Sn	7.3439	14.63225	30.50260	40.73502	72.28			
51	Sb	8.6084	16.53051	25.3	44.2	56	108		
52	Te	9.0096	18.6	27.96	37.41	58.75	70.7	137	
53	I	10.45126	19.1313	33					
54	Xe	12.1298	21.20979	32.1230					
55	Cs	3.89390	23.15745						
56	Ba	5.21170	10.00390						
57	La	5.5770	11.060	19.1773	49.95	61.6			
58	Ce	5.5387	10.85	20.198	36.758	65.55	77.6		
59	Pr	5.464	10.55	21.624	38.98	57.53			
60	Nd	5.5250	10.73	22.1	40.41				
61	Pm	5.58	10.90	22.3	41.1				
62	Sm	5.6436	11.07	23.4	41.4				
63	Eu	5.6704	11.241	24.92	42.7				
64	Gd	6.1501	12.09	20.63	44.0				
65	Tb	5.8638	11.52	21.91	39.79				
66	Dy	5.9389	11.67	22.8	41.47				
67	Ho	6.0215	11.80	22.84	42.5				
68	Er	6.1077	11.93	22.74	42.7				
69	Tm	6.18431	12.05	23.68	42.7				
70	Yb	6.25416	12.1761	25.05	43.56				
71	Lu	5.4259	13.9	20.9594	45.25	66.8			
72	Hf	6.82507	14.9	23.3	33.33				
73	Ta	7.5496							
74	W	7.8640							
75	Re	7.8335							
76	Os	8.4382							
77	Ir	8.9670							
78	Pt	8.9587	18.563						
79	Au	9.2255	20.5						
80	Hg	10.43750	18.756	34.2					
81	Tl	6.1082	20.428	29.83					
82	Pb	7.41666	15.0322	31.9373	42.32	68.8			
83	Bi	7.2856	16.69	25.56	45.3	56.0	88.3		
84	Po	8.41671							
85	At								
86	Rn	10.74850							
87	Fr	4.0727							
88	Ra	5.2784	10.14716						
89	Ac	5.17	12.1						
90	Th	6.3067	11.5	20.0	28.8				
91	Pa	5.89							
92	U	6.19405							
93	Np	6.2657							
94	Pu	6.0262							
95	Am	5.9738							
96	Cm	6.02							
97	Bk	6.23							
98	Cf	6.30							
99	Es	6.42							
100	Fm	6.50							
101	Md	6.58							
102	No	6.65							

IONIZATION POTENTIALS OF ATOMS AND ATOMIC IONS (continued)

+8 Ions to +15 Ions

Z	Element	IX	X	XI	XII	XIII	XIV	XV	XVI
9	F	1103.1176							
10	Ne	1195.8286	1362.1995						
11	Na	299.864	1465.121	1648.702					
12	Mg	328.06	367.50	1761.805	1962.6650				
13	Al	330.13	398.75	442.00	2085.98	2304.1410			
14	Si	351.12	401.37	476.36	523.42	2437.63	2673.182		
15	P	372.13	424.4	479.46	560.8	611.74	2816.91	3069.842	
16	S	379.55	447.5	504.8	564.44	652.2	707.01	3223.78	3494.1892
17	Cl	400.06	455.63	529.28	591.99	656.71	749.76	809.40	3658.521
18	Ar	422.45	478.69	538.96	618.26	686.10	755.74	854.77	918.03
19	K	175.8174	503.8	564.7	629.4	714.6	786.6	861.1	968
20	Ca	188.54	211.275	591.9	657.2	726.6	817.6	894.5	974
21	Sc	180.03	225.18	249.798	687.36	756.7	830.8	927.5	1009
22	Ti	192.1	215.92	265.07	291.500	787.84	863.1	941.9	1044
23	V	205.8	230.5	255.7	308.1	336.277	896.0	976	1060
24	Cr	209.3	244.4	270.8	298.0	354.8	384.168	1010.6	1097
25	Mn	221.8	248.3	286.0	314.4	343.6	403.0	435.163	1134.7
26	Fe	233.6	262.1	290.2	330.8	361.0	392.2	457	489.256
27	Co	186.13	275.4	305	336	379	411	444	511.96
28	Ni	193	224.6	321.0	352	384	430	464	499
29	Cu	199	232	265.3	369	401	435	484	520
30	Zn	203	238	274	310.8	419.7	454	490	542
36	Kr	230.85	268.2	308	350	391	447	492	541
37	Rb	150	277.1						
38	Sr	162	177	324.1					
39	Y	146.2	191	206	374.0				
42	Mo	164.12	186.4	209.3	230.28	279.1	302.60	544.0	570

+16 Ions to +23 Ions

Z	Element	XVII	XVIII	XIX	XX	XXI	XXII	XXIII	XXIV
17	Cl	3946.2960							
18	Ar	4120.8857	4426.2296						
19	K	1033.4	4610.8	4934.046					
20	Ca	1087	1157.8	5128.8	5469.864				
21	Sc	1094	1213	1287.97	5674.8	6033.712			
22	Ti	1131	1221	1346	1425.4	6249.0	6625.82		
23	V	1168	1260	1355	1486	1569.6	6851.3	7246.12	
24	Cr	1185	1299	1396	1496	1634	1721.4	7481.7	7894.81
25	Mn	1224	1317	1437	1539	1644	1788	1879.9	8140.6
26	Fe	1266	1358	1456	1582	1689	1799	1950	2023
27	Co	546.58	1397.2	1504.6	1603	1735	1846	1962	2119
28	Ni	571.08	607.06	1541	1648	1756	1894	2011	2131
29	Cu	557	633	670.588	1697	1804	1916	2060	2182
30	Zn	579	619	698	738	1856			
36	Kr	592	641	786	833	884	937	998	1051
42	Mo	636	702	767	833	902	968	1020	1082

+24 Ions to +29 Ions

Z	Element	XXV	XXVI	XXVII	XXVIII	XXIX	XXX
25	Mn	8571.94					
26	Fe	8828	9277.69				
27	Co	2219.0	9544.1	10012.12			
28	Ni	2295	2399.2	10288.8	10775.40		
29	Cu	2308	2478	2587.5	11062.38	11567.617	
36	Kr	1151	1205.3	2928	3070	3227	3381
42	Mo	1263	1323	1387	1449	1535	1601

IONIZATION ENERGIES OF GAS-PHASE MOLECULES

Sharon G. Lias

This table presents values for the first ionization energies (IP) of approximately 1000 molecules and atoms. Substances are listed by molecular formula in the modified Hill order (see introduction). Values enclosed in parentheses are considered not to be well established. Data appearing in the 1988 reference, were updated in 1996 for inclusion in the database of ionization energies available at the Internet site of the Standard Reference Data program of the National Institute of Standards and Technology (http://webbook.nist.gov). The list appearing here includes these updates.

The list also includes values for enthalpies of formation of the ions at 298 K, $\Delta_f H_{ion}$, given according to the ion convention used by mass spectrometrists; to convert these values to the electron convention used by thermodynamicists, add 6 kJ/mol. Details on the calculation of $\Delta_f H_{ion}$ as well as data for a much larger number of molecules, may be found in the reference and on the Internet site.

REFERENCE

Lias, S.G., Bartmess, J.E., Liebman, J.F., Holmes, J.L., Levin, R.D., and Mallard, W.G., *Gas-Phase Ion and Neutral Thermochemistry*, *J. Phys. Chem. Ref. Data*, Vol. 17, Suppl. No. 1, 1988.

Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
	Substances not containing carbon		
Ac	Actinium	5.17	905
Ag	Silver	7.57624	1016
AgCl	Silver(I) chloride	(≤ 10.08)	≤ 1065
AgF	Silver(I) fluoride	(11.0 ± 0.3)	1071
Al	Aluminum	5.98577	905
AlBr	Aluminum monobromide	(9.3)	913
$AlBr_3$	Aluminum tribromide	(10.4)	593
AlCl	Aluminum monochloride	9.4	855
$AlCl_3$	Aluminum trichloride	(12.01)	573
AlF	Aluminum monofluoride	9.73 ± 0.01	673
AlF_3	Aluminum trifluoride	≤ 15.45	≤ 282
AlI	Aluminum monoiodide	9.3 ± 0.3	965
AlI_3	Aluminum triiodide	(9.1)	673
Am	Americium	5.9738 ± 0.0002	860
Ar	Argon	15.75962	1521
As	Arsenic	9.8152	1250
$AsCl_3$	Arsenic(III) chloride	(10.55 ± 0.025)	754
AsF_3	Arsenic(III) fluoride	(12.84 ± 0.05)	452
AsH_3	Arsine	(9.89)	1021
Au	Gold	9.22567	1254
B	Boron	8.29803	1363
BBr_3	Boron tribromide	(10.51)	809
BCl_3	Boron trichloride	11.60 ± 0.02	718
BF	Fluoroborane	11.12 ± 0.01	957
	Difluoroborane	(9.4)	317
BF_3	Boron trifluoride	15.7 ± 0.3	365
BH	Boron monohydride	(9.77)	1385
BH_3	Borane	12.026 ± 0.024	1261
BI_3	Boron triiodide	(9.25 ± 0.03)	964
BO_2	Boron dioxide	(13.5 ± 0.3)	1001
B_2H_6	Diborane	11.38 ± 0.05	1134
B_2O_3	Boron oxide	13.5 ± 0.15	460
B_4H_{10}	Tetraborane	10.76 ± 0.04	1105
B_5H_9	Pentaborane(9)	9.90 ± 0.04	1028
B_6H_{10}	Hexaborane	(9.0)	965
Ba	Barium	5.21170	683
BaO	Barium oxide	6.91 ± 0.06	543
Be	Beryllium	9.32263	1224
BeO	Beryllium oxide	(10.1 ± 0.4)	1111
Bi	Bismuth	7.2855	908
$BiCl_3$	Bismuth trichloride	(10.4)	736
Bk	Berkelium	6.23	911

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IONIZATION ENERGIES OF GAS-PHASE MOLECULES (continued)

Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
Br	Bromine (atomic)	11.81381	1252
BrCl	Bromine chloride	11.01	1079
BrF	Bromine fluoride	11.86	1086
BrF_5	Bromine pentafluoride	13.172 ± 0.002	840
BrH	Hydrogen bromide	11.66 ± 0.03	1087
BrH_3Si	Bromosilane	10.6	943
BrI	Iodine bromide	9.790 ± 0.004	986
BrK	Potassium bromide	7.85 ± 0.1	578
BrLi	Lithium bromide	(8.7)	685
BrNO	Nitrosyl bromide	10.17 ± 0.03	1065
BrNa	Sodium bromide	8.31 ± 0.1	660
BrO	Bromine monoxide	10.46 ± 0.02	1135
BrRb	Rubidium bromide	7.94 ± 0.03	583
BrTl	Thallium(I) bromide	9.14 ± 0.02	844
Br_2	Bromine	10.516 ± 0.005	1046
Br_2Hg	Mercury(II) bromide	10.560 ± 0.003	935
Br_2Sn	Tin(II) bromide	9.0	839
Br_3Ga	Gallium(III) bromide	10.40	711
Br_3P	Phosphorus(III) bromide	9.7	798
Br_4Hf	Hafnium(IV) bromide	(10.9)	366
Br_4Sn	Tin(IV) bromide	10.6	709
Br_4Ti	Titanium(IV) bromide	10.3	375
Br_4Zr	Zirconium(IV) bromide	(10.7)	388
Ca	Calcium	6.11316	768
CaCl	Calcium monochloride	5.86 ± 0.07	462
CaO	Calcium oxide	6.66 ± 0.18	668
Cd	Cadmium	8.99367	980
Ce	Cerium	5.5387	957
Cf	Californium	6.30	805
Cl	Chlorine (atomic)	12.96764	1373
ClCs	Cesium chloride	(7.84 ± 0.05)	510
ClF	Chlorine fluoride	12.66 ± 0.01	1171
$ClFO_3$	Perchloryl fluoride	(12.945 ± 0.005)	1224
ClF_2	Chlorine difluoride	(12.77 ± 0.05)	1128
ClF_3	Chlorine trifluoride	(12.65 ± 0.05)	1057
ClF_5S	Sulfur chloride pentafluoride	(12.335 ± 0.005)	144
ClH	Hydrogen chloride	12.749 ± 0.009	1137
ClHO	Hypochlorous acid	(11.12 ± 0.01)	993
ClH_3Si	Chlorosilane	11.4	899
ClI	Iodine chloride	10.088 ± 0.01	991
ClIn	Indium(I) chloride	(9.51)	842
ClK	Potassium chloride	(8.0 ± 0.4)	557
ClLi	Lithium chloride	9.57	727
ClNO	Nitrosyl chloride	10.87 ± 0.01	1099
$ClNO_2$	Nitryl chloride	(11.84)	1155
ClNa	Sodium chloride	8.92 ± 0.06	681
ClO	Chlorine monoxide	10.95	1159
ClO_2	Chlorine dioxide	10.33 ± 0.02	1093
ClRb	Rubidium chloride	(8.50 ± 0.03)	590
ClTl	Thallium(I) chloride	9.70 ± 0.03	869
Cl_2	Chlorine	11.480 ± 0.005	1108
Cl_2CrO_2	Chromyl chloride	11.6	580
Cl_2Ge	Germanium(II) chloride	(10.20 ± 0.05)	813
Cl_2H_2Si	Dichlorosilane	11.4	765
Cl_2Hg	Mercury(II) chloride	11.380 ± 0.003	952
Cl_2O	Chlorine oxide	10.94	1135
Cl_2OS	Thionyl chloride	10.96	844
Cl_2O_2S	Sulfuryl chloride	12.05	807
Cl_2Pb	Lead(II) chloride	(10.2)	791
Cl_2S	Sulfur dichloride	9.45 ± 0.03	895

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IONIZATION ENERGIES OF GAS-PHASE MOLECULES (continued)

Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
Cl_2Si	Dichlorosilylene	(10.93 ± 0.10)	887
Cl_2Sn	Tin(II) chloride	(10.0)	760
Cl_3Ga	Gallium(III) chloride	11.52	664
Cl_3HSi	Trichlorosilane	(11.7)	648
Cl_3N	Nitrogen trichloride	(10.12 ± 0.1)	1244
Cl_3OP	Phosphorus(V) oxychloride	11.36 ± 0.02	540
Cl_3OV	Vanadyl trichloride	(11.6)	425
Cl_3P	Phosphorus(III) chloride	9.91	668
Cl_3PS	Phosphorus(V) sulfide trichloride	9.71 ± 0.03	573
Cl_3Sb	Antimony(III) chloride	(≤ 10.7)	s719
Cl_4Ge	Germanium(IV) chloride	11.68 ± 0.05	629
Cl_4Hf	Hafnium(IV) chloride	(11.7)	246
Cl_4Si	Tetrachlorosilane	11.79 ± 0.01	527
Cl_4Sn	Tin(IV) chloride	11.7 ± 0.2	656
Cl_4Ti	Titanium(IV) chloride	(11.5)	349
Cl_4V	Vanadium(IV) chloride	(9.2)	361
Cl_4Zr	Zirconium(IV) chloride	(11.2)	210
Cl_5Mo	Molybdenum(V) chloride	(8.7)	392
Cl_5Nb	Niobium(V) chloride	(10.97)	356
Cl_5P	Phosphorus(V) chloride	(10.2)	608
Cl_5Ta	Tantalum(V) chloride	(11.08)	303
Cl_6W	Tungsten(VI) chloride	(9.5)	348
Cm	Curium	6.02	966
Co	Cobalt	7.8810	1187
Cr	Chromium	6.76664	1050
Cs	Cesium	3.89390	452
CsF	Cesium fluoride	(8.80 ± 0.10)	489
CsNa	Cesium sodium	(4.05 ± 0.04)	535
Cu	Copper	7.72638	1084
CuF	Copper(I) fluoride	10.15 ± 0.02	984
Dy	Dysprosium	5.9389	862
Er	Erbium	6.1078	907
Es	Einsteinium	6.42	753
Eu	Europium	5.6704	723
F	Fluorine (atomic)	17.42282	1761
FGa	Gallium monofluoride	(9.6 ± 0.5)	700
FH	Hydrogen fluoride	16.044 ± 0.003	1276
FHO	Hypofluorous acid	12.71 ± 0.01	1130
FH_3Si	Fluorosilane	11.7	752
FI	Iodine fluoride	10.54 ± 0.01	922
FIn	Indium monofluoride	(9.6 ± 0.5)	740
FNO	Nitrosyl fluoride	12.63 ± 0.03	1152
FNO_2	Nitryl fluoride	(13.09)	1154
FNS	Thionitrosyl fluoride (NSF)	11.51 ± 0.04	1090
FO	Fluorine monoxide	12.78 ± 0.03	1342
FO_2	Fluorine superoxide (FOO)	(12.6 ± 0.2)	1228
FS	Sulfur fluoride	10.09	986
FTl	Thallium(I) fluoride	10.52	835
F_2	Fluorine	15.697 ± 0.003	1515
F_2Ge	Germanium(II) fluoride	(≤ 11.65)	551
F_2HN	Difluoramine	(11.53 ± 0.08)	1046
F_2H_2Si	Difluorosilane	(12.2)	386
F_2Mg	Magnesium fluoride	(13.6 ± 0.3)	588
F_2N	Difluoroamidogen	11.628 ± 0.01	1155
F_2N_2	*trans*-Difluorodiazine	(12.8)	1315
F_2O	Fluorine monoxide	13.11 ± 0.01	1290
F_2OS	Thionyl fluoride	12.25	688
F_2O_2S	Sulfuryl fluoride	13.04 ± 0.01	501
F_2Pb	Lead(II) fluoride	(11.5)	679
F_2S	Sulfur difluoride	(10.08)	676

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Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
F_2Si	Difluorosilylene	10.78 ± 0.05	450
F_2Sn	Tin(II) fluoride	(11.1)	586
F_2Xe	Xenon difluoride	12.35 ± 0.01	1083
F_3HSi	Trifluorosilane	(14.0)	150
F_3N	Nitrogen trifluoride	13.00 ± 0.02	1125
F_3NO	Trifluoramine oxide	13.31 ± 0.06	1121
F_3OP	Phosphorus(V) oxyfluoride	12.76 ± 0.01	-24
F_3P	Phosphorus(III) fluoride	11.60 ± 0.05	161
F_3PS	Phosphorus(V) sulfide trifluoride	≤ 11.05 ± 0.035	≤ 58
F_3Si	Trifluorosilyl	(9.99)	- 32
F_4Ge	Germanium(IV) fluoride	(15.5)	307
F_4N_2	Tetrafluorohydrazine	11.94 ± 0.03	1119
F_4S	Sulfur tetrafluoride	12.0 ± 0.3	399
F_4Si	Tetrafluorosilane	15.24 ± 0.14	-144
F_4Xe	Xenon tetrafluoride	12.65 ± 0.1	1016
F_5I	Iodine pentafluoride	12.943 ± 0.005	408
F_5P	Phosphorus(V) fluoride	(15.1)	-137
F_5S	Sulfur pentafluoride	9.60 ± 0.05	10
F_6Mo	Molybdenum(VI) fluoride	(14.5 ± 0.1)	-159
F_6S	Sulfur hexafluoride	15.32 ± 0.02	258
F_6U	Uranium(VI) fluoride	14.00 ± 0.10	-796
Fe	Iron	7.9024	1177
Fm	Fermium	6.50	627
Ga	Gallium	5.99930	851
GaI_3	Gallium(III) iodide	9.40	765
Gd	Gadolinium	6.1500	991
Ge	Germanium	7.900	1139
GeH_4	Germane	≤ 10.53	≤ 1108
GeI_4	Germanium(IV) iodide	(9.42)	850
GeO	Germanium(II) oxide	11.25 ± 0.01	1044
GeS	Germanium(II) sulfide	(9.98)	1055
H	Hydrogen (atomic)	13.59844	1530
HI	Hydrogen iodide	10.386 ± 0.001	1028
HLi	Lithium hydride	7.7	882
HN	Imidogen	≤ 13.49 ± 0.01	1678
HNO	Nitrosyl hydride	(10.1)	1075
HNO_2	Nitrous acid	≤ 11.3	≤ 1011
HNO_3	Nitric acid	11.95 ± 0.01	1019
HN_3	Hydrazoic acid	10.72 ± 0.025	1328
HO	Hydroxyl	13.0170 ± 0.0002	1294
HO_2	Hydroperoxy	11.35 ± 0.01	1106
HS	Mercapto	10.4219 ± 0.0004	1145
H_2	Hydrogen	15.42593 ± 0.00005	1488
H_2N	Amidogen	11.14 .01	1264
H_2O	Water	12.6206 ± 0.0020	976
H_2O_2	Hydrogen peroxide	10.58 ± 0.04	885
H_2S	Hydrogen sulfide	10.457 ± 0.012	989
H_2Se	Hydrogen selenide	9.892 ± 0.005	984
H_2Si	Silylene	8.244 ± 0.025	1084
H_3N	Ammonia	10.070 ± 0.020	925
H_3NO	Hydroxylamine	(10.00)	923
H_3P	Phosphine	9.869 ± 0.002	958
H_3Sb	Stibine	9.54 ± 0.03	1067
H_4N_2	Hydrazine	8.1 ± 0.15	877
H_4Si	Silane	11.00 ± 0.02	1095
H_4Sn	Stannane	(10.75)	1200
H_6Si_2	Disilane	9.74 ± 0.02	1019
H_8Si_3	Trisilane	(9.2)	1009
He	Helium	24.58741	2372
Hf	Hafnium	6.82507 ± 0.00004	1278

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Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
Hg	Mercury	10.43750	1069
HgI_2	Mercury(II) iodide	9.5088 ± 0.0022	900
Ho	Holmium	6.0216	882
I	Iodine (atomic)	10.45126	1115
IK	Potassium iodide	(7.21 ± 0.3)	570
ILi	Lithium iodide	(7.5)	633
INa	Sodium iodide	7.64 ± 0.02	659
ITl	Thallium(I) iodide	8.47 ± 0.02	826
I_2	Iodine	9.3074 ± 0.0002	960
I_4Ti	Titanium(IV) iodide	(9.1)	602
I_4Zr	Zirconium(IV) iodide	(9.3)	500
In	Indium	5.78636	802
Ir	Iridium	9.1	1543
K	Potassium	4.34066	508
KLi	Lithium potassium	4.57 ± 0.04	512
KNa	Potassium sodium	4.41636 ± 0.00017	561
K_2	Dipotassium	4.0637 ± 0.0002	519
Kr	Krypton	13.99961	1351
La	Lanthanum	5.5770	969
Li	Lithium	5.39172	680
LiNa	Lithium sodium	5.05 ± 0.04	571
LiO	Lithium monoxide	(8.44)	894
LiRb	Lithium rubidium	4.3 ± 0.1	486
Li_2	Dilithium	5.1127 ± 0.0003	709
Lu	Lutetium	5.42585	950
Md	Mendelevium	6.58	635
Mg	Magnesium	7.64624	885
MgO	Magnesium oxide	(8.76 ± 0.22)	901
Mn	Manganese	7.43402	998
Mo	Molybdenum	7.09243	1343
N	Nitrogen (atomic)	14.53414	1875
NO	Nitric oxide	9.26438 ± 0.00005	985
NO_2	Nitrogen dioxide	9.586 ± 0.002	958
NP	Phosphorus nitride	11.84 ± 0.04	1247
NS	Nitrogen sulfide	8.87 ± 0.01	1119
N_2	Nitrogen	15.5808	1503
N_2O	Nitrous oxide	12.886	1325
N_2O_4	Nitrogen tetroxide	(10.8)	1050
N_2O_5	Nitrogen pentoxide	(11.9)	1161
Na	Sodium	5.13908	603
NaRb	Rubidium sodium	4.32 ± 0.04	480
Na_2	Disodium	4.894 ± 0.003	614
Nb	Niobium	6.75885	1384
Nd	Neodymium	5.5250	859
Ne	Neon	21.56454	2081
Ni	Nickel	7.6398	1167
No	Nobelium	6.65	642
Np	Neptunium	6.2657 ± 0.0003	1069
O	Oxygen (atomic)	13.61806	1563
OPb	Lead(II) oxide	9.08 ± 0.10	939
OS	Sulfur monoxide	10.294 ± 0.004	998
OS_2	Sulfur oxide (SSO)	10.584 ± 0.005	971
OSi	Silicon monoxide	11.49 ± 0.20	1008
OSn	Tin(II) oxide	9.60 ± 0.02	944
OSr	Strontium oxide	6.6 ± 0.2	623
O_2	Oxygen	12.0697 ± 0.0002	1165
O_2S	Sulfur dioxide	12.349 ± 0.001	894
O_2Th	Thorium(IV) oxide	(8.7 ± 0.15)	342
O_2Ti	Titanium(IV) oxide	(9.54 ± 0.1)	623
O_2U	Uranium(IV) oxide	(5.4 ± 0.1)	57

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Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
O_3	Ozone	12.43	1342
O_3S	Sulfur trioxide	12.82 ± 0.03	841
O_3U	Uranium(VI) oxide	(10.5 ± 0.5)	214
O_4Os	Osmium(VIII) oxide	(12.32)	850
O_4Ru	Ruthenium(VIII) oxide	12.15 ± 0.03	988
O_7Re_2	Rhenium(VII) oxide	(12.7 ± 0.2)	125
Os	Osmium	8.7	1630
P	Phosphorus	10.48669	1328
P_2	Diphosphorus	10.53	1160
Pa	Protactinium	5.89	1133
Pb	Lead	7.41666	911
PbS	Lead(II) sulfide	(8.5 ± 0.5)	954
Pd	Palladium	8.3367	1181
Pm	Promethium	5.55	536
Pr	Praseodymium	5.464	883
Pt	Platinum	9.0	1433
Pu	Plutonium	6.025	926
Ra	Radium	5.27892	668
Rb	Rubidium	4.17713	484
Re	Rhenium	7.88	1530
Rh	Rhodium	7.45890	1276
Rn	Radon	10.74850	1037
Ru	Ruthenium	7.36050	1355
S	Sulfur	10.36001	1277
SSn	Tin(II) sulfide	(8.8)	966
S_2	Disulfur	9.356 ± 0.002	1031
Sb	Antimony	8.64	1096
Sc	Scandium	6.56144	1010
Se	Selenium	9.75238	1168
Si	Silicon	8.15169	1238
Sm	Samarium	5.6437	751
Sn	Tin	7.34381	1011
Sr	Strontium	5.69484	713
Ta	Tantalum	7.89	1544
Tb	Terbium	5.8639	955
Tc	Technetium	7.28	1380
Te	Tellurium	9.0096	1066
Th	Thorium	6.308 ± 0.003	1207
Ti	Titanium	6.8282	1127
Tl	Thallium	6.10829	771
Tm	Thulium	6.18431	827
U	Uranium	6.19405	1129
V	Vanadium	6.746 ± 0.002	1166
W	Tungsten	7.98	1621
Xe	Xenon	12.12987	1170
Y	Yttrium	6.217	1022
Yb	Ytterbium	6.25416	754
Zn	Zinc	9.39405	1037
Zr	Zirconium	6.63390	1251

Substances containing carbon

Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
C	Carbon	11.26030	1803
$CBrClF_2$	Bromochlorodifluoromethane	(11.21)	642
$CBrCl_3$	Bromotrichloromethane	(10.6)	980
$CBrF_3$	Bromotrifluoromethane	(11.40)	451
CBr_2F_2	Dibromodifluoromethane	11.03 ± 0.04	683
CBr_4	Tetrabromomethane	(10.31 ± 0.02)	1079
CCl	Chloromethylidyne	(8.9 ± 0.2)	1244
$CClF_3$	Chlorotrifluoromethane	12.6 ± 0.2	505

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Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
CClN	Cyanogen chloride	12.34 ± 0.01	1329
CCl_2	Dichloromethylene	(9.27)	1058
CCl_2F_2	Dichlorodifluoromethane	12.05 ± 0.24	685
CCl_2O	Carbonyl chloride	(11.5)	888
CCl_3F	Trichlorofluoromethane	11.77 ± 0.02	868
CCl_4	Tetrachloromethane	11.47 ± 0.01	1010
CF	Fluoromethylidyne	9.11 ± 0.01	1134
CFN	Cyanogen fluoride	13.34 ± 0.02	1325
CF_2	Difluoromethylene	11.44 ± 0.03	899
CF_2O	Carbonyl fluoride	13.035 ± 0.030	617
CF_3	Trifluoromethyl	8.7 ± 0.2	379
CF_3I	Trifluoroiodomethane	10.23	397
CH	Methylidyne	10.64 ± 0.01	1622
$CHBrCl_2$	Bromodichloromethane	10.6	973
$CHBr_2Cl$	Chlorodibromomethane	10.59 ± 0.01	1030
$CHBr_3$	Tribromomethane	10.48 ± 0.02	1035
CHCl	Chloromethylene	9.84	1247
$CHClF_2$	Chlorodifluoromethane	(12.2)	693
$CHCl_2F$	Dichlorofluoromethane	(11.5)	829
$CHCl_3$	Trichloromethane	11.37 ± 0.02	992
CHF	Fluoromethylene	10.06 ± 0.05	1121
CHF_3	Trifluoromethane	(13.86)	643
CHI_3	Triiodomethane	9.25 ± 0.02	1010
CHN	Hydrogen cyanide	13.60 ± 0.01	1447
CHN	Hydrogen isocyanide	(12.5 ± 0.1)	1407
CHNO	Isocyanic acid	11.595 ± 0.005	1016
CHNO	Fulminic acid	(10.83)	1263
CHO	Oxomethyl (HCO)	(8.55)	826
CH_2	Methylene	10.396 ± .003	1392
CH_2BrCl	Bromochloromethane	10.77 ± 0.01	1085
CH_2Br_2	Dibromomethane	(10.50 ± 0.02)	1013
CH_2ClF	Chlorofluoromethane	11.71 ± 0.01	870
CH_2Cl_2	Dichloromethane	11.32 ± .01	996
CH_2F_2	Difluoromethane	12.71	774
CH_2I_2	Diiodomethane	9.46 ± 0.02	1030
CH_2N_2	Diazomethane	8.999 ± 0.001	1098
CH_2N_2	Cyanamide	(10.4)	1137
CH_2O	Formaldehyde	10.88 ± 0.01	941
CH_2O_2	Formic acid	11.33 ± 0.01	715
CH_3	Methyl	9.843 ± 0.002	1095
CH_3BO	Borane carbonyl	11.14 ± 0.02	962
CH_3Br	Bromomethane	10.541 ± 0.003	979
CH_3Cl	Chloromethane	11.22 ± 0.01	1001
CH_3Cl_3Si	Methyltrichlorosilane	(11.36 ± 0.03)	548
CH_3F	Fluoromethane	12.47 ± 0.02	956
CH_3I	Iodomethane	9.538	936
CH_3NO	Formamide	10.16 ± 0.06	796
CH_3NO_2	Nitromethane	11.08 ± 0.07	994
CH_3N_3	Methyl azide	9.81 ± 0.02	1227
CH_3O	Methoxy	(10.72)	1050
CH_4	Methane	12.61 ± 0.01	1143
CH_4N_2O	Urea	9.7	690
CH_4O	Methanol	10.85 ± 0.01	845
CH_4S	Methanethiol	9.44 ± 0.005	888
CH_5N	Methylamine	(8.80)	826
CH_6N_2	Methylhydrazine	7.7 ± 0.15	835
CH_6Si	Methylsilane	(10.7)	1003
CN	Cyanide	13.5984	1748
CNO	Cyanate	11.76 ± 0.01	1290
CO	Carbon monoxide	14.014 ± 0.0003	1242

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Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
COS	Carbon oxysulfide	11.18 ± 0.01	936
COSe	Carbon oxyselenide	10.36 ± 0.01	929
CO_2	Carbon dioxide	13.773 ± 0.002	935
CS	Carbon sulfide	11.33 ± 0.01	1361
CS_2	Carbon disulfide	10.0685 ± 0.0020	1089
C_2	Dicarbon	(11.4 ± 0.3)	2000
$C_2Br_2F_4$	1,2-Dibromotetrafluoroethane	(11.1)	280
C_2ClF_3	Chlorotrifluoroethylene	9.81 ± 0.03	373
C_2ClF_5	Chloropentafluoroethane	(12.6)	99
C_2Cl_2	Dichloroacetylene	9.9	1165
$C_2Cl_2F_4$	1,2-Dichlorotetrafluoroethane	12.2	252
$C_2Cl_3F_3$	1,1,1-Trichlorotrifluoroethane	11.5	386
$C_2Cl_3F_3$	1,1,2-Trichlorotrifluoroethane	11.99 ± 0.02	429
C_2Cl_4	Tetrachloroethylene	9.326 ± 0.001	887
$C_2Cl_4F_2$	1,1,2,2-Tetrachloro-1,2-difluoroethane	(11.3)	563
C_2Cl_4O	Trichloroacetyl chloride	(11.0)	827
C_2Cl_6	Hexachloroethane	(11.1)	920
C_2F_3N	Trifluoroacetonitrile	13.93 ± 0.07	845
C_2F_4	Tetrafluoroethylene	10.12 ± 0.02	315
C_2F_6	Hexafluoroethane	(13.6)	-30
C_2H	Ethynyl	(11.61 ± 0.07)	1685
C_2HBr	Bromoacetylene	10.31 ± 0.02	1242
$C_2HBrClF_3$	2-Bromo-2-chloro-1,1,1-trifluoroethane	(11.0)	363
C_2HCl	Chloroacetylene	10.58 ± 0.02	1276
C_2HClF_2	1-Chloro-2,2-difluoroethylene	9.80 ± 0.04	628
C_2HCl_3	Trichloroethylene	9.46 ± 0.02	894
C_2HCl_3O	Dichloroacetyl chloride	(10.9)	809
C_2HCl_5	Pentachloroethane	(11.0)	919
C_2HF	Fluoroacetylene	11.26	1195
C_2HF_3	Trifluoroethylene	10.14	489
$C_2HF_3O_2$	Trifluoroacetic acid	11.46	75
C_2H_2	Acetylene	11.400 ± 0.002	1328
$C_2H_2Cl_2$	1,1-Dichloroethylene	9.81 ± 0.04	949
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethylene	9.66 ± 0.01	936
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethylene	9.64 ± 0.02	934
$C_2H_2Cl_2O$	Chloroacetyl chloride	(≤ 10.3)	815
$C_2H_2Cl_4$	1,1,1,2-Tetrachloroethane	(11.1)	920
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane	(≤ 11.62)	≤ 971
$C_2H_2F_2$	1,1-Difluoroethylene	10.29 ± 0.01	650
$C_2H_2F_2$	*cis*-1,2-Difluoroethylene	10.23 ± 0.02	690
C_2H_2O	Ketene	9.617 ± 0.003	880
$C_2H_2O_2$	Glyoxal	10.2	773
$C_2H_2S_2$	Thiirene	8.61	892
C_2H_3Br	Bromoethylene	9.83 ± 0.02	1028
C_2H_3Cl	Chloroethylene	9.99 ± 0.02	985
$C_2H_3ClF_2$	1-Chloro-1,1-difluoroethane	(11.98)	626
C_2H_3ClO	Acetyl chloride	10.82 ± 0.04	801
C_2H_3ClO	Chloroacetaldehyde	(10.48)	815
$C_2H_3ClO_2$	Chloroacetic acid	(10.7)	597
$C_2H_3Cl_3$	1,1,1-Trichloroethane	(11.0)	917
$C_2H_3Cl_3$	1,1,2-Trichloroethane	(11.0)	911
C_2H_3F	Fluoroethylene	10.36 ± 0.01	861
C_2H_3FO	Acetyl fluoride	(11.5)	667
$C_2H_3F_3$	1,1,1-Trifluoroethane	13.3 ± 0.5	536
C_2H_3N	Acetonitrile	12.20 ± 0.01	1253
C_2H_3NO	Methylisocyanate	(10.67)	900
C_2H_4	Ethylene	10.5138 ± 0.0006	1067
$C_2H_4Br_2$	1,2-Dibromoethane	10.35 ± 0.04	961
$C_2H_4Cl_2$	1,1-Dichloroethane	11.04 ± 0.02	935
$C_2H_4Cl_2$	1,2-Dichloroethane	11.04 ± 0.02	931

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IONIZATION ENERGIES OF GAS-PHASE MOLECULES (continued)

Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
$C_2H_4F_2$	1,1-Difluoroethane	(11.87)	643
C_2H_4O	Acetaldehyde	10.229 ± 0.0007	821
C_2H_4O	Ethylene oxide	10.56 ± 0.01	966
$C_2H_4O_2$	Acetic acid	10.65 ± 0.02	595
$C_2H_4O_2$	Methyl formate	10.835 ± 0.005	690
C_2H_5Br	Bromoethane	10.29 ± 0.01	931
C_2H_5Cl	Chloroethane	10.98 ± 0.02	947
C_2H_5ClO	2-Chloroethanol	(10.5)	756
C_2H_5F	Fluoroethane	(11.78)	873
C_2H_5I	Iodoethane	9.3492 ± 0.0006	893
C_2H_5N	Ethyleneimine	(9.5 ± 0.3)	1044
C_2H_5NO	Acetamide	9.65 ± 0.03	693
C_2H_5NO	*N*-Methylformamide	9.83 ± 0.04	760
$C_2H_5NO_2$	Nitroethane	10.88 ± 0.05	948
C_2H_6	Ethane	11.56 ± 0.02	1031
$C_2H_6Cl_2Si$	Dichlorodimethylsilane	(10.7)	576
C_2H_6O	Ethanol	10.43 ± 0.05	772
C_2H_6O	Dimethyl ether	10.025 ± 0.025	783
C_2H_6OS	Dimethyl sulfoxide	9.10 ± 0.03	727
$C_2H_6O_2$	Ethylene glycol	10.16	593
C_2H_6S	Ethanethiol	9.31 ± 0.03	851
C_2H_6S	Dimethyl sulfide	8.69 ± 0.02	801
$C_2H_6S_2$	Dimethyl disulfide	(7.4 ± 0.3)	690
C_2H_7N	Ethylamine	8.86 ± 0.02	808
C_2H_7N	Dimethylamine	8.24 ± 0.08	777
C_2H_7NO	Ethanolamine	8.96	664
$C_2H_8N_2$	1,2-Ethanediamine	(8.6)	812
$C_2H_8N_2$	1,1-Dimethylhydrazine	7.29 ± 0.05	787
C_2N_2	Cyanogen	13.37 ± 0.01	1597
C_3F_6	Perfluoropropene	10.60 ± 0.03	-103
C_3F_6O	Perfluoroacetone	(11.57 ± 0.13)	-282
C_3F_8	Perfluoropropane	(13.38)	-491
C_3HN	Cyanoacetylene	11.64 ± 0.01	1475
C_3H_2O	2-Propynal	(10.7 ± 0.1)	1145
$C_3H_3F_3$	3,3,3-Trifluoropropene	(10.9)	437
C_3H_3N	2-Propenenitrile	10.91 ± 0.01	1237
C_3H_3NO	Oxazole	(9.9)	940
C_3H_3NO	Isoxazole	(9.93)	1038
C_3H_4	Allene	9.692 ± 0.004	1126
C_3H_4	Propyne	10.37 ± 0.01	1187
C_3H_4	Cyclopropene	9.67 ± 0.01	1209
$C_3H_4N_2$	Imidazole	(8.81)	997
C_3H_4O	Propargyl alcohol	10.49 ± 0.02	1060
C_3H_4O	Acrolein	10.103 ± 0.006	900
C_3H_4O	Cyclopropanone	(9.1 ± 0.1)	895
$C_3H_4O_2$	Propenoic acid	10.60	701
$C_3H_4O_2$	2-Oxetanone	(9.70 ± 0.01)	653
C_3H_5Br	3-Bromopropene	(9.96)	1008
C_3H_5Cl	3-Chloropropene	10.04 ± 0.01	965
C_3H_5ClO	Epichlorohydrin	(10.64)	919
$C_3H_5ClO_2$	Methyl chloroacetate	(10.3)	575
C_3H_5F	3-Fluoropropene	(10.11)	821
C_3H_5N	Propanenitrile	11.84 ± 0.02	1194
C_3H_5NO	Acrylamide	(9.5)	720
C_3H_6	Propene	9.73 ± 0.02	959
C_3H_6	Cyclopropane	9.86	1005
$C_3H_6Br_2$	1,2-Dibromopropane	(10.1)	903
$C_3H_6Br_2$	1,3-Dibromopropane	(≤ 10.2)	≤ 919
$C_3H_6Cl_2$	1,2-Dichloropropane	10.8 ± 0.1	886
$C_3H_6Cl_2$	1,3-Dichloropropane	10.89 ± 0.04	892

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IONIZATION ENERGIES OF GAS-PHASE MOLECULES (continued)

Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
C_3H_6O	Allyl alcohol	9.67 ± 0.05	808
C_3H_6O	Methyl vinyl ether	8.95 ± 0.01	763
C_3H_6O	Propanal	9.96 ± 0.01	772
C_3H_6O	Acetone	9.703 ± 0.006	719
C_3H_6O	Methyloxirane	(10.22)	892
C_3H_6O	Oxetane	9.65 ± 0.01	851
$C_3H_6O_2$	Propanoic acid	10.525 ± 0.003	568
$C_3H_6O_2$	Ethyl formate	10.61 ± 0.01	639
$C_3H_6O_2$	Methyl acetate	10.25 ± 0.02	579
$C_3H_6O_2$	1,3-Dioxolane	(9.9)	658
$C_3H_6O_3$	1,3,5-Trioxane	(10.3)	528
C_3H_7Br	1-Bromopropane	10.18 ± 0.01	898
C_3H_7Br	2-Bromopropane	10.10 ± 0.03	877
C_3H_7Cl	1-Chloropropane	10.81 ± 0.01	911
C_3H_7Cl	2-Chloropropane	10.79 ± 0.02	896
C_3H_7F	1-Fluoropropane	(11.3)	806
C_3H_7F	2-Fluoropropane	(11.08)	776
C_3H_7I	1-Iodopropane	9.25 ± 0.01	860
C_3H_7I	2-Iodopropane	9.19 ± 0.02	845
C_3H_7N	Allylamine	(8.76)	891
C_3H_7N	Cyclopropylamine	(8.8)	926
C_3H_7N	Propyleneimine	(9.0)	960
C_3H_7NO	*N*,*N*-Dimethylformamide	(9.12)	688
$C_3H_7NO_2$	1-Nitropropane	(10.81)	919
$C_3H_7NO_2$	2-Nitropropane	(10.71)	894
C_3H_8	Propane	10.95 ± 0.05	952
C_3H_8O	1-Propanol	10.18 ± 0.06	727
C_3H_8O	2-Propanol	10.17 ± 0.02	709
C_3H_8O	Ethyl methyl ether	9.72 ± 0.07	722
$C_3H_8O_2$	Dimethoxymethane	9.7	588
C_3H_8S	1-Propanethiol	9.20 ± 0.01	819
C_3H_8S	2-Propanethiol	9.145 ± 0.005	806
C_3H_8S	Ethyl methyl sulfide	(8.55)	765
$C_3H_9BO_3$	Trimethyl borate	(10.0)	65
C_3H_9ClSi	Trimethylchlorosilane	(10.15)	624
C_3H_9N	Propylamine	(8.78)	777
C_3H_9N	Isopropylamine	(8.72)	758
C_3H_9N	Trimethylamine	7.82 ± 0.06	731
C_3H_9NO	3-Amino-1-propanol	(9.0)	651
$C_4H_2O_3$	Maleic anhydride	(10.8)	645
C_4H_4	1-Buten-3-yne	9.58 ± 0.02	1230
$C_4H_4N_2$	Succinonitrile	(12.1 ± 0.25)	1377
$C_4H_4N_2$	Pyrimidine	9.23	1087
$C_4H_4N_2$	Pyridazine	8.67 ± 0.03	1112
C_4H_4O	Furan	8.883 ± 0.003	822
$C_4H_4O_2$	Diketene	(9.6 ± 0.02)	736
$C_4H_4O_3$	Succinic anhydride	(10.6)	500
$C_4H_4O_4$	Fumaric acid	(10.7)	355
C_4H_4S	Thiophene	8.86 ± 0.02	970
C_4H_5N	Methylacrylonitrile	10.34	1127
C_4H_5N	Pyrrole	8.207 ± 0.005	900
C_4H_5N	Cyclopropanecarbonitrile	(10.25)	1173
C_4H_6	1,2-Butadiene	(9.03)	1034
C_4H_6	1,3-Butadiene	9.082 ± 0.004	986
C_4H_6	1-Butyne	10.19 ± 0.02	1148
C_4H_6	2-Butyne	9.59 ± 0.03	1071
C_4H_6	Cyclobutene	9.43 ± 0.02	1067
C_4H_6O	Divinyl ether	(8.7)	827
C_4H_6O	*trans*-2-Butenal	9.73 ± 0.01	835
C_4H_6O	2-Methylpropenal	(9.92)	834

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Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
C_4H_6O	Cyclobutanone	(9.35	815
$C_4H_6O_2$	*cis*-Crotonic acid	(10.08)	625
$C_4H_6O_2$	*trans*-Crotonic acid	(9.9)	604
$C_4H_6O_2$	Methacrylic acid	(10.15)	611
$C_4H_6O_2$	Vinyl acetate	9.19 ± 0.05	572
$C_4H_6O_2$	Methyl acrylate	(9.9)	641
$C_4H_6O_3$	Acetic anhydride	(10.0)	398
$C_4H_6O_4$	Dimethyl oxalate	(10.0)	287
C_4H_6S	2,5-Dihydrothiophene	(8.4)	898
C_4H_7N	Butanenitrile	(11.2)	1110
C_4H_7N	2-Methylpropanenitrile	(11.3)	1115
C_4H_7NO	2-Pyrrolidone	(9.2)	674
C_4H_8	1-Butene	9.55 ± 0.06	921
C_4H_8	*cis*-2-Butene	9.11 ± 0.01	871
C_4H_8	*trans*-2-Butene	9.10 ± 0.01	866
C_4H_8	Isobutene	9.239 ± 0.003	875
C_4H_8	Cyclobutane	(9.82 ± 0.05)	976
C_4H_8	Methylcyclopropane	(9.46)	936
$C_4H_8Br_2$	1,4-Dibromobutane	(10.15)	879
C_4H_8O	Ethyl vinyl ether	(8.98)	709
C_4H_8O	1,2-Epoxybutane	(≤ 10.15)	862
C_4H_8O	Butanal	9.84 ± 0.02	742
C_4H_8O	Isobutanal	9.71 ± 0.01	721
C_4H_8O	2-Butanone	9.52 ± 0.04	678
C_4H_8O	Tetrahydrofuran	9.38 ± 0.05	721
$C_4H_8O_2$	Butanoic acid	10.17 ± 0.05	509
$C_4H_8O_2$	2-Methylpropanoic acid	10.33 ± 0.03	516
$C_4H_8O_2$	Propyl formate	10.52 ± 0.02	555
$C_4H_8O_2$	Ethyl acetate	10.01 ± 0.05	522
$C_4H_8O_2$	Methyl propanoate	10.15 ± 0.03	548
$C_4H_8O_2$	1,3-Dioxane	9.8	607
$C_4H_8O_2$	1,4-Dioxane	9.19 ± 0.01	571
$C_4H_8O_2S$	Sulfolane	(9.8)	577
C_4H_8S	Tetrahydrothiophene	8.38	774
C_4H_9Br	1-Bromobutane	(10.12)	869
C_4H_9Br	2-Bromobutane	10.01 ± 0.02	845
C_4H_9Br	1-Bromo-2-methylpropane	10.09 ± 0.02	861
C_4H_9Br	2-Bromo-2-methylpropane	9.92 ± 0.03	823
C_4H_9Cl	1-Chlorobutane	10.67 ± 0.03	875
C_4H_9Cl	2-Chlorobutane	10.53	857
C_4H_9Cl	1-Chloro-2-methylpropane	10.73 ± 0.07	877
C_4H_9Cl	2-Chloro-2-methylpropane	(10.61)	842
C_4H_9I	1-Iodobutane	9.23 ± 0.01	840
C_4H_9I	2-Iodobutane	9.10 ± 0.02	815
C_4H_9I	1-Iodo-2-methylpropane	9.19 ± 0.01	824
C_4H_9I	2-Iodo-2-methylpropane	(9.02)	798
C_4H_9N	Pyrrolidine	(8.0)	769
C_4H_9NO	*N*,*N*-Dimethylacetamide	8.81 ± 0.03	616
C_4H_9NO	Morpholine	(8.2)	841
C_4H_{10}	Butane	10.53 ± 0.10	890
C_4H_{10}	Isobutane	(10.57)	886
$C_4H_{10}O$	1-Butanol	9.99 ± 0.05	689
$C_4H_{10}O$	2-Butanol	9.88 ± 0.03	658
$C_4H_{10}O$	2-Methyl-1-propanol	10.02 ± 0.04	683
$C_4H_{10}O$	2-Methyl-2-propanol	9.90 ± 0.02	642
$C_4H_{10}O$	Diethyl ether	9.51 ± 0.03	666
$C_4H_{10}O$	Methyl propyl ether	9.41 ± 0.07	670
$C_4H_{10}O$	Isopropyl methyl ether	9.45 ± 0.04	661
$C_4H_{10}O_2$	Ethylene glycol monoethyl ether	(9.6)	529
$C_4H_{10}O_2$	Ethylene glycol dimethyl ether	(9.3)	558

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Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
$C_4H_{10}S$	1-Butanethiol	9.14 ± 0.01	794
$C_4H_{10}S$	2-Butanethiol	(9.10)	781
$C_4H_{10}S$	2-Methyl-1-propanethiol	(9.12)	783
$C_4H_{10}S$	2-Methyl-2-propanethiol	(9.03)	762
$C_4H_{10}S$	Diethyl sulfide	(8.43)	730
$C_4H_{10}S$	Methyl propyl sulfide	(8.8)	767
$C_4H_{10}S$	Isopropyl methyl sulfide	(8.7)	749
$C_4H_{10}S_2$	Diethyl disulfide	(8.27)	724
$C_4H_{11}N$	Butylamine	8.7 ± 0.1	748
$C_4H_{11}N$	*sec*-Butylamine	8.46 ± 0.1	711
$C_4H_{11}N$	*tert*-Butylamine	8.46 ± 0.1	695
$C_4H_{11}N$	Isobutylamine	8.50 ± 0.1	721
$C_4H_{11}N$	Diethylamine	7.85 ± 0.1	684
$C_4H_{12}Si$	Tetramethylsilane	9.80 ± 0.04	713
$C_4H_{12}Sn$	Tetramethylstannane	8.89 ± 0.05	837
C_4NiO_4	Nickel carbonyl	8.27 ± 0.04	200
$C_5H_4O_2$	Furfural	9.22 ± 0.01	739
C_5H_5N	Pyridine	9.25	1031
C_5H_6	1-Penten-3-yne	9.00 ± 0.01	1119
C_5H_6	*cis*-3-Penten-1-yne	9.14 ± 0.04	1137
C_5H_6	*trans*-3-Penten-1-yne	9.05 ± 0.01	1128
C_5H_6	2-Methyl-1-buten-3-yne	9.25 ± 0.02	1152
C_5H_6	1,3-Cyclopentadiene	8.55 ± 0.02	955
C_5H_6O	2-Methylfuran	8.38 ± 0.02	729
C_5H_6O	3-Methylfuran	(8.64)	763
C_5H_6S	2-Methylthiophene	(8.14)	867
C_5H_6S	3-Methylthiophene	(8.40)	893
C_5H_8	*cis*-1,3-Pentadiene	8.63 ± 0.03	914
C_5H_8	*trans*-1,3-Pentadiene	8.59 ± 0.02	905
C_5H_8	1,4-Pentadiene	9.60 ± 0.02	1032
C_5H_8	2-Methyl-1,3-butadiene	8.84 ± 0.01	928
C_5H_8	1-Pentyne	10.10 ± 0.01	1119
C_5H_8	Cyclopentene	9.01 ± 0.01	905
C_5H_8	Spiropentane	(9.26)	1078
C_5H_8O	Cyclopropyl methyl ketone	(≤ 9.46)	796
C_5H_8O	Cyclopentanone	9.26 ± 0.01	701
C_5H_8O	3,4-Dihydro-2H-pyran	8.35 ± 0.01	681
$C_5H_8O_2$	Ethyl acrylate	(≤ 10.3)	617
$C_5H_8O_2$	Methyl methacrylate	(9.7)	589
$C_5H_8O_2$	2,4-Pentanedione	8.85 ± 0.01	469
C_5H_9NO	*N*-Methyl-2-pyrrolidone	(≤ 9.17)	≤ 676
C_5H_{10}	1-Pentene	9.51 ± 0.01	896
C_5H_{10}	*cis*-2-Pentene	9.01 ± 0.03	843
C_5H_{10}	*trans*-2-Pentene	9.04 ± 0.01	841
C_5H_{10}	2-Methyl-1-butene	9.12 ± 0.01	844
C_5H_{10}	3-Methyl-1-butene	9.52 ± 0.01	891
C_5H_{10}	2-Methyl-2-butene	8.69 ± 0.01	796
C_5H_{10}	Cyclopentane	(10.33 ± 0.15)	918
$C_5H_{10}O$	2,2-Dimethylpropanal	9.51 ± 0.01	675
$C_5H_{10}O$	Cyclopentanol	(9.72)	695
$C_5H_{10}O$	Pentanal	9.74 ± 0.04	709
$C_5H_{10}O$	2-Pentanone	9.38 ± 0.01	646
$C_5H_{10}O$	3-Pentanone	9.31 ± 0.01	640
$C_5H_{10}O$	3-Methyl-2-butanone	9.30 ± 0.01	635
$C_5H_{10}O$	Tetrahydropyran	9.25 ± 0.01	670
$C_5H_{10}O_2$	Pentanoic acid	(≤ 10.53)	≤ 527
$C_5H_{10}O_2$	3-Methylbutanoic acid	(≤ 10.51)	≤ 499
$C_5H_{10}O_2$	Butyl formate	10.52 ± 0.02	584
$C_5H_{10}O_2$	Propyl acetate	(≤ 9.92)	501
$C_5H_{10}O_2$	Isopropyl acetate	9.99 ± 0.03	482

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IONIZATION ENERGIES OF GAS-PHASE MOLECULES (continued)

Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
$C_5H_{10}O_2$	Ethyl propanoate	(10.00)	500
$C_5H_{10}O_2$	Methyl butanoate	(10.07)	520
$C_5H_{10}S$	Thiacyclohexane	(8.2)	728
$C_5H_{11}Br$	1-Bromopentane	10.10 ± 0.01	846
$C_5H_{11}I$	1-Iodopentane	9.20 ± 0.01	817
$C_5H_{11}N$	Piperidine	8.03 ± 0.11	726
$C_5H_{11}N$	*N*-Methylpyrrolidine	≤ 8.41 ± 0.02	≤ 809
C_5H_{12}	Pentane	10.28 ± 0.10	845
C_5H_{12}	Isopentane	10.32 ± 0.05	843
C_5H_{12}	Neopentane	(≤ 10.2)	≤ 818
$C_5H_{12}O$	1-Pentanol	(10.00)	668
$C_5H_{12}O$	2-Pentanol	(9.78)	630
$C_5H_{12}O$	3-Pentanol	9.78	628
$C_5H_{12}O$	2-Methyl-1-butanol	(9.86)	649
$C_5H_{12}O$	2-Methyl-2-butanol	(9.8)	615
$C_5H_{12}O$	3-Methyl-2-butanol	(9.88 ± 0.13)	637
$C_5H_{12}O$	Butyl methyl ether	(9.4 ± 0.1)	648
$C_5H_{12}O$	Methyl *tert*-butyl ether	(9.24)	608
$C_5H_{12}O$	Ethyl propyl ether	(9.45)	640
$C_5H_{12}S$	*tert*-Butyl methyl sulfide	(8.38)	687
$C_5H_{12}S$	Ethyl propyl sulfide	(8.50)	716
$C_5H_{12}S$	Ethyl isopropyl sulfide	(8.35)	689
C_6BrF_5	Bromopentafluorobenzene	(9.67)	222
C_6ClF_5	Chloropentafluorobenzene	(9.72)	126
C_6Cl_6	Hexachlorobenzene	(8.98)	822
C_6F_6	Hexafluorobenzene	9.89 ± 0.04	8
C_6F_{12}	Perfluorocyclohexane	(13.2)	-1095
C_6HF_5	Pentafluorobenzene	(9.63)	122
C_6HF_5O	Pentafluorophenol	(9.20)	-71
$C_6H_2F_4$	1,2,3,4-Tetrafluorobenzene	(9.53)	284
$C_6H_2F_4$	1,2,3,5-Tetrafluorobenzene	(9.53)	263
$C_6H_2F_4$	1,2,4,5-Tetrafluorobenzene	(9.35)	254
$C_6H_3Cl_3$	1,2,4-Trichlorobenzene	(9.04)	880
$C_6H_3Cl_3$	1,3,5-Trichlorobenzene	9.32 ± 0.02	899
$C_6H_4ClNO_2$	1-Chloro-3-nitrobenzene	(9.92 ± 0.1)	995
$C_6H_4ClNO_2$	1-Chloro-4-nitrobenzene	(9.96 ± 0.1)	999
$C_6H_4Cl_2$	*o*-Dichlorobenzene	9.06 ± 0.02	907
$C_6H_4Cl_2$	*m*-Dichlorobenzene	9.10 ± 0.02	906
$C_6H_4Cl_2$	*p*-Dichlorobenzene	8.92 ± 0.02	885
$C_6H_4FNO_2$	1-Fluoro-4-nitrobenzene	(9.90)	826
$C_6H_4F_2$	*o*-Difluorobenzene	9.29 ± 0.01	602
$C_6H_4F_2$	*m*-Difluorobenzene	9.33 ± 0.01	591
$C_6H_4F_2$	*p*-Difluorobenzene	9.1589 ± 0.0003	577
$C_6H_4O_2$	*p*-Benzoquinone	10.01 ± 0.06	844
C_6H_5Br	Bromobenzene	9.00 ± 0.02	971
C_6H_5Cl	Chlorobenzene	9.07 ± 0.02	930
C_6H_5ClO	*m*-Chlorophenol	8.655 ± 0.001	680
C_6H_5ClO	*p*-Chlorophenol	(≤ 8.69)	≤ 692
C_6H_5F	Fluorobenzene	9.20 ± 0.01	772
C_6H_5I	Iodobenzene	8.685	1003
$C_6H_5NO_2$	Nitrobenzene	9.86 ± 0.02	1019
$C_6H_5NO_3$	*o*-Nitrophenol	(9.1)	782
$C_6H_5NO_3$	*m*-Nitrophenol	(9.0)	755
$C_6H_5NO_3$	*p*-Nitrophenol	(9.1)	761
C_6H_6	Benzene	9.24378 ± 0.00007	975
C_6H_6	Fulvene	(8.36)	1031
C_6H_6ClN	*o*-Chloroaniline	(8.50)	883
C_6H_6ClN	*m*-Chloroaniline	(8.09)	835
C_6H_6ClN	*p*-Chloroaniline	(≤ 8.18)	≤ 844
$C_6H_6N_2O_2$	*o*-Nitroaniline	(8.27)	861

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Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
$C_6H_6N_2O_2$	*m*-Nitroaniline	(8.31)	865
$C_6H_6N_2O_2$	*p*-Nitroaniline	(8.34)	859
C_6H_6O	Phenol	8.49 ± 0.02	723
$C_6H_6O_2$	*p*-Hydroquinone	7.94 ± 0.01	503
C_6H_6S	Benzenethiol	(8.32)	915
C_6H_7N	Aniline	7.720 ± 0.002	832
C_6H_7N	2-Methylpyridine	(9.02)	970
C_6H_7N	3-Methylpyridine	(9.04)	979
C_6H_7N	4-Methylpyridine	(9.04)	976
$C_6H_8N_2$	*o*-Phenylenediamine	(7.2)	787
$C_6H_8N_2$	*m*-Phenylenediamine	(7.14)	777
$C_6H_8N_2$	*p*-Phenylenediamine	(6.87 ± 0.05)	759
C_6H_{10}	1,5-Hexadiene	9.27 ± 0.05	978
C_6H_{10}	1-Hexyne	10.03 ± 0.05	1089
C_6H_{10}	3,3-Dimethyl-1-butyne	9.90 ± 0.04	1060
C_6H_{10}	Cyclohexene	8.945 ± 0.01	859
$C_6H_{10}O$	Cyclohexanone	9.14 ± 0.01	656
$C_6H_{10}O$	Mesityl oxide	9.10 ± 0.01	694
$C_6H_{10}O_4$	Diethyl oxalate	(9.8)	205
$C_6H_{11}NO$	Caprolactam	(9.07 ± 0.02)	629
C_6H_{12}	1-Hexene	9.44 ± 0.04	869
C_6H_{12}	*cis*-2-Hexene	(8.97 ± 0.01)	818
C_6H_{12}	*trans*-2-Hexene	(8.97 ± 0.01)	814
C_6H_{12}	2-Methyl-1-pentene	(9.08 ± 0.01)	817
C_6H_{12}	4-Methyl-1-pentene	9.45 ± 0.01	862
C_6H_{12}	2-Methyl-2-pentene	(8.58)	761
C_6H_{12}	4-Methyl-*cis*-2-pentene	8.98 ± 0.01	809
C_6H_{12}	4-Methyl-*trans*-2-pentene	(8.97 ± 0.01)	804
C_6H_{12}	2-Ethyl-1-butene	(9.06 ± 0.02)	818
C_6H_{12}	2,3-Dimethyl-1-butene	(9.07 ± 0.01)	812
C_6H_{12}	2,3-Dimethyl-2-butene	8.27 ± 0.01	729
C_6H_{12}	Cyclohexane	9.86 ± 0.03	828
C_6H_{12}	Methylcyclopentane	(9.85)	845
$C_6H_{12}O$	Hexanal	9.72 ± 0.05	691
$C_6H_{12}O$	2-Hexanone	9.3 ± 0.1	626
$C_6H_{12}O$	3-Hexanone	9.12 ± 0.02	600
$C_6H_{12}O$	3-Methyl-2-pentanone	9.21 ± 0.01	600
$C_6H_{12}O$	4-Methyl-2-pentanone	9.30 ± 0.01	609
$C_6H_{12}O$	2-Methyl-3-pentanone	9.10 ± 0.01	592
$C_6H_{12}O$	3,3-Dimethyl-2-butanone	9.12 ± 0.02	589
$C_6H_{12}O$	Cyclohexanol	(9.75)	651
$C_6H_{12}O_2$	Hexanoic acid	≤ 10.12	≤ 463
$C_6H_{12}O_2$	Butyl acetate	(9.92 ± .05)	471
$C_6H_{12}O_2$	*sec*-Butyl acetate	9.90	453
$C_6H_{12}O_2$	Methyl 2,2-dimethylpropanoate	(9.90 ± 0.04)	466
$C_6H_{13}I$	1-Iodohexane	9.179	794
$C_6H_{13}N$	Cyclohexylamine	(8.86)	750
C_6H_{14}	Hexane	10.13	810
C_6H_{14}	2-Methylpentane	(10.12)	802
C_6H_{14}	3-Methylpentane	(10.08)	801
C_6H_{14}	2,2-Dimethylbutane	(10.06)	787
C_6H_{14}	2,3-Dimethylbutane	(10.02)	791
$C_6H_{14}O$	1-Hexanol	(9.89)	639
$C_6H_{14}O$	2-Hexanol	(9.80 ± 0.03)	611
$C_6H_{14}O$	3-Hexanol	(9.63 ± 0.03)	599
$C_6H_{14}O$	Dipropyl ether	(9.27)	602
$C_6H_{14}O$	Diisopropyl ether	9.20 ± 0.05	569
$C_6H_{14}O$	Butyl ethyl ether	(9.36)	610
$C_6H_{14}O$	Methyl pentyl ether	(≤ 9.67)	≤ 657
$C_6H_{14}O_2$	1,1-Diethoxyethane	(9.2)	434

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IONIZATION ENERGIES OF GAS-PHASE MOLECULES (continued)

Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
$C_6H_{14}O_3$	Diethylene glycol dimethyl ether	≤ 9.8	≤ 448
$C_6H_{14}S$	Dipropyl sulfide	8.30 ± 0.02	676
$C_6H_{14}S$	Diisopropyl sulfide	(8.2 ± 0.2)	649
$C_6H_{15}N$	Hexylamine	(8.63 ± 0.05)	699
$C_6H_{15}N$	Dipropylamine	(7.84 ± 0.02)	641
$C_6H_{15}N$	Diisopropylamine	(7.73 ± 0.03)	602
$C_6H_{15}N$	Triethylamine	(7.50 ± 0.02)	631
$C_6H_{15}NO_3$	Triethanolamine	(7.9)	206
$C_7H_3F_5$	2,3,4,5,6-Pentafluorotoluene	(9.4)	64
C_7H_5ClO	Benzoyl chloride	(9.53)	815
$C_7H_5Cl_3$	(Trichloromethyl)benzene	(≤ 9.60)	≤ 914
$C_7H_5F_3$	(Trifluoromethyl)benzene	9.685 ± 0.005	335
C_7H_5N	Benzonitrile	9.70 ± 0.01	1154
C_7H_6O	Benzaldehyde	9.49 ± 0.02	878
$C_7H_6O_2$	Benzoic acid	(9.3)	604
C_7H_7Br	*p*-Bromotoluene	8.67 ± 0.02	908
C_7H_7Cl	*o*-Chlorotoluene	(8.7 ± 0.1)	856
C_7H_7Cl	*m*-Chlorotoluene	(8.83)	869
C_7H_7Cl	*p*-Chlorotoluene	(8.69)	855
C_7H_7Cl	(Chloromethyl)benzene	9.10 ± 0.02	897
C_7H_7F	*o*-Fluorotoluene	8.91 ± 0.01	709
C_7H_7F	*m*-Fluorotoluene	8.91 ± 0.01	709
C_7H_7F	*p*-Fluorotoluene	8.79 ± 0.01	701
C_7H_7NO	Benzamide	(9.25)	792
$C_7H_7NO_2$	*o*-Nitrotoluene	9.24	946
$C_7H_7NO_2$	*m*-Nitrotoluene	9.45 ± 0.1	941
$C_7H_7NO_2$	*p*-Nitrotoluene	9.46 ± 0.05	942
C_7H_8	Toluene	8.8276 ± 0.0006	901
C_7H_8O	*o*-Cresol	(8.24)	670
C_7H_8O	*m*-Cresol	8.29 ± 0.07	668
C_7H_8O	*p*-Cresol	(8.3)	675
C_7H_8O	Benzyl alcohol	(8.3)	701
C_7H_8O	Anisole	8.22 ± 0.03	725
C_7H_9N	Benzylamine	(8.64)	917
C_7H_9N	*o*-Methylaniline	(7.44 ± 0.02)	772
C_7H_9N	*m*-Methylaniline	(7.50 ± 0.02)	778
C_7H_9N	*p*-Methylaniline	(7.24 ± 0.02)	753
C_7H_9N	*N*-Methylaniline	7.34 ± 0.04	792
C_7H_9N	2,3-Dimethylpyridine	(8.85 ± 0.02)	922
C_7H_9N	2,4-Dimethylpyridine	(8.85 ± 0.03)	918
C_7H_9N	2,5-Dimethylpyridine	(≤ 8.80 ± 0.05)	≤ 916
C_7H_9N	2,6-Dimethylpyridine	8.86 ± 0.03	913
C_7H_9N	3,4-Dimethylpyridine	(≤ 9.15)	≤ 953
C_7H_9N	3,5-Dimethylpyridine	(≤ 9.25)	≤ 965
$C_7H_{10}O$	Dicyclopropyl ketone	(9.1)	1041
C_7H_{14}	1-Heptene	9.34 ± 0.10	839
C_7H_{14}	*trans*-3-Heptene	(8.92)	790
C_7H_{14}	Cycloheptane	9.97	844
C_7H_{14}	Methylcyclohexane	9.64	775
C_7H_{14}	*cis*-1,2-Dimethylcyclopentane	(9.92 ± 0.05)	828
C_7H_{14}	*trans*-1,2-Dimethylcyclopentane	9.7 ± 0.2	799
$C_7H_{14}O$	1-Heptanal	(9.65)	668
$C_7H_{14}O$	2-Heptanone	9.28 ± 0.10	594
$C_7H_{14}O$	3-Heptanone	9.18 ± 0.08	589
$C_7H_{14}O$	4-Heptanone	9.10 ± 0.06	577
$C_7H_{14}O$	5-Methyl-2-hexanone	(9.28)	586
$C_7H_{14}O$	2,4-Dimethyl-3-pentanone	8.95 ± 0.01	552
$C_7H_{14}O$	1-Methylcyclohexanol	(9.8 ± 0.2)	586
C_7H_{16}	Heptane	9.93 ± 0.10	771
$C_7H_{16}O$	1-Heptanol	(9.84)	614

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Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
$C_7H_{16}O$	2-Heptanol	(9.70)	580
$C_7H_{16}O$	3-Heptanol	(9.68)	578
$C_7H_{16}O$	4-Heptanol	(9.61)	572
$C_7H_{16}O$	Ethyl pentyl ether	(≤ 9.49)	≤ 602
$C_8H_4O_3$	Phthalic anhydride	(10.1)	603
$C_8H_6O_4$	Isophthalic acid	(9.98)	268
$C_8H_6O_4$	Terephthalic acid	(9.86)	232
C_8H_7N	2-Methylbenzonitrile	(≤ 9.38)	1085
C_8H_7N	3-Methylbenzonitrile	(≤ 9.34)	1085
C_8H_7N	4-Methylbenzonitrile	9.32 ± 0.02	1083
C_8H_7N	Indole	7.7602 ± 0.0006	908
C_8H_8	Styrene	8.464 ± 0.001	964
C_8H_8O	*p*-Tolualdehyde	(9.33)	825
C_8H_8O	Acetophenone	9.29 ± 0.03	810
$C_8H_8O_2$	*o*-Toluic acid	(9.1)	558
$C_8H_8O_2$	*m*-Toluic acid	(9.43)	579
$C_8H_8O_2$	*p*-Toluic acid	(9.23)	560
$C_8H_8O_2$	Benzeneacetic acid	(8.26)	479
$C_8H_8O_2$	Methyl benzoate	9.32 ± 0.03	611
C_8H_{10}	Ethylbenzene	8.77 ± 0.01	876
C_8H_{10}	*o*-Xylene	8.56 ± 0.01	844
C_8H_{10}	*m*-Xylene	8.56 ± 0.01	843
C_8H_{10}	*p*-Xylene	8.44 ± 0.01	832
$C_8H_{10}O$	*p*-Ethylphenol	(7.84)	613
$C_8H_{10}O$	2,3-Xylenol	(8.26)	640
$C_8H_{10}O$	2,4-Xylenol	(8.0)	609
$C_8H_{10}O$	2,6-Xylenol	(8.05)	615
$C_8H_{10}O$	3,4-Xylenol	(8.09)	624
$C_8H_{10}O$	Phenetole	(8.13)	683
$C_8H_{11}N$	2,4,6-Trimethylpyridine	(≤ 8.9)	≤ 880
$C_8H_{11}N$	*N*-Ethylaniline	(≤ 7.67)	≤ 794
$C_8H_{11}N$	*N*,*N*-Dimethylaniline	7.12 ± 0.02	787
C_8H_{14}	1-Octyne	(9.95 ± 0.02)	1040
C_8H_{14}	2-Octyne	9.31 ± 0.01	961
C_8H_{14}	3-Octyne	9.22 ± 0.01	952
C_8H_{14}	4-Octyne	9.20 ± 0.01	946
C_8H_{16}	1-Octene	9.43 ± 0.01	829
C_8H_{16}	Cyclooctane	9.75 ± 0.05	816
C_8H_{16}	Ethylcyclohexane	(9.54)	748
C_8H_{16}	1,1-Dimethylcyclohexane	(9.42)	728
C_8H_{16}	*cis*-1,2-Dimethylcyclohexane	(<9.78)	772
C_8H_{16}	*trans*-1,2-Dimethylcyclohexane	9.41	728
C_8H_{16}	*cis*-1,3-Dimethylcyclohexane	(<9.98)	778
C_8H_{16}	*trans*-1,3-Dimethylcyclohexane	9.53	743
C_8H_{16}	*cis*-1,4-Dimethylcyclohexane	(<9.93)	782
C_8H_{16}	*trans*-1,4-Dimethylcyclohexane	(9.56)	738
C_8H_{16}	Propylcyclopentane	(9.34)	753
$C_8H_{16}O$	2,2,4-Trimethyl-3-pentanone	(8.80)	511
C_8H_{18}	Octane	9.80 ± 0.10	737
C_8H_{18}	2-Methylheptane	(9.84)	734
C_8H_{18}	2,2,4-Trimethylpentane	(9.86)	713
C_8H_{18}	2,2,3,3-Tetramethylbutane	9.8	720
$C_8H_{18}O$	Dibutyl ether	(9.28)	s 560
$C_8H_{18}O$	Di-*sec*-butyl ether	(9.11)	511
$C_8H_{18}O$	Di-*tert*-butyl ether	8.88 ± 0.07	493
$C_8H_{18}S$	Dibutyl sulfide	(8.2)	624
$C_8H_{18}S$	Di-*tert*-butyl sulfide	(8.0)	583
$C_8H_{18}S$	Diisobutyl sulfide	(8.34)	625
$C_8H_{19}N$	Dibutylamine	(7.69)	586
$C_8H_{19}N$	Diisobutylamine	(7.8)	574

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Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
$C_8H_{20}Si$	Tetraethylsilane	(8.9)	595
C_9H_7N	Quinoline	8.62 ± 0.01	1041
C_9H_7N	Isoquinoline	8.53 ± 0.03	1032
C_9H_8	Indene	8.14 ± 0.01	949
C_9H_{10}	*o*-Methylstyrene	(8.20)	908
C_9H_{10}	*m*-Methylstyrene	(8.15)	899
C_9H_{10}	*p*-Methylstyrene	(8.1)	895
C_9H_{10}	Cyclopropylbenzene	(8.35)	956
C_9H_{10}	Indan	(8.3)	864
$C_9H_{10}O_2$	Ethyl benzoate	(8.9)	537
C_9H_{12}	Propylbenzene	8.713 ± 0.010	848
C_9H_{12}	Isopropylbenzene	8.73 ± 0.01	847
C_9H_{12}	1,2,3-Trimethylbenzene	8.42 ± 0.02	803
C_9H_{12}	1,2,4-Trimethylbenzene	8.27 ± 0.01	784
C_9H_{12}	1,3,5-Trimethylbenzene	8.41 ± 0.01	796
$C_9H_{13}N$	*N*,*N*-Dimethyl-*o*-toluidine	7.40 ± 0.02	814
$C_9H_{14}O$	Isophorone	(≤ 9.07)	≤ 670
C_9H_{18}	Butylcyclopentane	(9.95)	793
C_9H_{18}	Propylcyclohexane	(9.46)	720
C_9H_{18}	Isopropylcyclohexane	(9.33)	704
$C_9H_{18}O$	2-Nonanone	(9.16)	545
$C_9H_{18}O$	5-Nonanone	(9.07)	530
$C_9H_{18}O$	2,6-Dimethyl-4-heptanone	9.01 ± 0.06	512
C_9H_{20}	Nonane	9.71 ± 0.10	709
$C_{10}F_8$	Perfluoronaphthalene	8.85	-368
$C_{10}H_7Br$	1-Bromonaphthalene	8.08 ± 0.03	955
$C_{10}H_7Cl$	1-Chloronaphthalene	(8.13)	906
$C_{10}H_8$	Naphthalene	8.1442 ± 0.0009	936
$C_{10}H_8$	Azulene	7.38 ± 0.05	1001
$C_{10}H_8O$	1-Naphthol	7.76 ± 0.03	719
$C_{10}H_8O$	2-Naphthol	7.87 ± 0.06	729
$C_{10}H_{10}O_4$	Dimethyl phthalate	(9.64 ± 0.07)	277
$C_{10}H_{12}$	1,2,3,4-Tetrahydronaphthalene	8.46 ± 0.02	841
$C_{10}H_{14}$	Butylbenzene	8.69 ± 0.02	826
$C_{10}H_{14}$	*sec*-Butylbenzene	8.68 ± 0.02	820
$C_{10}H_{14}$	*tert*-Butylbenzene	8.68 ± 0.05	816
$C_{10}H_{14}$	Isobutylbenzene	8.69 ± 0.02	817
$C_{10}H_{14}$	*p*-Cymene	(8.29)	771
$C_{10}H_{14}$	*o*-Diethylbenzene	(≤ 8.51)	≤ 804
$C_{10}H_{14}$	*m*-Diethylbenzene	(8.49)	798
$C_{10}H_{14}$	*p*-Diethylbenzene	(8.40)	790
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene	8.04 ± 0.02	730
$C_{10}H_{14}O$	*p*-*tert*-Butylphenol	(7.8)	552
$C_{10}H_{16}$	α-Pinene	(8.07)	808
$C_{10}H_{16}O$	Camphor	(8.76)	577
$C_{10}H_{18}$	*cis*-Decahydronaphthalene	9.36 ± 0.04	734
$C_{10}H_{18}$	*trans*-Decahydronaphthalene	9.34 ± 0.04	720
$C_{10}H_{20}$	1-Decene	9.42 ± 0.05	786
$C_{10}H_{20}$	Butylcyclohexane	(9.41)	695
$C_{10}H_{22}$	Decane	(9.65)	682
$C_{11}H_{10}$	1-Methylnaphthalene	7.97 ± 0.03	882
$C_{11}H_{10}$	2-Methylnaphthalene	7.91 ± 0.08	877
$C_{11}H_{16}$	*p*-*tert*-Butyltoluene	(8.12)	730
$C_{11}H_{24}$	Undecane	(9.56)	650
$C_{11}H_{24}$	2-Methyldecane	(9.7)	658
$C_{12}H_8$	Acenaphthylene	(8.22)	1053
$C_{12}H_9N$	Carbazole	(7.57)	961
$C_{12}H_{10}$	Acenaphthene	7.75 ± 0.07	903
$C_{12}H_{10}$	Biphenyl	8.23 ± 0.10	977
$C_{12}H_{10}N_2O$	*trans*-Azoxybenzene	(8.1)	1123

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IONIZATION ENERGIES OF GAS-PHASE MOLECULES (continued)

Mol. Form.	Name	IP/eV	$\Delta_f H_{ion}$ kJ/mol
$C_{12}H_{10}O$	Diphenyl ether	(8.09)	766
$C_{12}H_{11}N$	Diphenylamine	7.16 ± 0.04	908
$C_{12}H_{18}$	5,7-Dodecadiyne	(8.67)	1079
$C_{12}H_{18}$	Hexamethylbenzene	7.85 ± 0.01	670
$C_{12}H_{22}$	Cyclohexylcyclohexane	(9.41)	690
$C_{12}H_{27}N$	Tributylamine	(7.4)	492
$C_{13}H_{10}$	9H-Fluorene	7.91 ± 0.02	952
$C_{13}H_{10}O$	Benzophenone	9.08 ± 0.05	926
$C_{13}H_{12}$	Diphenylmethane	(8.55)	963
$C_{14}H_{10}$	Anthracene	7.439 ± 0.006	948
$C_{14}H_{10}$	Phenanthrene	7.8914 ± 0.0006	966
$C_{14}H_{10}$	Diphenylacetylene	7.94 ± 0.03	1168
$C_{14}H_{12}$	*cis*-Stilbene	(7.80)	1005
$C_{14}H_{12}$	*trans*-Stilbene	7.656 ± 0.001	973
$C_{14}H_{14}$	1,2-Diphenylethane	8.9 ± 0.1	1002
$C_{16}H_{10}$	Fluoranthene	7.9 ± 0.1	1052
$C_{16}H_{10}$	Pyrene	7.4256 ± 0.0006	935
$C_{18}H_{12}$	Chrysene	7.60 ± 0.01	1017
$C_{18}H_{14}$	*o*-Terphenyl	(7.99)	1056
$C_{18}H_{14}$	*m*-Terphenyl	(8.01)	1057
$C_{18}H_{14}$	*p*-Terphenyl	7.80 ± 0.03	1037
$C_{20}H_{12}$	Perylene	6.960 ± 0.001	981
$C_{24}H_{12}$	Coronene	7.29 ± 0.01	1026

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X-RAY ATOMIC ENERGY LEVELS

The energy levels in this tables are the values recommended by Bearden and Burr on the basis of a thorough review of the literature on x-ray wavelengths and related data. All values are in electron volts (eV). Values in parentheses are interpolated, and an asterisk * indicates a level which is not resolved from the level above it. See Reference 1 for uncertainties in the levels and a complete description of how the recommended values were obtained.

REFERENCES

1. Bearden, J. A., and Burr, A. F., *Rev. Mod. Phys*., 39, 125, 1967; also published as *X-Ray Wavelengths and X-Ray Atomic Energy Levels*, Natl. Stand. Ref. Data Sys.- Natl. Bur. Standards (U.S.), No. 14, 1967.
2. Gray, D. E., Editor, *American Institute of Physics Handbook, Third Edition*, pp. **7**-158 to **7**-167, McGraw-Hill, New York, 1972.

Level	^{1}H	^{2}He	^{3}Li	^{4}Be	^{5}B	^{6}C	^{7}N	^{8}O
K	13.59811	24.58678	54.75	111.0	188.0	283.8	401.6	532.0
L_{I}								23.7
$L_{II,III}$					4.7	6.4	9.2	7.1

Level	^{9}F	^{10}Ne	^{11}Na	^{12}Mg	^{13}Al	^{14}Si	^{15}P	^{16}S
K	685.4	866.9	1072.1	1305.0	1559.6	1838.9	2145.5	2472.0
L_{I}	(31)	(45)	63.3	89.4	117.7	148.7	189.3	229.2
$L_{II,III}$	8.6	18.3	31.1	51.4	73.1	99.2	132.2	164.8

Level	^{17}Cl	^{18}Ar	^{19}K	^{20}Ca	^{21}Sc	^{22}Ti	^{23}V	^{24}Cr
K	2822.4	3202.9	3607.4	4038.1	4492.8	4966.4	5465.1	5989.2
L_{I}	270.2	320	377.1	437.8	500.4	563.7	628.2	694.6
L_{II}	201.6	247.3	296.3	350.0	406.7	461.5	520.5	583.7
L_{III}	200.0	245.2	293.6	346.4	402.2	455.5	512.9	574.5
M_{I}	17.5	25.3	33.9	43.7	53.8	60.3	66.5	74.1
$M_{II,III}$	6.8	12.4	17.8	25.4	32.3	34.6	37.8	42.5
$M_{IV,V}$					6.6	3.7	2.2	2.3

Level	^{25}Mn	^{26}Fe	^{27}Co	^{28}Ni	^{29}Cu	^{30}Zn	^{31}Ga	^{32}Ge
K	6539.0	7112.0	7708.9	8332.8	8978.9	9658.6	10367.1	11103.1
L_{I}	769.0	846.1	925.6	1008.1	1096.1	1193.6	1297.7	1414.3
L_{II}	651.4	721.1	793.6	871.9	951.0	1042.8	1142.3	1247.8
L_{III}	640.3	708.1	778.6	854.7	931.1	1019.7	1115.4	1216.7
M_{I}	83.9	92.9	100.7	111.8	119.8	135.9	158.1	180.0
M_{II}	48.6	54.0	59.5	68.1	73.6	86.6	106.8	127.9
M_{III}	48.6*	54.0*	59.5*	68.1*	73.6*	86.6*	102.9	120.8
$M_{IV,V}$	3.3	3.6	2.9	3.6	1.6	8.1	17.4	28.7

Level	^{33}As	^{34}Se	^{35}Br	^{36}Kr	^{37}Rb	^{38}Sr	^{39}Y	^{40}Zr
K	11866.7	12657.8	13473.7	14325.6	15199.7	16104.6	17038.4	17997.6
L_{I}	1526.5	1653.9	1782.0	1921.0	2065.1	2216.3	2372.5	2531.6
L_{II}	1358.6	1476.2	1596.0	1727.2	1863.9	2006.8	2155.5	2306.7
L_{III}	1323.1	1435.8	1549.9	1674.9	1804.4	1939.6	2080.0	2222.3
M_{I}	203.5	231.5	256.5		322.1	357.5	393.6	430.3
M_{II}	146.4	168.2	189.3	222.7	247.4	279.8	312.4	344.2
M_{III}	140.5	161.9	181.5	213.8	238.5	269.1	300.3	330.5
M_{IV}	41.2	56.7	70.1	88.9	111.8	135.0	159.6	182.4
M_{V}	41.2*	56.7*	69.0	88.9*	110.3	133.1	157.4	180.0
N_{I}			27.3	24.0	29.3	37.7	45.4	51.3
N_{II}	2.5	5.6	5.2	10.6	14.8	19.9	25.6	28.7
N_{III}	2.5*	5.6*	4.6	10.6*	14.0	19.9*	25.6*	28.7*

X-RAY ATOMIC ENERGY LEVELS (continued)

Level	^{41}Nb	^{42}Mo	^{43}Tc	^{44}Ru	^{45}Rh	^{46}Pd	^{47}Ag	^{48}Cd
K	18985.6	19999.5	21044.0	22117.2	23219.9	24350.3	25514.0	26711.2
L_{I}	2697.7	2865.5	3042.5	3224.0	3411.9	3604.3	3805.8	4018.0
L_{II}	2464.7	2625.1	2793.2	2966.9	3146.1	3330.3	3523.7	3727.0
L_{III}	2370.5	2520.2	2676.9	2837.9	3003.8	3173.3	3351.1	3537.5
M_{I}	468.4	504.6		585.0	627.1	669.9	717.5	770.2
M_{II}	378.4	409.7	444.9	482.8	521.0	559.1	602.4	650.7
M_{III}	363.0	392.3	425.0	460.6	496.2	531.5	571.4	616.5
M_{IV}	207.4	230.3	256.4	283.6	311.7	340.0	372.8	410.5
M_{V}	204.6	227.0	252.9	279.4	307.0	334.7	366.7	403.7
N_{I}	58.1	61.8		74.9	81.0	86.4	95.2	107.6
N_{II}	33.9	34.8	38.9	43.1	47.9	51.1	62.6	66.9
N_{III}	33.9*	34.8*	38.9*	43.1*	47.9*	51.1*	55.9	66.9*
$N_{IV,V}$	3.2	1.8		2.0	2.5	1.5	3.3	9.3

Level	^{49}In	^{50}Sn	^{51}Sb	^{52}Te	^{53}I	^{54}Xe	^{55}Cs	^{56}Ba
K	27939.9	29200.1	30491.2	31813.8	33169.4	34561.4	35984.6	37440.6
L_{I}	4237.5	4464.7	4698.3	4939.2	5188.1	5452.8	5714.3	5988.8
L_{II}	3938.0	4156.1	4380.4	4612.0	4852.1	5103.7	5359.4	5623.6
L_{III}	3730.1	3928.8	4132.2	4341.4	4557.1	4782.2	5011.9	5247.0
M_{I}	825.6	883.8	943.7	1006.0	1072.1		1217.1	1292.8
M_{II}	702.2	756.4	811.9	869.7	930.5	999.0	1065.0	1136.7
M_{III}	664.3	714.4	765.6	818.7	874.6	937.0	997.6	1062.2
M_{IV}	450.8	493.3	536.9	582.5	631.3		739.5	796.1
M_{V}	443.1	484.8	527.5	572.1	619.4	672.3	725.5	780.7
N_{I}	121.9	136.5	152.0	168.3	186.4		230.8	253.0
N_{II}	77.4	88.6	98.4	110.2	122.7	146.7	172.3	191.8
N_{III}	77.4*	88.6*	98.4*	110.2*	122.7*	146.7*	161.6	179.7
N_{IV}	16.2	23.9	31.4	39.8	49.6		78.8	92.5
N_{V}	16.2*	23.9*	31.4*	39.8*	49.6*		76.5	89.9
O_{I}	0.1	0.9	6.7	11.6	13.6		22.7	39.1
O_{II}	0.8	1.1	2.1	2.3	3.3		13.1	16.6
O_{III}	0.8*	1.1*	2.1*	2.3*	3.3*		11.4	14.6

Level	^{57}La	^{58}Ce	^{59}Pr	^{60}Nd	^{61}Pm	^{62}Sm	^{63}Eu	^{64}Gd
K	38924.6	40443.0	41990.6	43568.9	45184.0	46834.2	48519.0	50239.1
L_{I}	6266.3	6548.8	6834.8	7126.0	7427.9	7736.8	8052.0	8375.6
L_{II}	5890.6	6164.2	6440.4	6721.5	7012.8	7311.8	7617.1	7930.3
L_{III}	5482.7	5723.4	5964.3	6207.9	6459.3	6716.2	6976.9	7242.8
M_{I}	1361.3	1434.6	1511.0	1575.3		1722.8	1800.0	1880.8
M_{II}	1204.4	1272.8	1337.4	1402.8	1471.4	1540.7	1613.9	1688.3
M_{III}	1123.4	1185.4	1242.2	1297.4	1356.9	1419.8	1480.6	1544.0
M_{IV}	848.5	901.3	951.1	999.9	1051.5	1106.0	1160.6	1217.2
M_{V}	831.7	883.3	931.0	977.7	1026.9	1080.2	1130.9	1185.2
N_{I}	270.4	289.6	304.5	315.2		345.7	360.2	375.8
N_{II}	205.8	223.3	236.3	243.3	242	265.6	283.9	288.5
N_{III}	191.4	207.2	217.6	224.6	242*	247.4	256.6	270.9
$N_{IV,V}$	98.9	110.0	113.2	117.5	120.4	129.0	133.2	140.5
$N_{VI,VII}$		0.1	2.0	1.5		5.5	0.0	0.1
O_{I}	32.3	37.8	37.4	37.5		37.4	31.8	36.1
$O_{II,III}$	14.4	19.8	22.3	21.1		21.3	22.0	20.3

Level	^{65}Tb	^{66}Dy	^{67}Ho	^{68}Er	^{69}Tm	^{70}Yb	^{71}Lu	^{72}Hf
K	51995.7	53788.5	55617.7	57485.5	59389.6	61332.3	63313.8	65350.8
L_{I}	8708.0	9045.8	9394.2	9751.3	10115.7	10486.4	10870.4	11270.7
L_{II}	8251.6	8580.6	8917.8	9264.3	9616.9	9978.2	10348.6	10739.4
L_{III}	7514.0	7790.1	8071.1	8357.9	8648.0	8943.6	9244.1	9560.7
M_{I}	1967.5	2046.8	2128.3	2206.5	2306.8	2398.1	2491.2	2600.9

X-RAY ATOMIC ENERGY LEVELS (continued)

Level	**^{65}Tb**	**^{66}Dy**	**^{67}Ho**	**^{68}Er**	**^{69}Tm**	**^{70}Yb**	**^{71}Lu**	**^{72}Hf**
M_{II}	1767.7	1841.8	1922.8	2005.8	2089.8	2173.0	2263.5	2365.4
M_{III}	1611.3	1675.6	1741.2	1811.8	1884.5	1949.8	2023.6	2107.6
M_{IV}	1275.0	1332.5	1391.5	1453.3	1514.6	1576.3	1639.4	1716.4
M_{V}	1241.2	1294.9	1351.4	1409.3	1467.7	1527.8	1588.5	1661.7
N_{I}	397.9	416.3	435.7	449.1	471.7	487.2	506.2	538.1
N_{II}	310.2	331.8	343.5	366.2	385.9	396.7	410.1	437.0
N_{III}	385.0	292.9	306.6	320.0	336.6	343.5	359.3	380.4
N_{IV}	147.0	154.2	161.0	176.7	179.6	198.1	204.8	223.8
N_{V}	147.0*	154.2*	161.0*	167.6	179.6*	184.9	195.0	213.7
$N_{VI,VII}$	2.6	4.2	3.7	4.3	5.3	6.3	6.9	17.1
O_{I}	39.0	62.9	51.2	59.8	53.2	54.1	56.8	64.9
O_{II}	25.4	26.3	20.3	29.4	32.3	23.4	28.0	38.1
O_{III}	25.4*	26.3*	20.3*	29.4*	32.3*	23.4*	28.0*	30.6

Level	**^{73}Ta**	**^{74}W**	**^{75}Re**	**^{76}Os**	**^{77}Ir**	**^{78}Pt**	**^{79}Au**	**^{80}Hg**
K	67416.4	69525.0	71676.4	73870.8	76111.0	78394.8	80724.9	83102.3
L_{I}	11681.5	12099.8	12526.7	12968.0	13418.5	13879.9	14352.8	14839.3
L_{II}	11136.1	11544.0	11958.7	12385.0	12824.1	13272.6	13733.6	14208.7
L_{III}	9881.1	10206.8	10535.3	10870.9	11215.2	11563.7	11918.7	12283.9
M_{I}	2708.0	2819.6	2931.7	3048.5	3173.7	3296.0	3424.9	3561.6
M_{II}	2468.7	2574.9	2681.6	2792.2	2908.7	3026.5	3147.8	3278.5
M_{III}	2194.0	2281.0	2367.3	2457.2	2550.7	2645.4	2743.0	2847.1
M_{IV}	1793.2	1871.6	1948.9	2030.8	2116.1	2201.9	2291.1	2384.9
M_{V}	1735.1	1809.2	1882.9	1960.1	2040.4	2121.6	2205.7	2294.9
N_{I}	565.5	595.0	625.0	654.3	690.1	722.0	758.8	800.3
N_{II}	464.8	491.6	517.9	546.5	577.1	609.2	643.7	676.9
N_{III}	404.5	425.3	444.4	468.2	494.3	519.0	545.4	571.0
N_{IV}	241.3	258.8	273.7	289.4	311.4	330.8	352.0	378.3
N_{V}	229.3	245.4	260.2	272.8	294.9	313.3	333.9	359.8
N_{VI}	25.0	36.5	40.6	46.3	63.4	74.3	86.4	102.2
N_{VII}	25.0*	33.6	40.6*	46.3*	60.5	71.1	82.8	98.5
O_{I}	71.1	77.1	82.8	83.7	95.2	101.7	107.8	120.3
O_{II}	44.9	46.8	45.6	58.0	63.0	65.3	71.7	80.5
O_{III}	36.4	35.6	34.6	45.4	50.5	51.7	53.7	57.6
$O_{IV,V}$	5.7	6.1	3.5		3.8	2.2	2.5	6.4

Level	**^{81}Tl**	**^{82}Pb**	**^{83}Bi**	**^{84}Po**	**^{85}At**	**^{86}Rn**	**^{87}Fr**	**^{88}Ra**
K	85530.4	88004.5	90525.9	93105.0	95729.9	98404	101137	103921.9
L_{I}	15346.7	15860.8	16387.5	16939.3	17493	18049	18639	19236.7
L_{II}	14697.9	15200.0	15711.1	16244.3	16784.7	17337.1	17906.5	18484.3
L_{III}	12657.5	13035.2	13418.6	13813.8	14213.5	14619.4	15031.2	15444.4
M_{I}	3704.1	3850.7	3999.1	4149.4	(4317)	(4482)	(4652)	4822.0
M_{II}	3415.7	3554.2	3696.3	3854.1	4008	4159	4327	4489.5
M_{III}	2956.6	3066.4	3176.9	3301.9	3426	3538	3663	3791.8
M_{IV}	2485.1	2585.6	2687.6	2798.0	2908.7	3021.5	3136.2	3248.4
M_{V}	2389.3	2484.0	2579.6	2683.0	2786.7	2892.4	2999.9	3104.9
N_{I}	845.5	893.6	938.2	995.3	(1042)	(1097)	(1153)	1208.4
N_{II}	721.3	763.9	805.3	851	886	929	980	1057.6
N_{III}	609.0	644.5	678.9	705	740	768	810	879.1
N_{IV}	406.6	435.2	463.6	500.2	533.2	566.6	603.3	635.9
N_{V}	386.2	412.9	440.0	473.4			577	602.7
N_{VI}	122.8	142.9	161.9					298.9
N_{VII}	118.5	138.1	157.4					298.9*
O_{I}	136.3	147.3	159.3					254.4
O_{II}	99.6	104.8	116.8					200.4
O_{III}	75.4	86.0	92.8					152.8

X-RAY ATOMIC ENERGY LEVELS (continued)

Level	^{81}Tl	^{82}Pb	^{83}Bi	^{84}Po	^{85}At	^{86}Rn	^{87}Fr	^{88}Ra
O_{IV}	15.3	21.8	26.5	31.4				67.2
O_{V}	13.1	19.2	24.4	31.4*				67.2*
P_{I}		3.1						43.5
$P_{II,III}$		0.7	2.7					18.8

Level	^{89}Ac	^{90}Th	^{91}Pa	^{92}U	^{93}Np	^{94}Pu	^{95}Am	^{96}Cm
K	106755.3	109650.9	112601.4	115606.1	118678	121818	125027	128220
L_{I}	19840	20472.1	21104.6	21757.4	22426.8	23097.2	23772.9	24460
L_{II}	19083.2	19693.2	20313.7	20947.6	21600.5	22266.2	22944.0	23779
L_{III}	15871.0	16300.3	16733.1	17166.3	17610.0	18056.8	18504.1	18930
M_{I}	(5002)	5182.3	5366.9	5548.0	5723.2	5932.9	6120.5	6288
M_{II}	4656	4830.4	5000.9	5182.2	5366.2	5541.2	5710.2	5895
M_{III}	3909	4046.1	4173.8	4303.4	4434.7	4556.6	4667.0	4797
M_{IV}	3370.2	3490.8	3611.2	3727.6	3850.3	3972.6	4092.1	4227
M_{V}	3219.0	3332.0	3441.8	3551.7	3665.8	3778.1	3886.9	3971
N_{I}	(1269)	1329.5	1387.1	1440.8	1500.7	1558.6	1617.1	1643
N_{II}	1080	1168.2	1224.3	1272.6	1327.7	1372.1	1411.8	1440
N_{III}	890	967.3	1006.7	1044.9	1086.8	1114.8	(1135.7)	1154
N_{IV}	674.9	714.1	743.4	780.4	815.9	848.9	878.7	
N_{V}		676.4	708.2	737.7	770.3	801.4	827.6	
N_{VI}		344.4	371.2	391.3	415.0	445.8		
N_{VII}		335.2	359.5	380.9	404.4	432.4		
O_{I}		290.2	309.6	323.7		351.9		385
O_{II}		229.4	222.9	259.3	283.4	274.1		
O_{III}		181.8	222.9*	195.1	206.1	206.5		
O_{IV}		94.3	94.1	105.0	109.3	116.0	115.8	
O_{V}		87.9	94.1*	96.3	101.3	105.4	103.3	
P_{I}		59.5		70.7				
P_{II}		49.0		42.3				
P_{III}		43.0		32.3				

Level	^{97}Bk	^{98}Cf	^{99}Es	^{100}Fm	^{101}Md	^{102}No	^{103}Lr
K	131590	135960	139490	143090	146780	150540	154380
L_{I}	25275	26110	26900	27700	28530	29380	30240
L_{II}	24385	25250	26020	26810	27610	28440	29280
L_{III}	19452	19930	20410	20900	21390	21880	22360
M_{I}	6556	6754	6977	7205	7441	7675	7900
M_{II}	6147	6359	6574	6793	7019	7245	7460
M_{III}	4977	5109	5252	5397	5546	5688	5710
M_{IV}	4366	4497	4630	4766	4903	5037	5150
M_{V}	4132	4253	4374	4498	4622	4741	4860
N_{I}	1755	1799	1868	1937	2010	2078	2140
N_{II}	1554	1616	1680	1747	1814	1876	1930
N_{III}	1235	1279	1321	1366	1410	1448	1480
O_{I}	398	419	435	454	472	484	490

ELECTRON BINDING ENERGIES OF THE ELEMENTS

Gwyn P. Williams

This table gives the binding energies in electron volts (eV) for selected electronic levels of the elements. For metallic elements the binding energy is referred to the Fermi level; for semiconductors, to the valence band maximum; and for gases and insulators, to the vacuum level. The atomic number is listed after the element name.

REFERENCES

1. Fluggle and Martensson, J. *Elect. Spect.*, 21, 275, 1980.
2. Cardona, M. and Ley, L., *Photoemission from Solids*, Springer Verlag, Heidelberg, 1978.
3. Bearden, J. A. and Burr, A. F., *Rev. Mod. Phys.*, 39, 125, 1967.

Actinium (89)

K	1s	106755
L I	2s	19840
L II	$2p_{1/2}$	19083
L III	$2p_{3/2}$	15871
M I	3s	5002
M II	$3p_{1/2}$	4656
M III	$3p_{3/2}$	3909
M IV	$3d_{3/2}$	3370
M V	$3d_{5/2}$	3219
N I	4s	1269[a]
N II	$4p_{1/2}$	1080[a]
N III	$4p_{3/2}$	890[a]
N IV	$4d_{3/2}$	675[a]
N V	$4d_{5/2}$	639[a]
N VI	$4f_{5/2}$	319[a]
N VII	$4f_{7/2}$	319[a]
O I	5s	272[a]
O II	$5p_{1/2}$	215[a]
O III	$5p_{3/2}$	167[a]
O IV	$5d_{3/2}$	80[a]
O V	$5d_{5/2}$	80[a]
P I	6s	—
P II	$6p_{1/2}$	—
P III	$6p_{3/2}$	—

Aluminum (13)

K	1s	1559.0
L I	2s	117.8[a]
L II	$2p_{1/2}$	72.9[a]
L III	$2p_{3/2}$	72.5[a]

Antimony (51)

K	1s	30419
L I	2s	4698
L II	$2p_{1/2}$	4380
L III	$2p_{3/2}$	4132
M I	3s	946[b]
M II	$3p_{1/2}$	812.7[b]
M III	$3p_{3/2}$	766.4[b]
M IV	$3d_{3/2}$	537.5[b]
M V	$3d_{5/2}$	528.2[b]
N I	4s	153.2[b]
N II	$4p_{1/2}$	95.6[b,c]
N III	$4p_{3/2}$	95.6[b]
N IV	$4d_{3/2}$	33.3[b]
N V	$4d_{5/2}$	32.1[b]

Argon (18)

K	1s	3205.9[a]
L I	2s	326.3[a]
L II	$2p_{1/2}$	250.6[a]
L III	$2p_{3/2}$	248.4[a]
M I	3s	29.3[a]
M II	$3p_{1/2}$	15.9[a]
M III	$3p_{3/2}$	15.7[a]

Arsenic (33)

K	1s	11867
L I	2s	1527.0[a,d]
L II	$2p_{1/2}$	1359.1[a,d]
L III	$2p_{3/2}$	1323.6[a,d]
M I	3s	204.7[a]
M II	$3p_{1/2}$	146.2[a]
M III	$3p_{3/2}$	141.2[a]
M IV	$3d_{3/2}$	41.7[a]
M V	$3d_{5/2}$	41.7[a]

Astatine (85)

K	1s	95730
L I	2s	17493
L II	$2p_{1/2}$	16785
L III	$2p_{3/2}$	14214
M I	3s	4317
M II	$3p_{1/2}$	4008
M III	$3p_{3/2}$	3426
M IV	$3d_{3/2}$	2909
M V	$3d_{5/2}$	2787
N I	4s	1042[a]
N II	$4p_{1/2}$	886[a]
N III	$4p_{3/2}$	740[a]
N IV	$4d_{3/2}$	533[a]
N V	$4d_{5/2}$	507[a]
N VI	$4f_{5/2}$	210[a]
N VII	$4f_{7/2}$	210[a]
O I	5s	195[a]
O II	$5p_{1/2}$	148[a]
O III	$5p_{3/2}$	115[a]
O IV	$5d_{3/2}$	40[a]
O V	$5d_{5/2}$	40[a]

Barium (56)

K	1s	37441
L I	2s	5989
L II	$2p_{1/2}$	5624
L III	$2p_{3/2}$	5247
M I	3s	1293[a,d]
M II	$3p_{1/2}$	1137[a,d]
M III	$3p_{3/2}$	1063[a,d]
M IV	$3d_{3/2}$	795.7[a]
M V	$3d_{5/2}$	780.5[a]
N I	4s	253.5[b]
N II	$4p_{1/2}$	192
N III	$4p_{3/2}$	178.6[b]
N IV	$4d_{3/2}$	92.6[b]
N V	$4d_{5/2}$	89.9[b]
N VI	$4f_{5/2}$	—
N VII	$4f_{7/2}$	—
O I	5s	30.3[b]
O II	$5p_{1/2}$	17.0[b]
O III	$5p_{3/2}$	14.8[b]

Beryllium (4)

K	1s	111.5[a]

Bismuth (83)

K	1s	90526
L I	2s	16388
L II	$2p_{1/2}$	15711
L III	$2p_{3/2}$	13419
M I	3s	3999
M II	$3p_{1/2}$	3696
M III	$3p_{3/2}$	3177
M IV	$3d_{3/2}$	2688
M V	$3d_{5/2}$	2580
N I	4s	939[b]
N II	$4p_{1/2}$	805.2[b]
N III	$4p_{3/2}$	678.8[b]
N IV	$4d_{3/2}$	464.0[b]
N V	$4d_{5/2}$	440.1[b]
N VI	$4f_{5/2}$	162.3[b]
N VII	$4f_{7/2}$	157.0[b]
O I	5s	159.3[a,d]
O II	$5p_{1/2}$	119.0[b]
O III	$5p_{3/2}$	92.6[b]
O IV	$5d_{3/2}$	26.9[b]
O V	$5d_{5/2}$	23.8[b]

Boron (5)

K	1s	188[a]

Bromine (35)

K	1s	13474
L I	2s	1782[a]
L II	$2p_{1/2}$	1596[a]
L III	$2p_{3/2}$	1550[a]
M I	3s	257[a]
M II	$3p_{1/2}$	189[a]
M III	$3p_{3/2}$	182[a]
M IV	$3d_{3/2}$	70[a]
M V	$3d_{5/2}$	69[a]

Cadmium (48)

K	1s	26711
L I	2s	4018
L II	$2p_{1/2}$	3727
L III	$2p_{3/2}$	3538
M I	3s	772.0[b]
M II	$3p_{1/2}$	652.6[b]
M III	$3p_{3/2}$	618.4[b]
M IV	$3d_{3/2}$	411.9[b]
M V	$3d_{5/2}$	405.2[b]
N I	4s	109.8[b]
N II	$4p_{1/2}$	63.9[b,c]
N III	$4p_{3/2}$	63.9[b,c]
N IV	$4d_{3/2}$	11.7[b]
N V	$4d_{5/2}$	10.7[b]

Calcium (20)

K	1s	4038.5[a]
L I	2s	438.4[b]
L II	$2p_{1/2}$	349.7[b]
L III	$2p_{3/2}$	346.2[b]
M I	3s	44.3[b]
M II	$3p_{1/2}$	25.4[b]
M III	$3p_{3/2}$	25.4[b]

Carbon (6)

K	1s	284.2[a]

Cerium (58)

K	1s	40443
L I	2s	6548
L II	$2p_{1/2}$	6164
L III	$2p_{3/2}$	5723
M I	3s	1436[a,d]
M II	$3p_{1/2}$	1274[a,d]
M III	$3p_{3/2}$	1187[a,d]
M IV	$3d_{3/2}$	902.4[a]
M V	$3d_{5/2}$	883.8[a]

N I	4s	291.0[a]
N II	$4p_{1/2}$	223.3
N III	$4p_{3/2}$	206.5[a]
N IV	$4d_{3/2}$	109[a]
N V	$4d_{5/2}$	—
N VI	$4f_{5/2}$	0.1
N VII	$4f_{7/2}$	0.1
O I	5s	37.8
O II	$5p_{1/2}$	19.8[a]
O III	$5p_{3/2}$	17.0[a]

Cesium (55)

K	1s	35985
L I	2s	5714
L II	$2p_{1/2}$	5359
L III	$2p_{3/2}$	5012
M I	3s	1211[a,d]
M II	$3p_{1/2}$	1071[a]
M III	$3p_{3/2}$	1003[a]
M IV	$3d_{3/2}$	740.5[a]
M V	$3d_{5/2}$	726.6[a]
N I	4s	232.3[a]
N II	$4p_{1/2}$	172.4[a]
N III	$4p_{3/2}$	161.3[a]
N IV	$4d_{3/2}$	79.8[a]
N V	$4d_{5/2}$	77.5[a]
N VI	$4f_{5/2}$	—
N VII	$4f_{7/2}$	—
O I	5s	22.7
O II	$5p_{1/2}$	14.2[a]
O III	$5p_{3/2}$	12.1[a]

Chlorine (17)

K	1s	2822.0
L I	2s	270[a]
L II	$2p_{1/2}$	202[a]
L III	$2p_{3/2}$	200[a]

Chromium(24)

K	1s	5989
L I	2s	696.0[b]
L II	$2p_{1/2}$	583.8[b]
L III	$2p_{3/2}$	574.1[b]
M I	3s	74.1[b]
M II	$3p_{1/2}$	42.2[b]
M III	$3p_{3/2}$	42.2[b]

Cobalt (27)

K	1s	7709
L I	2s	925.1[b]
L II	$2p_{1/2}$	793.2[b]
L III	$2p_{3/2}$	778.1[b]
M I	3s	101.0[b]
M II	$3p_{1/2}$	58.9[b]
M III	$3p_{3/2}$	58.9[b]

Copper (29)

K	1s	8979
L I	2s	1096.7[b]
L II	$2p_{1/2}$	952.3[b]
L III	$2p_{3/2}$	932.5[b]
M I	3s	122.5[b]
M II	$3p_{1/2}$	77.3[b]
M III	$3p_{3/2}$	75.1[b]

Dysprosium (66)

K	1s	53789
L I	2s	9046
L II	$2p_{1/2}$	8581
L III	$2p_{3/2}$	7790
M I	3s	2047
M II	$3p_{1/2}$	1842
M III	$3p_{3/2}$	1676
M IV	$3d_{3/2}$	1333
M V	$3d_{5/2}$	1292[a]
N I	4s	414.2[a]
N II	$4p_{1/2}$	333.5[a]
N III	$4p_{3/2}$	293.2[a]
N IV	$4d_{3/2}$	153.6[a]
N V	$4d_{5/2}$	153.6[a]
N VI	$4f_{5/2}$	8.0[a]
N VII	$4f_{7/2}$	4.3[a]
O I	5s	49.9[a]
O II	$5p_{1/2}$	26.3
O III	$5p_{3/2}$	26.3

Erbium (68)

K	1s	57486
L I	2s	9751
L II	$2p_{1/2}$	9264
L III	$2p_{3/2}$	8358
M I	3s	2206
M II	$3p_{1/2}$	2006
M III	$3p_{3/2}$	1812
M IV	$3d_{3/2}$	1453
M V	$3d_{5/2}$	1409
N I	4s	449.8[a]
N II	$4p_{1/2}$	366.2
N III	$4p_{3/2}$	320.2[a]
N IV	$4d_{3/2}$	167.6[a]
N V	$4d_{5/2}$	167.6[a]
N VI	$4f_{5/2}$	—
N VII	$4f_{7/2}$	4.7[a]
O I	5s	50.6[a]
O II	$5p_{1/2}$	31.4[a]
O III	$5p_{3/2}$	24.7[a]

Europium (63)

K	1s	48519
L I	2s	8052
L II	$2p_{1/2}$	7617
L III	$2p_{3/2}$	6977
M I	3s	1800
M II	$3p_{1/2}$	1614
M III	$3p_{3/2}$	1481
M IV	$3d_{3/2}$	1158.6[a]
M V	$3d_{5/2}$	1127.5[a]
N I	4s	360
N II	$4p_{1/2}$	284
N III	$4p_{3/2}$	257
N IV	$4d_{3/2}$	133
N V	$4d_{5/2}$	1227[a]
N VI	$4f_{5/2}$	0
N VII	$4f_{7/2}$	0
O I	5s	32
O II	$5p_{1/2}$	22
O III	$5p_{3/2}$	22

Fluorine (9)

K	1s	696.7[a]

Francium (87)

K	1s	101137
L I	2s	18639
L II	$2p_{1/2}$	17907
L III	$2p_{3/2}$	15031
M I	3s	4652
M II	$3p_{1/2}$	4327
M III	$3p_{3/2}$	3663
M IV	$3d_{3/2}$	3136
M V	$3d_{5/2}$	3000
N I	4s	1153[a]
N II	$4p_{1/2}$	980[a]
N III	$4p_{3/2}$	810[a]
N IV	$4d_{3/2}$	603[a]
N V	$4d_{5/2}$	577[a]
N VI	$4f_{5/2}$	268[a]
N VII	$4f_{7/2}$	268[a]
O I	5s	234[a]
O II	$5p_{1/2}$	182[a]
O III	$5p_{3/2}$	140[a]
O IV	$5d_{3/2}$	58[a]
O V	$5d_{5/2}$	58[a]
P I	6s	34
P II	$6p_{1/2}$	15
P III	$6p_{3/2}$	15

Gadolinium (64)

K	1s	50239
L I	2s	8376
L II	$2p_{1/2}$	7930
L III	$2p_{3/2}$	7243
M I	3s	1881
M II	$3p_{1/2}$	1688
M III	$3p_{3/2}$	1544
M IV	$3d_{3/2}$	1221.9[a]
M V	$3d_{5/2}$	1189.6[a]
N I	4s	378.6[a]
N II	$4p_{1/2}$	286
N III	$4p_{3/2}$	271
N IV	$4d_{3/2}$	—
N V	$4d_{5/2}$	142.6[a]
N VI	$4f_{5/2}$	8.6[a]
N VII	$4f_{7/2}$	8.6[a]
O I	5s	36
O II	$5p_{1/2}$	20
O III	$5p_{3/2}$	20

Gallium (31)

K	1s	10367
L I	2s	1299.0[a,d]
L II	$2p_{1/2}$	1143.2[b]
L III	$2p_{3/2}$	1116.4[b]
M I	3s	159.5[b]
M II	$3p_{1/2}$	103.5[b]
M III	$3p_{3/2}$	100.0[b]
M IV	$3d_{3/2}$	18.7[b]
M V	$3d_{5/2}$	18.7[b]

Germanium (32)

K	1s	11103
L I	2s	1414.6[a,d]
L II	$2p_{1/2}$	1248.1[a,d]
L III	$2p_{3/2}$	1217.0[a,d]
M I	3s	180.1[a]
M II	$3p_{1/2}$	124.9[a]
M III	$3p_{3/2}$	120.8[a]
M IV	$3d_{3/2}$	29.8[a]
M V	$3d_{5/2}$	29.2[a]

Gold (79)

K	1s	80725
L I	2s	14353
L II	$2p_{1/2}$	13734
L III	$2p_{3/2}$	11919
M I	3s	3425
M II	$3p_{1/2}$	3148
M III	$3p_{3/2}$	2743
M IV	$3d_{3/2}$	2291
M V	$3d_{5/2}$	2206
N I	4s	762.1[b]
N II	$4p_{1/2}$	642.7[b]
N III	$4p_{3/2}$	546.3[b]
N IV	$4d_{3/2}$	353.2[b]
N V	$4d_{5/2}$	335.1[b]
N VI	$4f_{5/2}$	87.6[b]
N VII	$4f_{7/2}$	83.9[b]
O I	5s	107.2[a,d]
O II	$5p_{1/2}$	74.2[b]
O III	$5p_{3/2}$	57.2[b]

Hafnium (72)

K	1s	65351
L I	2s	11271
L II	$2p_{1/2}$	10739
L III	$2p_{3/2}$	9561
M I	3s	2601
M II	$3p_{1/2}$	2365
M III	$3p_{3/2}$	2107
M IV	$3d_{3/2}$	1176
M V	$3d_{5/2}$	1662
N I	4s	538[a]
N II	$4p_{1/2}$	438.2[b]
N III	$4p_{3/2}$	380.7[b]
N IV	$4d_{3/2}$	220.0[b]
N V	$4d_{5/2}$	211.5[b]
N VI	$4f_{5/2}$	15.9[b]

N VII	$4f_{7/2}$	14.2[b]
O I	5s	64.2[b]
O II	$5p_{1/2}$	38[a]
O III	$5p_{3/2}$	29.9[b]

Helium (2)

K	1s	24.6[a]

Holmium (67)

K	1s	55618
L I	2s	9394
L II	$2p_{1/2}$	8918
L III	$2p_{3/2}$	8071
M I	3s	2128
M II	$3p_{1/2}$	1923
M III	$3p_{3/2}$	1741
M IV	$3d_{3/2}$	1392
M V	$3d_{5/2}$	1351
N I	4s	432.4[a]
N II	$4p_{1/2}$	343.5
N III	$4p_{3/2}$	308.2[a]
N IV	$4d_{3/2}$	160[a]
N V	$4d_{5/2}$	160[a]
N VI	$4f_{5/2}$	8.6[a]
N VII	$4f_{7/2}$	5.2[a]
O I	5s	49.3[a]
O II	$5p_{1/2}$	30.8[a]
O III	$5p_{3/2}$	24.1[a]

Hydrogen (1)

K	1s	13.6

Indium (49)

K	1s	27940
L I	2s	4238
L II	$2p_{1/2}$	3938
L III	$2p_{3/2}$	3730
M I	3s	827.2[b]
M II	$3p_{1/2}$	703.2[b]
M III	$3p_{3/2}$	665.3[b]
M IV	$3d_{3/2}$	451.4[b]
M V	$3d_{5/2}$	443.9[b]
N I	4s	122.9[b]
N II	$4p_{1/2}$	73.5[b,c]
N III	$4p_{3/2}$	73.5[b,c]
N IV	$4d_{3/2}$	17.7[b]
N V	$4d_{5/2}$	16.9[b]

Iodine (53)

K	1s	33169
L I	2s	5188
L II	$2p_{1/2}$	4852
L III	$2p_{3/2}$	4557
M I	3s	1072[a]
M II	$3p_{1/2}$	931[a]
M III	$3p_{3/2}$	875[a]
M IV	$3d_{3/2}$	631[a]
M V	$3d_{5/2}$	620[a]
N I	4s	186[a]
N II	$4p_{1/2}$	123[a]
N III	$4p_{3/2}$	123[a]
N IV	$4d_{3/2}$	50[a]
N V	$4d_{5/2}$	50[a]

Iridium (77)

K	1s	76111
L I	2s	13419
L II	$2p_{1/2}$	12824
L III	$2p_{3/2}$	11215
M I	3s	3174
M II	$3p_{1/2}$	2909
M III	$3p_{3/2}$	2551
M IV	$3d_{3/2}$	2116
M V	$3d_{5/2}$	2040
N I	4s	691.1[b]
N II	$4p_{1/2}$	577.8[b]
N III	$4p_{3/2}$	495.8[b]
N IV	$4d_{3/2}$	311.9[b]
N V	$4d_{5/2}$	296.3[b]
N VI	$4f_{5/2}$	63.8[b]
N VII	$4f_{7/2}$	60.8[b]
O I	52	95.2[a,d]
O II	$5p_{1/2}$	63.0[a,d]
O III	$5p_{3/2}$	48.0[b]

Iron (26)

K	1s	7112
L I	2s	844.6[b]
L II	$2p_{1/2}$	719.9[b]
L III	$2p_{3/2}$	706.8[b]
M I	3s	91.3[b]
M II	$3p_{1/2}$	52.7[b]
M III	$3p_{3/2}$	52.7[b]

Krypton (36)

K	1s	14326
L I	2s	1921
L II	$2p_{1/2}$	1730.9[a]
L III	$2p_{3/2}$	1678.4[a]
M I	3s	292.8[a]
M II	$3p_{1/2}$	222.2[a]
M III	$3p_{3/2}$	214.4[a]
M IV	$3d_{3/2}$	95.0[a]
M V	$3d_{5/2}$	93.8[a]
N I	4s	27.5[a]
N II	$4p_{1/2}$	14.1[a]
N III	$4p_{3/2}$	14.1[a]

Lanthanum (57)

K	1s	38925
L I	2s	6266
L II	$2p_{1/2}$	5891
L III	$2p_{3/2}$	5483
M I	3s	1362[a,d]
M II	$3p_{1/2}$	1209[a,d]
M III	$3p_{3/2}$	1128[a,d]
M IV	$3d_{3/2}$	853[a]
M V	$3d_{5/2}$	836[a]
N I	4s	247.7[a]
N II	$4p_{1/2}$	205.8
N III	$4p_{3/2}$	196.0[a]
N IV	$4d_{3/2}$	105.3[a]
N V	$4d_{5/2}$	102.5[a]
N VI	$4f_{5/2}$	—
N VII	$4f_{7/2}$	—
O I	5s	34.3[a]
O II	$5p_{1/2}$	19.3[a]
O III	$5p_{3/2}$	16.8[a]

Lead (82)

K	1s	88005
L I	2s	15861
L II	$2p_{1/2}$	15200
L III	$2p_{3/2}$	13055
M I	3s	3851
M II	$3p_{1/2}$	3554
M III	$3p_{3/2}$	3066
M IV	$3d_{3/2}$	2586
M V	$3d_{5/2}$	2484
N I	4s	891.8[b]
N II	$4p_{1/2}$	761.9[b]
N III	$4p_{3/2}$	643.5[b]
N IV	$4d_{3/2}$	434.3[b]
N V	$4d_{5/2}$	412.2[b]
N VI	$4f_{5/2}$	141.7[b]
N VII	$4f_{7/2}$	136.9[b]
O I	5s	147[a,d]
O II	$5p_{1/2}$	106.4[b]
O III	$5p_{3/2}$	83.3[b]
O IV	$5d_{3/2}$	20.7[b]
O V	$5d_{5/2}$	18.1[b]

Lithium (3)

K	1s	54.7[a]

Lutetium

K	1s	63314
L I	2s	10870
L II	$2p_{1/2}$	10349
L III	$2p_{3/2}$	9244
M I	3s	2491
M II	$3p_{1/2}$	2264
M III	$3p_{3/2}$	2024
M IV	$3d_{3/2}$	1639
M V	$3d_{5/2}$	1589
N I	4s	506.8[a]
N II	$4p_{1/2}$	412.4[a]
N III	$4p_{3/2}$	359.2[a]
N IV	$4d_{3/2}$	206.1[a]
N V	$4d_{5/2}$	196.3[a]
N VI	$4f_{5/2}$	8.9[a]
N VII	$4f_{7/2}$	7.5[a]
O I	5s	57.3[a]
O II	$5p_{1/2}$	33.6[a]
O III	$5p_{3/2}$	26.7[a]

Magnesium (12)

K	1s	1303.0[b]
L I	2s	88.6[a]
L II	$2p_{1/2}$	49.6[b]
L III	$2p_{3/2}$	49.2[a]

Manganese (25)

K	1s	6539
L I	2s	769.1[b]
L II	$2p_{1/2}$	649.9[b]
L III	$2p_{3/2}$	638.7[b]
M I	3s	82.3[b]
M II	$3p_{1/2}$	47.2[b]
M III	$3p_{3/2}$	47.2[b]

Mercury (80)

K	1s	83102
L I	2s	14839
L II	$2p_{1/2}$	14209
L III	$2p_{3/2}$	12284
M I	3s	3562
M II	$3p_{1/2}$	3279
M III	$3p_{3/2}$	2847
M IV	$3d_{3/2}$	2385
M V	$3d_{5/2}$	2295
N I	4s	802.2[b]
N II	$4p_{1/2}$	680.2[b]
N III	$4p_{3/2}$	576.6[b]
N IV	$4d_{3/2}$	378.2[b]
N V	$4d_{5/2}$	358.8[b]
N VI	$4f_{5/2}$	104.0[b]
N VII	$4f_{7/2}$	99.9[b]
O I	5s	127[b]
O II	$5p_{3/2}$	83.1[b]
O III	$5p_{3/2}$	64.5[b]
O IV	$5d_{3/2}$	9.6[b]
O V	$5d_{5/2}$	7.8[b]

Molybdenum (42)

K	1s	20000
L I	2s	2866
L II	$2p_{1/2}$	2625
L III	$2p_{3/2}$	2520
M I	3s	506.3[b]
M II	$3p_{1/2}$	411.6[b]
M III	$3p_{3/2}$	394.0[b]
M IV	$3d_{3/2}$	231.1[b]
M V	$3d_{5/2}$	227.9[b]
N I	4s	63.2[b]
N II	$4p_{1/2}$	37.6[b]
N III	$4p_{3/2}$	35.5[b]

Neodymium (60)

K	1s	43569
L I	2s	7126
L II	$2p_{1/2}$	6722
L III	$2p_{3/2}$	6208
M I	3s	1575
M II	$3p_{1/2}$	1403
M III	$3p_{3/2}$	1297
M IV	$3d_{3/2}$	1003.3[a]
M V	$3d_{5/2}$	980.4[a]
N I	4s	319.2[a]
N II	$4p_{1/2}$	243.3
N III	$4p_{3/2}$	224.6
N IV	$4d_{3/2}$	120.5[a]

N V	$4d_{5/2}$	120.5[a]
N VI	$4f_{5/2}$	1.5
N VII	$4f_{7/2}$	1.5
O I	5s	37.5
O II	$5p_{1/2}$	21.1
O III	$5p_{3/2}$	21.1

Neon (10)

K	1s	870.2[a]
L I	2s	48.5[a]
L II	$2p_{1/2}$	21.7[a]
L III	$2p_{3/2}$	21.6[a]

Nickel (28)

K	1s	8333
L I	2s	1008.6[b]
L II	$2p_{1/2}$	870.0[b]
L III	$2p_{3/2}$	852.7[b]
M I	3s	110.8[b]
M II	$3p_{1/2}$	68.0[b]
M III	$3p_{3/2}$	66.2[b]

Niobium (41)

K	1s	18986
L I	2s	2698
L II	$2p_{1/2}$	2465
L III	$2p_{3/2}$	2371
M I	3s	466.6[b]
M II	$3p_{1/2}$	376.1[b]
M III	$3p_{3/2}$	360.6[b]
M IV	$3d_{3/2}$	205.0[b]
M V	$3d_{5/2}$	202.3[b]
N I	4s	56.4[b]
N II	$4p_{1/2}$	32.6[b]
N III	$4p_{3/2}$	30.8[b]

Nitrogen (7)

K	1s	409.9[a]
L I	2s	37.3[a]

Osmium (76)

K	1s	73871
L I	2s	12968
L II	$2p_{1/2}$	12385
L III	$2p_{3/2}$	10871
M I	3s	3049
M II	$3p_{1/2}$	2792
M III	$3p_{3/2}$	2457
M IV	$3d_{3/2}$	2031
M V	$3d_{5/2}$	1960
N I	4s	658.2[b]
N II	$4p_{1/2}$	549.1[b]
N III	$4p_{3/2}$	470.7[b]
N IV	$4d_{3/2}$	293.1[b]
N V	$4d_{5/2}$	278.5[b]
N VI	$4f_{5/2}$	53.4[b]
N VII	$4f_{7/2}$	50.7[b]
O I	5s	84[a]
O II	$5p_{1/2}$	58[a]
O III	$5p_{3/2}$	44.5[b]

Oxygen (8)

K	1s	543.1[a]
L I	2s	41.6[a]

Palladium (46)

K	1s	24350
L I	2s	3604
L II	$2p_{1/2}$	3330
L III	$2p_{3/2}$	3173
M I	3s	671.6[b]
M II	$3p_{1/2}$	559.9[b]
M III	$3p_{3/2}$	532.3[b]
M IV	$3d_{3/2}$	340.5[b]
M V	$3d_{5/2}$	335.2[b]
N I	4s	87.1[a,d]
N II	$4p_{1/2}$	55.7[b,c]
N III	$4p_{3/2}$	50.9[b,c]

Phosphorus (15)

K	1s	2145.5
L I	2s	189[a]
L II	$2p_{1/2}$	136[a]
L III	$2p_{3/2}$	135[a]

Platinum (78)

K	1s	78395
L I	2s	13880
L II	$2p_{1/2}$	13273
L III	$2p_{3/2}$	11564
M I	3s	3296
M II	$3p_{1/2}$	3027
M III	$3p_{3/2}$	2645
M IV	$3d_{3/2}$	2202
M V	$3d_{5/2}$	2122
N I	4s	725.4[b]
N II	$4p_{1/2}$	609.1[b]
N III	$4p_{3/2}$	519.4[b]
N IV	$4d_{3/2}$	331.6[b]
N V	$4d_{5/2}$	314.6[b]
N VI	$4f_{5/2}$	74.5[b]
N VII	$4f_{7/2}$	71.2[b]
O I	5s	101.7[a,d]
O II	$5p_{1/2}$	65.3[a,b]
O III	$5p_{3/2}$	51.7[b]

Polonium (84)

K	1s	93105
L I	2s	16939
L II	$2p_{1/2}$	16244
L III	$2p_{3/2}$	13814
M I	3s	4149
M II	$3p_{1/2}$	3854
M III	$3p_{3/2}$	3302
M IV	$3d_{3/2}$	2798
M V	$3d_{5/2}$	2683
N I	4s	995[a]
N II	$4p_{1/2}$	851[a]
N III	$4p_{3/2}$	705[a]
N IV	$4d_{3/2}$	500[a]
N V	$4d_{5/2}$	473[a]
N VI	$4f_{5/2}$	184[a]
N VII	$4f_{7/2}$	184[a]
O I	5s	177[a]
O II	$5p_{1/2}$	132[a]
O III	$5p_{3/2}$	104[a]
O IV	$5d_{3/2}$	31[a]
O V	$5d_{5/2}$	31[a]

Potassium (19)

K	1s	3608.4[a]
L I	2s	378.6[a]
L II	$2p_{1/2}$	297.3[a]
L III	$2p_{3/2}$	294.6[a]
M I	3s	34.8[a]
M II	$3p_{1/2}$	18.3[a]
M III	$3p_{3/2}$	18.3[a]

Praseodymium (59)

K	1s	41991
L I	2s	6835
L II	$2p_{1/2}$	6440
L III	$2p_{3/2}$	5964
M I	3s	1511
M II	$3p_{1/2}$	1337
M III	$3p_{3/2}$	1242
M IV	$3d_{3/2}$	948.3[a]
M V	$3d_{5/2}$	928.8[a]
N I	4s	304.5
N II	$4p_{1/2}$	236.3
N III	$4p_{3/2}$	217.6
N IV	$4d_{3/2}$	115.1[a]
N V	$4d_{5/2}$	115.1[a]
N VI	$4f_{5/2}$	2.0
N VII	$4f_{7/2}$	2.0
O I	5s	37.4
O II	$5p_{1/2}$	22.3
O III	$5p_{3/2}$	22.3

Promethium (61)

K	1s	45184
L I	2s	7428
L II	$2p_{1/2}$	7013
L III	$2p_{3/2}$	6459
M I	3s	—
M II	$3p_{1/2}$	1471.4
M III	$3p_{3/2}$	1357
M IV	$3d_{3/2}$	1052
M V	$3d_{5/2}$	1027
N I	4s	—
N II	$4p_{1/2}$	242
N III	$4p_{3/2}$	242
N IV	$4d_{3/2}$	120
N V	$4d_{5/2}$	120

Protactinium (91)

K	1s	112601
L I	2s	21105
L II	$2p_{1/2}$	20314
L III	$2p_{3/2}$	16733
M I	3s	5367
M II	$3p_{1/2}$	5001
M III	$3p_{3/2}$	4174
M IV	$3d_{3/2}$	3611
M V	$3d_{5/2}$	3442
N I	4s	1387[a]
N II	$4p_{1/2}$	1224[a]
N III	$4p_{3/2}$	1007[a]
N IV	$4d_{3/2}$	743[a]
N V	$4d_{5/2}$	708[a]
N VI	$4f_{5/2}$	371[a]
N VII	$4f_{7/2}$	360[a]
O I	5s	310[a]
O II	$5p_{1/2}$	232[a]
O III	$5p_{3/2}$	232[a]
O IV	$5d_{3/2}$	94[a]
O V	$5d_{5/2}$	94[a]
P I	6s	—
P II	$6p_{1/2}$	—
P III	$6p_{3/2}$	—

Radium (88)

K	1s	103922
L I	2s	19237
L II	$2p_{1/2}$	18484
L III	$2p_{3/2}$	15444
M I	3s	4822
M II	$3p_{1/2}$	4490
M III	$3p_{3/2}$	3792
M IV	$3d_{3/2}$	3248
M V	$3d_{5/2}$	3105
N I	4s	1208[a]
N II	$4p_{1/2}$	1058
N III	$4p_{3/2}$	879[a]
N IV	$4d_{3/2}$	636[a]
N V	$4d_{5/2}$	603[a]
N VI	$4f_{5/2}$	299[a]
N VII	$4f_{7/2}$	299[a]
O I	5s	254[a]
O II	$5p_{1/2}$	200[a]
O III	$5p_{3/2}$	153[a]
O IV	$5d_{3/2}$	68[a]
O V	$5d_{5/2}$	68[a]
P I	6s	44
P II	$6p_{1/2}$	19
P III	$6p_{3/2}$	19

Radon (86)

K	1s	98404
L I	2s	18049
L II	$2p_{1/2}$	17337
L III	$2p_{3/2}$	14619
M I	3s	4482
M II	$3p_{1/2}$	4159
M III	$3p_{3/2}$	3538
M IV	$3d_{3/2}$	3022
M V	$3d_{5/2}$	2892

N I	4s	1097[a]
N II	$4p_{1/2}$	929[a]
N III	$4p_{3/2}$	768[a]
N IV	$4d_{3/2}$	567[a]
N V	$4d_{5/2}$	541[a]
N VI	$4f_{5/2}$	238[a]
N VII	$4f_{7/2}$	238[a]
O I	5s	214[a]
O II	$5p_{1/2}$	164[a]
O III	$5p_{3/2}$	127[a]
O IV	$5d_{3/2}$	48[a]
O V	$5d_{5/2}$	48[a]
P I	6s	26

Rhenium (75)

K	1s	71676
L I	2s	12527
L II	$2p_{1/2}$	11959
L III	$2p_{3/2}$	10535
M I	3s	2932
M II	$3p_{1/2}$	2682
M III	$3p_{3/2}$	2367
M IV	$3d_{3/2}$	1949
M V	$3d_{5/2}$	1883
N I	4s	625.4[b]
N II	$4p_{1/2}$	518.7[b]
N III	$4p_{3/2}$	446.8[b]
N IV	$4d_{3/2}$	273.9[b]
N V	$4d_{5/2}$	260.5[b]
N VI	$4f_{5/2}$	42.9[a]
N VII	$4f_{7/2}$	40.5[a]
O I	5s	83[b]
O II	$5p_{1/2}$	45.6[b]
O III	$5p_{3/2}$	34.6[a,d]

Rhodium (45)

K	1s	23220
L I	2s	3412
L II	$2p_{1/2}$	3146
L III	$2p_{3/2}$	3004
M I	3s	628.1[b]
M II	$3p_{1/2}$	521.3[b]
M III	$3p_{3/2}$	496.5[b]
M IV	$3d_{3/2}$	311.9[b]
M V	$3d_{5/2}$	307.2[b]
N I	4s	81.4[a,d]
N II	$4p_{1/2}$	50.5[b]
N III	$4p_{3/2}$	47.3[b]

Rubidium (37)

K	1s	15200
L I	2s	2065
L II	$2p_{1/2}$	1864
L III	$2p_{3/2}$	1804
M I	3s	326.7[a]
M II	$3p_{1/2}$	248.7[a]
M III	$3p_{3/2}$	239.1[a]
M IV	$3d_{3/2}$	113.0[a]
M V	$3d_{5/2}$	112[a]
N I	4s	30.5[a]
N II	$4p_{1/2}$	16.3[a]
N III	$4p_{3/2}$	15.3[a]

Ruthenium (44)

K	1s	22117
L I	2s	3224
L II	$2p_{1/2}$	2967
L III	$2p_{3/2}$	2838
M I	3s	586.2[b]
M II	$3p_{1/2}$	483.3[b]
M III	$3p_{3/2}$	461.5[b]
M IV	$3d_{3/2}$	284.2[b]
M V	$3d_{5/2}$	280.0[b]
N I	4s	75.0[b]
N II	$4p_{1/2}$	46.5[b]
N III	$4p_{3/2}$	43.2[b]

Samarium (62)

K	1s	46834
L I	2s	7737
L II	$2p_{1/2}$	7312
L III	$2p_{3/2}$	6716
M I	3s	1723
M II	$3p_{1/2}$	1541
M III	$3p_{3/2}$	1419.8
M IV	$3d_{3/2}$	1110.9[a]
M V	$3d_{5/2}$	1083.4[a]
N I	4s	347.2[a]
N II	$4p_{1/2}$	265.6
N III	$4p_{3/2}$	247.4
N IV	$4d_{3/2}$	129.0
N V	$4d_{5/2}$	129.0
N VI	$4f_{5/2}$	5.2
N VII	$4f_{7/2}$	5.2
O I	5s	37.4
O II	$5p_{1/2}$	21.3
O III	$5p_{3/2}$	21.3

Scandium (21)

K	1s	4492
L I	2s	498.0[a]
L II	$2p_{1/2}$	403.6[a]
L III	$2p_{3/2}$	389.7[a]
M I	3s	51.1[a]
M II	$3p_{1/2}$	28.3[a]
M III	$3p_{3/2}$	28.3[a]

Selenium (34)

K	1s	12658
L I	2s	1652.0[a,d]
L II	$2p_{1/2}$	1474.3[a,d]
L III	$2p_{3/2}$	1433.9[a,d]
M I	3s	229.6[a]
M II	$3p_{1/2}$	166.5[a]
M III	$3p_{3/2}$	160.7[a]
M IV	$3d_{3/2}$	55.5[a]
M V	$3d_{5/2}$	54.6[a]

Silicon (14)

K	1s	1839
L I	2s	149.7[a,d]
L II	$2p_{1/2}$	99.8[a]
L III	$2p_{3/2}$	99.2[a]

Silver (47)

K	1s	25514
L I	2s	3806
L II	$2p_{1/2}$	3524
L III	$2p_{3/2}$	3351
M I	3s	719.0[b]
M II	$3p_{1/2}$	603.8[b]
M III	$3p_{3/2}$	573.0[b]
M IV	$3d_{3/2}$	374.0[b]
M V	$3d_{5/2}$	368.0[b]
N I	4s	97.0[b]
N II	$4p_{1/2}$	63.7[b]
N III	$4p_{3/2}$	58.3[b]

Sodium (11)

K	1s	1070.8[b]
L I	2s	63.5[b]
L II	$2p_{1/2}$	30.4[b]
L III	$2p_{3/2}$	30.5[a]

Strontium (38)

K	1s	16105
L I	2s	2216
L II	$2p_{1/2}$	2007
L III	$2p_{3/2}$	1940
M I	3s	358.7[b]
M II	$3p_{1/2}$	280.3[b]
M III	$3p_{3/2}$	270.0[b]
M IV	$3d_{3/2}$	136.0[b]
M V	$3d_{5/2}$	134.2[b]
N I	4s	38.9[b]
N II	$4p_{1/2}$	21.6[b]
N III	$4p_{3/2}$	20.1[b]

Sulfur (16)

K	1s	2472
L I	2s	230.9[a,d]
L II	$2p_{1/2}$	163.6[a]
L III	$2p_{3/2}$	162.5[a]

Tantalum (73)

K	1s	67416
L I	2s	11682
L II	$2p_{1/2}$	11136
L III	$2p_{3/2}$	9881
M I	3s	2708
M II	$3p_{1/2}$	2469
M III	$3p_{3/2}$	2194
M IV	$3d_{3/2}$	1793
M V	$3d_{5/2}$	1735
N I	4s	563.4[b]
N II	$4p_{1/2}$	463.4[b]
N III	$4p_{3/2}$	400.9[b]
N IV	$4d_{3/2}$	237.9[b]
N V	$4d_{5/2}$	226.4[b]
N VI	$4f_{5/2}$	23.5[b]
N VII	$4f_{7/2}$	21.6[b]
O I	5s	69.7[b]
O II	$5p_{1/2}$	42.2[a]
O III	$5p_{3/2}$	32.7[b]

Technetium (43)

K	1s	21044
L I	2s	3043
L II	$2p_{1/2}$	2793
L III	$2p_{3/2}$	2677
M I	3s	586.1[a]
M II	$3p_{1/2}$	447.6[a]
M III	$3p_{3/2}$	417.7[a]
M IV	$3d_{3/2}$	257.6[a]
M V	$3d_{5/2}$	253.9[a]
N I	4s	69.5[a]
N II	$4p_{1/2}$	42.3[a]
N III	$4p_{3/2}$	39.9[a]

Tellurium (52)

K	1s	31814
L I	2s	4939
L II	$2p_{1/2}$	4612
L III	$2p_{3/2}$	4341
M I	3s	1006[b]
M II	$3p_{1/2}$	870.8[b]
M III	$3p_{3/2}$	820.0[b]
M IV	$3d_{3/2}$	583.4[b]
M V	$3d_{5/2}$	573.0[b]
N I	4s	169.4[b]
N II	$4p_{1/2}$	103.3[b,c]
N III	$4p_{3/2}$	103.3[b,c]
N IV	$4d_{3/2}$	41.9[b]
N V	$4d_{5/2}$	40.4[b]

Terbium (65)

K	1s	51996
L I	2s	8708
L II	$2p_{1/2}$	8252
L III	$2p_{3/2}$	7514
M I	3s	1968
M II	$3p_{1/2}$	1768
M III	$3p_{3/2}$	1611
M IV	$3d_{3/2}$	1267.9[a]
M V	$3d_{5/2}$	1241.1[a]
N I	4s	396.0[a]
N II	$4p_{1/2}$	322.4[a]
N III	$4p_{3/2}$	284.1[a]
N IV	$4d_{3/2}$	150.5[a]
N V	$4d_{5/2}$	150.5[a]
N VI	$4f_{5/2}$	7.7[a]
N VII	$4f_{7/2}$	2.4[a]
O I	5s	45.6[a]
O II	$5p_{1/2}$	28.7[a]
O III	$5p_{3/2}$	22.6[a]

Thallium (81)

K	1s	85530
L I	2s	15347
L II	$2p_{1/2}$	14698
L III	$2p_{3/2}$	12658
M I	3s	3704
M II	$3p_{1/2}$	3416
M III	$3p_{3/2}$	2957
M IV	$3d_{3/2}$	2485
M V	$3d_{5/2}$	2389
N I	4s	846.2[b]
N II	$4p_{1/2}$	720.5[b]
N III	$4p_{3/2}$	609.5[b]
N IV	$4d_{3/2}$	405.7[b]
N V	$4d_{5/2}$	385.0[b]
N VI	$4f_{5/2}$	122.2[b]
N VII	$4f_{7/2}$	117.8[b]
O I	5s	136[a,d]
O II	$5p_{1/2}$	94.6[b]
O III	$5p_{3/2}$	73.5[b]
O IV	$5d_{3/2}$	14.7[b]
O V	$5d_{5/2}$	12.5[b]

Thorium (90)

K	1s	109651
L I	2s	20472
L II	$2p_{1/2}$	19693
L III	$2p_{3/2}$	16300
M I	3s	5182
M II	$3p_{1/2}$	4830
M III	$3p_{3/2}$	4046
M IV	$3d_{3/2}$	3491
M V	$3d_{5/2}$	3332
N I	4s	1330[a]
N II	$4p_{1/2}$	1168[a]
N III	$4p_{3/2}$	966.4[b]
N IV	$4d_{3/2}$	712.1[b]
N V	$4d_{5/2}$	675.2[b]
N VI	$4f_{5/2}$	342.4[b]
N VII	$4f_{7/2}$	333.1[b]
O I	5s	290[a,c]
O II	$5p_{1/2}$	229[a,c]
O III	$5p_{3/2}$	182[a,c]
O IV	$5d_{3/2}$	92.5[b]
O V	$5d_{5/2}$	85.4[b]
P I	6s	41.4[b]
P II	$6p_{1/2}$	24.5[b]
P III	$6p_{3/2}$	16.6[b]

Thulium (69)

K	1s	59390
L I	2s	10116
L II	$2p_{1/2}$	9617
L III	$2p_{3/2}$	8648
M I	3s	2307
M II	$3p_{1/2}$	2090
M III	$3p_{3/2}$	1885
M IV	$3d_{3/2}$	1515
M V	$3d_{5/2}$	1468
N I	4s	470.9[a]
N II	$4p_{1/2}$	385.9[a]
N III	$4p_{3/2}$	332.6[a]
N IV	$4d_{3/2}$	175.5[a]
N V	$4d_{5/2}$	175.5[a]
N VI	$4f_{5/2}$	—
N VII	$4f_{7/2}$	4.6
O I	5s	54.7[a]
O II	$5p_{1/2}$	31.8[a]
O III	$5p_{3/2}$	25.0[a]

Tin (50)

K	1s	29200
L I	2s	4465
L II	$2p_{1/2}$	4156
L III	$2p_{3/2}$	3929
M I	3s	884.7[b]
M II	$3p_{1/2}$	756.5[b]
M III	$3p_{3/2}$	714.6[b]
M IV	$3d_{3/2}$	493.2[b]
M V	$3d_{5/2}$	484.9[b]
N I	4s	137.1[b]
N II	$4p_{1/2}$	83.6[b,c]
N III	$4p_{3/2}$	83.6[b,c]
N IV	$4d_{3/2}$	24.9[b]
N V	$4d_{5/2}$	23.9[b]

Titanium (22)

K	1s	4966
L I	2s	560.9[b]
L II	$2p_{1/2}$	460.2[b]
L III	$2p_{3/2}$	453.8[b]
M I	3s	58.7[b]
M II	$3p_{1/2}$	32.6[b]
M III	$3p_{3/2}$	32.6[b]

Tungsten (74)

K	1s	69525
L I	2s	12100
L II	$2p_{1/2}$	11544
L III	$2p_{3/2}$	10207
M I	3s	2820
M II	$3p_{1/2}$	2575
M III	$3p_{3/2}$	2281
M IV	$3d_{3/2}$	1949
M V	$3d_{5/2}$	1809
N I	4s	594.1[b]
N II	$4p_{1/2}$	490.4[b]
N III	$4p_{3/2}$	423.6[b]
N IV	$4d_{3/2}$	255.9[b]
N V	$4d_{5/2}$	243.5[b]
N VI	$4f_{5/2}$	33.6[a]
N VII	$4f_{7/2}$	31.4[b]
O I	5s	75.6[b]
O II	$5p_{1/2}$	453[a,d]
O III	$5p_{3/2}$	36.8[b]

Uranium (92)

K	1s	115606
L I	2s	21757
L II	$2p_{1/2}$	20948
L III	$2p_{3/2}$	17166
M I	3s	5548
M II	$3p_{1/2}$	5182
M III	$3p_{3/2}$	4303
M IV	$3d_{3/2}$	3728
M V	$3d_{5/2}$	3552
N I	4s	1439[a,d]
N II	$4p_{1/2}$	1271[a,d]
N III	$4p_{3/2}$	1043[b]
N IV	$4d_{3/2}$	778.3[b]
N V	$4d_{5/2}$	736.2[b]
N VI	$4f_{5/2}$	388.2[a]
N VII	$4f_{7/2}$	377.4[b]
O I	5s	321[a,c,d]
O II	$5p_{1/2}$	257[a,c,d]
O III	$5p_{3/2}$	192[a,c,d]
O IV	$5d_{3/2}$	102.8[b]
O V	$5d_{5/2}$	94.2[b]
P I	6s	43.9[b]
P II	$6p_{1/2}$	26.8[b]
P III	$6p_{3/2}$	16.8[b]

Vanadium (23)

K	1s	5465
L I	2s	626.7[b]
L II	$2p_{1/2}$	519.8[b]
L III	$2p_{3/2}$	521.1[b]
M I	3s	66.3[b]
M II	$3p_{1/2}$	37.2[b]
M III	$3p_{3/2}$	37.2[b]

Xenon (54)

K	1s	34561
L I	2s	5453
L II	$2p_{1/2}$	5107
L III	$2p_{3/2}$	4786
M I	3s	1148.7[a]
M II	$3p_{1/2}$	1002.1[a]
M III	$3p_{3/2}$	940.6[a]
M IV	$3d_{3/2}$	689.0[a]
M V	$3d_{5/2}$	676.4[a]
N I	4s	213.2[a]
N II	$4p_{1/2}$	146.7
N III	$4p_{3/2}$	145.5[a]
N IV	$4d_{3/2}$	69.5[a]
N V	$4d_{5/2}$	67.5[a]
N VI	$4f_{5/2}$	—
N VII	$4f_{7/2}$	—
O I	5s	23.3[a]
O II	$5p_{1/2}$	13.4[a]
O III	$5p_{3/2}$	12.1[a]

Ytterbium (70)

K	1s	61332
L I	2s	10486
L II	$2p_{1/2}$	9978
L III	$2p_{3/2}$	8944
M I	3s	2398
M II	$3p_{1/2}$	2173
M III	$3p_{3/2}$	1950
M IV	$3d_{3/2}$	1576
M V	$3d_{5/2}$	1528
N I	4s	480.5[a]
N II	$4p_{1/2}$	388.7[a]
N III	$4p_{3/2}$	339.7[a]
N IV	$4d_{3/2}$	191.2[a]
N V	$4d_{5/2}$	182.4[a]
N VI	$4f_{5/2}$	2.5[a]
N VII	$4f_{7/2}$	1.3[a]
O I	5s	52.0[a]
O II	$5p_{1/2}$	30.3[a]
O III	$5p_{3/2}$	24.1[a]

Yttrium (39)

K	1s	17038
L I	2s	2373
L II	$2p_{1/2}$	2156
L III	$2p_{3/2}$	2080
M I	3s	392.0[a,d]
M II	$3p_{1/2}$	310.6[a]
M III	$3p_{3/2}$	298.8[a]
M IV	$3d_{3/2}$	157.7[b]
M V	$3d_{5/2}$	155.8[b]
N I	4s	43.8[a]
N II	$4p_{1/2}$	24.4[a]
N III	$4p_{3/2}$	23.1[a]

Zinc (30)

K	1s	9659
L I	2s	1196.2[a]
L II	$2p_{1/2}$	1044.9[a]
L III	$2p_{3/2}$	1021.8[a]
M I	3s	139.8[a]
M II	$3p_{1/2}$	91.4[a]
M III	$3p_{3/2}$	88.6[a]
M IV	$3d_{3/2}$	10.2[a]
M V	$3d_{5/2}$	10.1[a]

Zirconium (40)

K	1s	17998
L I	2s	2532
L II	$2p_{1/2}$	2307
L III	$2p_{3/2}$	2223
M I	3s	430.3[b]
M II	$3p_{1/2}$	343.5[b]
M III	$3p_{3/2}$	329.8[b]
M IV	$3d_{3/2}$	181.1[b]
M V	$3d_{5/2}$	178.8[b]
N I	4s	50.6[b]
N II	$4p_{1/2}$	28.5[b]
N III	$4p_{3/2}$	27.1[b]

[a] Reference 1.
[b] Reference 2 (remaining values from Reference 3).
[c] One-particle approximation not valid.
[d] Derived using energy differences from Reference 3.

NATURAL WIDTH OF X-RAY LINES

Natural widths of K X-ray lines in eV:

Element	$K\alpha_1$	$K\alpha_2$	$K\beta_1$	$K\beta_3$	Element	$K\alpha_1$	$K\alpha_2$	$K\beta_1$	$K\beta_3$
Ca	1.00	0.98			Ce	18.60	19.50	20.60	18.60
Ti	1.45	2.13			Nd	21.50	21.50	23.25	21.33
Cr	2.05	2.64			Sm	26.00	24.70	25.65	24.65
Fe	2.45	3.20			Gd	29.50	28.00	29.37	28.00
Ni	3.00	3.70			Dy	33.90	32.20	32.73	32.00
Zn	3.40	3.96			Er	35.00	35.50	36.20	35.70
Ge	3.75	4.18			Yb	38.80	40.60	41.43	41.15
Se	4.10	4.43			Hf	42.70	44.30	46.00	46.10
Kr	4.23	4.62			W	46.80	48.00	51.83	51.50
Sr	5.17	4.97			Os	49.00	49.40	55.90	55.95
Zr	5.70	5.25			Pt	54.10	54.30	59.98	62.13
Mo	6.82	6.80			Hg	64.75	68.20	65.75	68.95
Ru	7.41	7.96			Pb	67.10	72.30	72.20	73.80
Pd	8.80	9.20			Po	73.20	75.10	78.60	80.10
Cd	9.80	10.40			Rn	80.00	81.50	85.50	86.50
Sn	11.20	12.40	11.80	11.00	Ra	87.00	88.20	94.20	95.50
Te	12.80	14.20	13.30	13.10	Th	94.70	95.00	99.70	101.00
Xe	14.20	15.10	15.30	14.50	U	103.00	104.30	105.00	107.30
Ba	16.10	16.80	18.15	16.70					

From Salem, S. I. and Lee, P. L., *At. Data Nucl. Data Tables,* 18, 233, 1976.

Natural widths of L X-ray lines in eV:

Element	$L\alpha_1$	$L\alpha_2$	$L\beta_1$	$L\beta_2$	$L\beta_3$	$L\beta_4$	$L\gamma_1$
Zr	1.68	1.52	1.87	5.13	5.50	5.60	3.34
Mo	1.86	1.80	2.03	5.30	5.90	5.78	3.76
Ru	2.03	1.98	2.18	5.45	6.35	5.96	4.15
Pd	2.21	2.16	2.36	5.63	6.80	6.18	4.50
Gd	2.43	2.40	2.54	5.82	7.23	6.28	4.83
Sn	2.62	2.62	2.75	6.10	7.70	6.60	5.23
Tc	2.88	2.88	2.96	6.25	8.22	6.82	5.60
Xe	3.15	3.15	3.20	6.43	8.70	7.15	5.95
Ba	3.39	3.45	3.45	6.70	9.20	7.42	6.35
Ce	3.70	3.78	3.73	6.86	9.70	7.82	6.75
Nd	3.93	4.08	4.00	7.18	10.30	8.15	7.16
Sm	4.13	4.50	4.33	7.42	10.80	8.60	7.50
Cd	4.46	4.90	4.63	7.70	11.20	9.08	7.83
Dy	4.81	5.35	5.03	7.90	11.50	9.60	8.30
Er	5.17	5.73	5.45	8.28	11.85	10.03	8.75
Yb	5.40	6.22	5.90	8.58	12.20	11.00	9.20
Hf	5.83	6.70	6.36	8.92	12.40	12.80	9.63
W	6.50	7.20	6.90	9.06	13.10	14.60	10.20
Os	7.04	7.70	7.42	9.60	14.60	16.50	10.65
Pt	7.60	8.28	8.00	9.95	16.10	18.00	11.20
Hg	8.10	8.80	8.70	10.40	17.40	19.70	11.80
Pb	8.82	9.35	9.35	10.75	18.65	21.30	12.30
Po	9.50	9.95	10.10	11.25	19.90	22.70	13.05
Rn	10.03	10.50	10.65	11.65	21.00	24.00	13.55
Ra	11.00	11.20	11.60	12.20	22.00	25.20	14.30
Th	11.90	11.80	12.40	12.80	22.85	26.35	15.00
U	12.40	12.40	13.50	13.30	23.70	27.50	15.70
Pu	13.20	13.00	14.10	13.90	24.10	28.30	16.40
Cm	14.80	13.60	15.70	14.60	25.00	29.40	17.10

PHOTON ATTENUATION COEFFICIENTS

Martin J. Berger and John H. Hubbell

This table gives mass attenuation coefficients for photons for all elements at energies between 1 keV (soft x-rays) and 1 GeV (hard gamma rays). The mass attenuation coefficient μ describes the attenuation of radiation as it passes through matter by the relation

$$I(x)/I_o = e^{-\mu\rho x}$$

where I_o is the initial intensity, $I(x)$ the intensity after path length x, and ρ is the mass density of the element in question. To a high approximation the mass attenuation coefficient is additive for the elements present, independent of the way in which they are bound in chemical compounds.

The power of ten is indicated beside each number in the table; i.e., 7.41 + 03 means 7.41×10^3. A vertical line between two columns indicates that an absorption edge lies between those energy values. The various edges are labeled at the bottom of the table.

The attenuation coefficients were calculated with the computer program XCOM (Reference 1), which uses a cross-section database compiled at the Photon and Charged Particle Data Center at the National Institute of Standards and Technology. Their accuracy has been confirmed at all energies by extensive comparisons with experimental attenuation coefficients. Such comparisons for X-ray energies up to 100 keV can be found in Reference 2.

REFERENCES

1. Berger, M. J. and Hubbell, J. H., National Bureau of Standards Report NBSIR-87-3597, 1987.
2. Saloman, E. B., Hubbell, J. H., and Scofield, J. H., *Atomic Data and Nuclear Data Tables*, 38, 1, 1988.

PHOTON ATTENUATION COEFFICIENTS (continued)

Mass attenuation coefficient, cm²/g

	Atomic no.	Photon energy, MeV 0.001	0.002	0.005	0.01	0.02	0.05	0.1	0.2	0.5
H	1	7.21 + 00	1.06 + 00	4.19-01	3.85-01	3.69-01	3.36-01	2.94-01	2.43-01	1.73-01
He	2	6.08 + 01	6.86 + 00	5.77-01	2.48-01	1.96-01	1.70-01	1.49-01	1.22-01	8.71-02
Li	3	2.34 + 02	2.71 + 01	1.62 + 00	3.40-01	1.86-01	1.49-01	1.29-01	1.06-01	7.53-02
Be	4	6.04 + 02	7.47 + 01	4.37 + 00	6.47-01	2.25-01	1.55-01	1.33-01	1.09-01	7.74-02
B	5	1.23 + 03	1.60 + 02	9.68 + 00	1.25 + 00	3.01-01	1.66-01	1.39-01	1.14-01	8.07-02
C	6	2.21 + 03	3.03 + 02	1.91 + 01	2.37 + 00	4.42-01	1.87-01	1.51-01	1.23-01	8.72-02
N	7	3.31 + 03	4.77 + 02	3.14 + 01	3.88 + 00	6.18-01	1.98-01	1.53-01	1.23-01	8.72-02
O	8	4.59 + 03	6.95 + 02	4.79 + 01	5.95 + 00	8.65-01	2.13-01	1.55-01	1.24-01	8.73-02
F	9	5.65 + 03	9.05 + 02	6.51 + 01	8.21 + 00	1.13 + 00	2.21-01	1.50-01	1.18-01	8.27-02
Ne	10	7.41 + 03	1.24 + 03	9.34 + 01	1.20 + 01	1.61 + 00	2.58-01	1.60-01	1.24-01	8.66-02
Na	11	6.54 + 02	1.52 + 03	1.19 + 02	1.56 + 01	2.06 + 00	2.80-01	1.59-01	1.20-01	8.37-02
Mg	12	9.22 + 02	1.93 + 03	1.58 + 02	2.11 + 01	2.76 + 00	3.29-01	1.69-01	1.24-01	8.65-02
Al	13	1.19 + 03	2.26 + 03	1.93 + 02	2.62 + 01	3.44 + 00	3.68-01	1.70-01	1.22-01	8.44-02
Si	14	1.57 + 03	2.78 + 03	2.45 + 02	3.39 + 01	4.46 + 00	4.38-01	1.84-01	1.28-01	8.75-02
P	15	1.91 + 03	3.02 + 02	2.86 + 02	4.04 + 01	5.35 + 00	4.92-01	1.87-01	1.25-01	8.51-02
S	16	2.43 + 03	3.85 + 02	3.49 + 02	5.01 + 01	6.71 + 00	5.85-01	2.02-01	1.30-01	8.78-02
Cl	17	2.83 + 03	4.52 + 02	3.90 + 02	5.73 + 01	7.74 + 00	6.48-01	2.05-01	1.27-01	8.45-02
Ar	18	3.18 + 03	5.12 + 02	4.23 + 02	6.32 + 01	8.63 + 00	7.01-01	2.04-01	1.20-01	7.96-02
K	19	4.06 + 03	6.59 + 02	5.19 + 02	7.91 + 01	1.09 + 01	8.68-01	2.34-01	1.32-01	8.60-02
Ca	20	4.87 + 03	8.00 + 02	6.03 + 02	9.34 + 01	1.31 + 01	1.02 + 00	2.57-01	1.38-01	8.85-02
Sc	21	5.24 + 03	8.70 + 02	6.31 + 02	9.95 + 01	1.41 + 01	1.09 + 00	2.58-01	1.31-01	8.31-02
Ti	22	5.87 + 03	9.86 + 02	6.84 + 02	1.11 + 02	1.59 + 01	1.21 + 00	2.72-01	1.31-01	8.19-02
V	23	6.50 + 03	1.11 + 03	9.29 + 01	1.22 + 02	1.77 + 01	1.35 + 00	2.88-01	1.32-01	8.07-02
Cr	24	7.40 + 03	1.28 + 03	1.08 + 02	1.39 + 02	2.04 + 01	1.55 + 00	3.17-01	1.38-01	8.28-02
Mn	25	8.09 + 03	1.42 + 03	1.21 + 02	1.51 + 02	2.25 + 01	1.71 + 00	3.37-01	1.39-01	8.19-02
Fe	26	9.09 + 03	1.63 + 03	1.40 + 02	1.71 + 02	2.57 + 01	1.96 + 00	3.72-01	1.46-01	8.41-02
Co	27	9.80 + 03	1.78 + 03	1.54 + 02	1.84 + 02	2.80 + 01	2.14 + 00	3.95-01	1.48-01	8.32-02
Ni	28	9.86 + 03	2.05 + 03	1.79 + 02	2.09 + 02	3.22 + 01	2.47 + 00	4.44-01	1.58-01	8.70-02
Cu	29	1.06 + 04	2.15 + 03	1.90 + 02	2.16 + 02	3.38 + 01	2.61 + 00	4.58-01	1.56-01	8.36-02
Zn	30	1.55 + 03	2.37 + 03	2.12 + 02	2.33 + 02	3.72 + 01	2.89 + 00	4.97-01	1.62-01	8.45-02
Ga	31	1.70 + 03	2.52 + 03	2.27 + 02	3.42 + 01	3.93 + 01	3.08 + 00	5.20-01	1.62-01	8.24-02
Ge	32	1.89 + 03	2.71 + 03	2.47 + 02	3.74 + 01	4.22 + 01	3.34 + 00	5.55-01	1.66-01	8.21-02
As	33	2.12 + 03	2.93 + 03	2.71 + 02	4.12 + 01	4.56 + 01	3.63 + 00	5.97-01	1.72-01	8.26-02
Se	34	2.32 + 03	3.10 + 03	2.90 + 02	4.41 + 01	4.82 + 01	3.86 + 00	6.28-01	1.74-01	8.13-02
Br	35	2.62 + 03	3.41 + 03	3.21 + 02	4.91 + 01	5.27 + 01	4.26 + 00	6.86-01	1.84-01	8.33-02
Kr	36	2.85 + 03	3.60 + 03	3.43 + 02	5.26 + 01	5.55 + 01	4.52 + 00	7.22-01	1.87-01	8.23-02
Rb	37	3.17 + 03	3.41 + 03	3.74 + 02	5.77 + 01	5.98 + 01	4.92 + 00	7.80-01	1.96-01	8.36-02
Sr	38	3.49 + 03	2.59 + 03	4.06 + 02	6.27 + 01	6.39 + 01	5.31 + 00	8.37-01	2.04-01	8.44-02
Y	39	3.86 + 03	7.42 + 02	4.42 + 02	6.87 + 01	6.86 + 01	5.76 + 00	9.05-01	2.15-01	8.61-02
Zr	40	4.21 + 03	8.12 + 02	4.76 + 02	7.42 + 01	7.24 + 01	6.17 + 00	9.66-01	2.24-01	8.69-02
Nb	41	4.60 + 03	8.89 + 02	5.13 + 02	8.04 + 01	7.71 + 01	6.64 + 00	1.04 + 00	2.34-01	8.83-02
Mo	42	4.94 + 03	9.60 + 02	5.45 + 02	8.58 + 01	1.31 + 01	7.04 + 00	1.10 + 00	2.42-01	8.85-02
Tc	43	5.36 + 03	1.04 + 03	5.84 + 02	9.23 + 01	1.41 + 01	7.52 + 00	1.17 + 00	2.53-01	8.97-02
Ru	44	5.72 + 03	1.12 + 03	6.17 + 02	9.80 + 01	1.50 + 01	7.92 + 00	1.23 + 00	2.62-01	8.99-02
Rh	45	6.17 + 03	1.21 + 03	6.59 + 02	1.05 + 02	1.61 + 01	8.45 + 00	1.31 + 00	2.74-01	9.13-02
Pd	46	6.54 + 03	1.29 + 03	6.91 + 02	1.11 + 02	1.70 + 01	8.85 + 00	1.38 + 00	2.83-01	9.13-02
Ag	47	7.04 + 03	1.40 + 03	7.39 + 02	1.19 + 02	1.84 + 01	9.45 + 00	1.47 + 00	2.97-01	9.32-02
Cd	48	7.35 + 03	1.47 + 03	7.69 + 02	1.24 + 02	1.92 + 01	9.78 + 00	1.52 + 00	3.04-01	9.25-02
In	49	7.81 + 03	1.58 + 03	8.13 + 02	1.32 + 02	2.04 + 01	1.03 + 01	1.61 + 00	3.17-01	9.37-02
Sn	50	8.16 + 03	1.66 + 03	8.47 + 02	1.38 + 02	2.15 + 01	1.07 + 01	1.68 + 00	3.26-01	9.37-02

L_3 L_1 L_2 K EDGE

PHOTON ATTENUATION COEFFICIENTS (continued)

Mass attenuation coefficient, cm²/g

		Photon energy, MeV								
	Atomic no.	1.0	2.0	5.0	10.0	20.0	50.0	100.0	500.0	1000.0
H	1	1.26-01	8.77-02	5.05-02	3.25-02	2.15-02	1.42-02	1.19-02	1.14-02	1.16-02
He	2	6.36-02	4.42-02	2.58-02	1.70-02	1.18-02	8.61-03	7.78-03	7.79-03	7.95-03
Li	3	5.50-02	3.83-02	2.26-02	1.53-02	1.11-02	8.68-03	8.21-03	8.61-03	8.87-03
Be	4	5.65-02	3.94-02	2.35-02	1.63-02	1.23-02	1.02-02	9.94-03	1.08-02	1.12-02
B	5	5.89-02	4.11-02	2.48-02	1.76-02	1.37-02	1.19-02	1.19-02	1.32-02	1.37-02
C	6	6.36-02	4.44-02	2.71-02	1.96-02	1.58-02	1.43-02	1.46-02	1.64-02	1.70-02
N	7	6.36-02	4.45-02	2.74-02	2.02-02	1.67-02	1.57-02	1.63-02	1.85-02	1.92-02
O	8	6.37-02	4.46-02	2.78-02	2.09-02	1.77-02	1.71-02	1.79-02	2.06-02	2.13-02
F	9	6.04-02	4.23-02	2.66-02	2.04-02	1.77-02	1.75-02	1.86-02	2.14-02	2.21-02
Ne	10	6.32-02	4.43-02	2.82-02	2.20-02	1.95-02	1.96-02	2.11-02	2.43-02	2.51-02
Na	11	6.10-02	4.28-02	2.75-02	2.18-02	1.97-02	2.03-02	2.19-02	2.53-02	2.62-02
Mg	12	6.30-02	4.43-02	2.87-02	2.31-02	2.13-02	2.23-02	2.42-02	2.81-02	2.90-02
Al	13	6.15-02	4.32-02	2.84-02	2.32-02	2.17-02	2.31-02	2.52-02	2.93-02	3.03-02
Si	14	6.36-02	4.48-02	2.97-02	2.46-02	2.34-02	2.52-02	2.76-02	3.23-02	3.34-02
P	15	6.18-02	4.36-02	2.91-02	2.45-02	2.36-02	2.58-02	2.84-02	3.33-02	3.45-02
S	16	6.37-02	4.50-02	3.04-02	2.59-02	2.53-02	2.79-02	3.08-02	3.62-02	3.75-02
Cl	17	6.13-02	4.33-02	2.95-02	2.55-02	2.52-02	2.81-02	3.11-02	3.67-02	3.80-02
Ar	18	5.76-02	4.07-02	2.80-02	2.45-02	2.45-02	2.76-02	3.07-02	3.62-02	3.75-02
K	19	6.22-02	4.40-02	3.05-02	2.70-02	2.74-02	3.11-02	3.46-02	4.09-02	4.24-02
Ca	20	6.39-02	4.52-02	3.17-02	2.84-02	2.90-02	3.32-02	3.71-02	4.40-02	4.56-02
Sc	21	5.98-02	4.24-02	3.00-02	2.72-02	2.80-02	3.23-02	3.62-02	4.30-02	4.45-02
Ti	22	5.89-02	4.18-02	2.98-02	2.73-02	2.84-02	3.30-02	3.71-02	4.40-02	4.56-02
V	23	5.79-02	4.11-02	2.96-02	2.74-02	2.88-02	3.36-02	3.78-02	4.49-02	4.65-02
Cr	24	5.93-02	4.21-02	3.06-02	2.86-02	3.03-02	3.56-02	4.01-02	4.76-02	4.93-02
Mn	25	5.85-02	4.16-02	3.04-02	2.87-02	3.07-02	3.63-02	4.09-02	4.86-02	5.04-02
Fe	26	5.99-02	4.26-02	3.15-02	2.99-02	3.22-02	3.83-02	4.33-02	5.15-02	5.33-02
Co	27	5.91-02	4.20-02	3.13-02	3.00-02	3.26-02	3.88-02	4.40-02	5.23-02	5.41-02
Ni	28	6.16-02	4.39-02	3.29-02	3.18-02	3.48-02	4.17-02	4.73-02	5.61-02	5.81-02
Cu	29	5.90-02	4.20-02	3.18-02	3.10-02	3.41-02	4.10-02	4.66-02	5.53-02	5.72-02
Zn	30	5.94-02	4.24-02	3.22-02	3.18-02	3.51-02	4.24-02	4.82-02	5.72-02	5.91-02
Ga	31	5.77-02	4.11-02	3.16-02	3.13-02	3.48-02	4.22-02	4.80-02	5.70-02	5.89-02
Ge	32	5.73-02	4.09-02	3.16-02	3.16-02	3.53-02	4.30-02	4.89-02	5.80-02	6.00-02
As	33	5.73-02	4.09-02	3.19-02	3.21-02	3.60-02	4.40-02	5.01-02	5.95-02	6.15-02
Se	34	5.62-02	4.01-02	3.14-02	3.19-02	3.60-02	4.41-02	5.03-02	5.97-02	6.17-02
Br	35	5.73-02	4.09-02	3.23-02	3.29-02	3.74-02	4.60-02	5.24-02	6.22-02	6.43-02
Kr	36	5.63-02	4.02-02	3.20-02	3.28-02	3.74-02	4.61-02	5.26-02	6.25-02	6.46-02
Rb	37	5.69-02	4.06-02	3.25-02	3.36-02	3.85-02	4.75-02	5.43-02	6.45-02	6.67-02
Sr	38	5.71-02	4.08-02	3.29-02	3.41-02	3.93-02	4.87-02	5.56-02	6.61-02	6.83-02
Y	39	5.80-02	4.14-02	3.35-02	3.50-02	4.05-02	5.03-02	5.75-02	6.83-02	7.06-02
Zr	40	5.81-02	4.15-02	3.38-02	3.55-02	4.12-02	5.13-02	5.87-02	6.98-02	7.22-02
Nb	41	5.87-02	4.18-02	3.44-02	3.63-02	4.22-02	5.27-02	6.03-02	7.17-02	7.42-02
Mo	42	5.84-02	4.16-02	3.44-02	3.65-02	4.26-02	5.33-02	6.10-02	7.26-02	7.51-02
Tc	43	5.88-02	4.19-02	3.48-02	3.71-02	4.35-02	5.45-02	6.24-02	7.43-02	7.68-02
Ru	44	5.85-02	4.16-02	3.48-02	3.73-02	4.39-02	5.50-02	6.30-02	7.51-02	7.77-02
Rh	45	5.89-02	4.20-02	3.53-02	3.80-02	4.48-02	5.63-02	6.45-02	7.69-02	7.94-02
Pd	46	5.85-02	4.16-02	3.52-02	3.80-02	4.50-02	5.66-02	6.49-02	7.73-02	8.00-02
Ag	47	5.92-02	4.21-02	3.58-02	3.88-02	4.61-02	5.81-02	6.67-02	7.93-02	8.20-02
Cd	48	5.83-02	4.14-02	3.54-02	3.85-02	4.59-02	5.79-02	6.64-02	7.91-02	8.18-02
In	49	5.85-02	4.15-02	3.56-02	3.90-02	4.65-02	5.88-02	6.75-02	8.04-02	8.32-02
Sn	50	5.80-02	4.11-02	3.55-02	3.90-02	4.66-02	5.90-02	6.78-02	8.07-02	8.35-02

Mass attenuation coefficients, cm²/g

Photon energy, MeV

	Atomic no.	0.001	0.002	0.005	0.01	0.02	0.05	0.1	0.2	0.5
Sb	51	8.58 + 03	1.77 + 03	8.85 + 02	1.46 + 02	2.27 + 01	1.12 + 01	1.76 + 00	3.38-01	9.45-02
Te	52	8.43 + 03	1.83 + 03	9.01 + 02	1.50 + 02	2.34 + 01	1.14 + 01	1.80 + 00	3.43-01	9.33-02
I	53	9.10 + 03	2.00 + 03	8.43 + 02	1.63 + 02	2.54 + 01	1.23 + 01	1.94 + 00	3.66-01	9.70-02
Xe	54	9.41 + 03	2.09 + 03	6.39 + 02	1.69 + 02	2.65 + 01	1.27 + 01	2.01 + 00	3.76-01	9.70-02
Cs	55	9.37 + 03	2.23 + 03	2.30 + 02	1.79 + 02	2.82 + 01	1.34 + 01	2.12 + 00	3.94-01	9.91-02
ZB	56	8.54 + 03	2.32 + 03	2.41 + 02	1.86 + 02	2.94 + 01	1.38 + 01	2.20 + 00	4.05-01	9.92-02
La	57	9.09 + 03	2.46 + 03	2.58 + 02	1.97 + 02	3.12 + 01	1.45 + 01	2.32 + 00	4.24-01	1.01-01
Ce	58	9.71 + 03	2.61 + 03	2.74 + 02	2.08 + 02	3.31 + 01	1.52 + 01	2.45 + 00	4.45-01	1.04-01
Pr	59	1.06 + 04	2.77 + 03	2.92 + 02	2.21 + 02	3.53 + 01	1.60 + 01	2.59 + 00	4.69-01	1.07-01
Nd	60	6.63 + 03	2.88 + 03	3.06 + 02	2.30 + 02	3.68 + 01	1.65 + 01	2.69 + 00	4.84-01	1.08-01
Pm	61	2.06 + 03	3.05 + 03	3.26 + 02	2.44 + 02	3.92 + 01	1.73 + 01	2.84 + 00	5.10-01	1.12-01
Sm	62	2.11 + 03	3.12 + 03	3.36 + 02	2.50 + 02	4.03 + 01	1.77 + 01	2.90 + 00	5.19-01	1.11-01
Eu	63	2.22 + 03	3.28 + 03	3.54 + 02	2.63 + 02	4.24 + 01	1.85 + 01	3.04 + 00	5.43-01	1.14-01
Gd	64	2.29 + 03	3.36 + 03	3.65 + 02	2.69 + 02	4.36 + 01	3.86 + 00	3.11 + 00	5.54-01	1.14-01
Tb	65	2.40 + 03	3.51 + 03	3.84 + 02	2.82 + 02	4.59 + 01	4.06 + 00	3.25 + 00	5.77-01	1.17-01
Dy	66	2.49 + 03	3.47 + 03	3.99 + 02	2.90 + 02	4.76 + 01	4.23 + 00	3.36 + 00	5.95-01	1.18-01
Ho	67	2.62 + 03	3.59 + 03	4.17 + 02	3.01 + 02	4.98 + 01	4.43 + 00	3.49 + 00	6.18-01	1.20-01
Er	68	2.75 + 03	3.52 + 03	4.36 + 02	3.13 + 02	5.20 + 01	4.63 + 00	3.63 + 00	6.41-01	1.23-01
Tm	69	2.90 + 03	3.69 + 03	4.57 + 02	2.83 + 02	5.45 + 01	4.87 + 00	3.78 + 00	6.68-01	1.26-01
Yb	70	3.02 + 03	3.80 + 03	4.72 + 02	2.94 + 02	5.63 + 01	5.04 + 00	3.88 + 00	6.86-01	1.27-01
Lu	71	3.19 + 03	3.45 + 03	4.94 + 02	2.21 + 02	5.88 + 01	5.28 + 00	4.03 + 00	7.13-01	1.30-01
Hf	72	3.34 + 03	3.60 + 03	5.11 + 02	2.30 + 02	6.09 + 01	5.48 + 00	4.15 + 00	7.34-01	1.32-01
Ta	73	3.51 + 03	3.77 + 03	5.33 + 02	2.38 + 02	6.33 + 01	5.72 + 00	4.30 + 00	7.60-01	1.35-01
W	74	3.68 + 03	3.92 + 03	5.53 + 02	9.69 + 01	6.57 + 01	5.95 + 00	4.44 + 00	7.84-01	1.38-01
Re	75	3.87 + 03	3.77 + 03	5.76 + 02	1.01 + 02	6.84 + 01	6.21 + 00	4.59 + 00	8.12-01	1.41-01
Os	76	4.03 + 03	2.22 + 03	5.93 + 02	1.04 + 02	7.04 + 01	6.41 + 00	4.70 + 00	8.33-01	1.43-01
Ir	77	4.24 + 03	1.03 + 03	6.18 + 02	1.09 + 02	7.32 + 01	6.69 + 00	4.86 + 00	8.63-01	1.46-01
Pt	78	4.43 + 03	1.08 + 03	6.40 + 02	1.13 + 02	7.57 + 01	6.95 + 00	4.99 + 00	8.90-01	1.49-01
Au	79	4.65 + 03	1.14 + 03	6.66 + 02	1.18 + 02	7.88 + 01	7.26 + 00	5.16 + 00	9.22-01	1.53-01
Hg	80	4.83 + 03	1.18 + 03	6.87 + 02	1.22 + 02	8.12 + 01	7.50 + 00	5.28 + 00	9.46-01	1.56-01
Tl	81	5.01 + 03	1.23 + 03	7.07 + 02	1.26 + 02	8.36 + 01	7.75 + 00	5.40 + 00	9.69-01	1.58-01
Pb	82	5.21 + 03	1.29 + 03	7.30 + 02	1.31 + 02	8.64 + 01	8.04 + 00	5.55 + 00	9.99-01	1.61-01
Bi	83	5.44 + 03	1.35 + 03	7.58 + 02	1.36 + 02	8.95 + 01	8.38 + 00	5.74 + 00	1.03 + 00	1.66-01
Po	84	5.72 + 03	1.42 + 03	7.93 + 02	1.43 + 02	9.35 + 01	8.80 + 00	5.99 + 00	1.08 + 00	1.71-01
At	85	5.87 + 03	1.49 + 03	8.25 + 02	1.49 + 02	9.70 + 01	9.19 + 00	6.17 + 00	1.12 + 00	1.77-01
Rn	86	5.83 + 03	1.49 + 03	8.16 + 02	1.48 + 02	9.56 + 01	9.12 + 00	6.09 + 00	1.10 + 00	1.73-01
Fr	87	6.08 + 03	1.56 + 03	8.49 + 02	1.54 + 02	9.93 + 01	9.52 + 00	1.66 + 00	1.14 + 00	1.78-01
Ra	88	6.20 + 03	1.62 + 03	8.74 + 02	1.59 + 02	1.02 + 02	9.85 + 00	1.71 + 00	1.17 + 00	1.82-01
Ac	89	6.47 + 03	1.70 + 03	8.69 + 02	1.65 + 02	1.06 + 02	1.03 + 01	1.79 + 00	1.21 + 00	1.87-01
Th	90	6.61 + 03	1.74 + 03	8.88 + 02	1.69 + 02	9.37 + 01	1.05 + 01	1.83 + 00	1.23 + 00	1.90-01
Pa	91	6.53 + 03	1.83 + 03	8.76 + 02	1.77 + 02	7.03 + 01	1.10 + 01	1.92 + 00	1.29 + 00	1.97-01
U	92	6.63 + 03	1.86 + 03	8.89 + 02	1.79 + 02	7.11 + 01	1.12 + 01	1.95 + 00	1.30 + 00	1.98-01
Np	93	6.95 + 03	1.96 + 03	9.32 + 02	1.87 + 02	7.45 + 01	1.18 + 01	2.05 + 00	1.35 + 00	2.05-01
Pu	94	7.19 + 03	2.04 + 03	9.65 + 02	1.94 + 02	7.71 + 01	1.22 + 01	2.13 + 00	1.39 + 00	2.10-01
Am	95	7.37 + 03	2.10 + 03	9.90 + 02	1.98 + 02	7.93 + 01	1.25 + 01	2.19 + 00	1.42 + 00	2.14-01
Cm	96	7.54 + 03	2.15 + 03	1.02 + 03	2.03 + 02	8.14 + 01	1.28 + 01	2.25 + 00	1.44 + 00	2.18-01
Bk	97	7.84 + 03	2.25 + 03	1.06 + 03	2.10 + 02	8.39 + 01	1.34 + 01	2.35 + 00	1.50 + 00	2.25-01
Cf	98	7.89 + 03	2.31 + 03	9.27 + 02	2.15 + 02	8.58 + 01	1.37 + 01	2.41 + 00	1.52 + 00	2.29-01
Es	99	7.79 + 03	2.40 + 03	9.59 + 02	2.22 + 02	4.01 + 01	1.42 + 01	2.51 + 00	1.57 + 00	2.36-01
Fm	100	7.13 + 03	2.46 + 03	9.77 + 02	2.26 + 02	4.09 + 01	1.45 + 01	2.57 + 00	1.59 + 00	2.39-01

N_5 N_4 N_3 N_2 N_1 M_5 M_4 M_3 M_2 M_1 L_3 L_2 L_1 **K EDGE**

PHOTON ATTENUATION COEFFICIENTS (continued)

Mass attenuation coefficients, cm^2/g

		Photon Energy, MeV								
	Atomic no.	**1.0**	**2.0**	**5.0**	**10.0**	**20.0**	**50.0**	**100.0**	**500.0**	**1000.0**
Sb	51	5.80-02	4.10-02	3.56-02	3.92-02	4.70-02	5.96-02	6.85-02	8.16-02	8.44-02
Te	52	5.67-02	4.01-02	3.49-02	3.86-02	4.64-02	5.89-02	6.77-02	8.07-02	8.35-02
I	53	5.84-02	4.12-02	3.61-02	4.00-02	4.82-02	6.13-02	7.04-02	8.40-02	8.69-02
Xe	54	5.78-02	4.08-02	3.58-02	3.99-02	4.82-02	6.12-02	7.04-02	8.40-02	8.69-02
Cs	55	5.85-02	4.12-02	3.64-02	4.06-02	4.91-02	6.25-02	7.19-02	8.58-02	8.88-02
ZB	56	5.80-02	4.08-02	3.61-02	4.04-02	4.90-02	6.25-02	7.19-02	8.58-02	8.88-02
La	57	5.88-02	4.12-02	3.66-02	4.11-02	5.00-02	6.37-02	7.34-02	8.76-02	9.06-02
Ce	58	5.96-02	4.18-02	3.73-02	4.19-02	5.10-02	6.52-02	7.50-02	8.96-02	9.27-02
Pr	59	6.07-02	4.24-02	3.80-02	4.29-02	5.23-02	6.68-02	7.69-02	9.19-02	9.50-02
Nd	60	6.07-02	4.24-02	3.81-02	4.30-02	5.26-02	6.72-02	7.74-02	9.25-02	9.56-02
Pm	61	6.19-02	4.31-02	3.88-02	4.40-02	5.38-02	6.89-02	7.94-02	9.48-02	9.81-02
Sm	62	6.11-02	4.24-02	3.83-02	4.35-02	5.34-02	6.84-02	7.88-02	9.41-02	9.73-02
Eu	63	6.19-02	4.28-02	3.88-02	4.42-02	5.42-02	6.96-02	8.02-02	9.57-02	9.90-02
Gd	64	6.12-02	4.23-02	3.84-02	4.38-02	5.38-02	6.91-02	7.97-02	9.51-02	9.83-02
Tb	65	6.20-02	4.27-02	3.89-02	4.45-02	5.47-02	7.03-02	8.11-02	9.67-02	1.00-01
Dy	66	6.20-02	4.26-02	3.90-02	4.46-02	5.49-02	7.06-02	8.15-02	9.72-02	1.00-01
Ho	67	6.26-02	4.29-02	3.93-02	4.50-02	5.55-02	7.14-02	8.24-02	9.83-02	1.02-01
Er	68	6.32-02	4.32-02	3.96-02	4.55-02	5.61-02	7.23-02	8.34-02	9.95-02	1.03-01
Tm	69	6.40-02	4.36-02	4.01-02	4.61-02	5.70-02	7.35-02	8.48-02	1.01-01	1.04-01
Yb	70	6.40-02	4.35-02	4.00-02	4.61-02	5.70-02	7.35-02	8.49-02	1.01-01	1.04-01
Lu	71	6.48-02	4.39-02	4.05-02	4.66-02	5.77-02	7.45-02	8.60-02	1.02-01	1.06-01
Hf	72	6.50-02	4.39-02	4.05-02	4.68-02	5.80-02	7.48-02	8.64-02	1.03-01	1.06-01
Ta	73	6.57-02	4.41-02	4.08-02	4.72-02	5.85-02	7.56-02	8.73-02	1.04-01	1.07-01
W	74	6.62-02	4.43-02	4.10-02	4.75-02	5.89-02	7.62-02	8.80-02	1.05-01	1.08-01
Re	75	6.69-02	4.46-02	4.14-02	4.79-02	5.95-02	7.70-02	8.89-02	1.06-01	1.09-01
Os	76	6.71-02	4.46-02	4.13-02	4.79-02	5.96-02	7.71-02	8.90-02	1.06-01	1.10-01
Ir	77	6.79-02	4.50-02	4.17-02	4.84-02	6.02-02	7.80-02	9.01-02	1.07-01	1.11-01
Pt	78	6.86-02	4.52-02	4.20-02	4.87-02	6.06-02	7.86-02	9.08-02	1.08-01	1.12-01
Au	79	6.95-02	4.57-02	4.24-02	4.93-02	6.14-02	7.95-02	9.19-02	1.09-01	1.13-01
Hg	80	6.99-02	4.57-02	4.25-02	4.94-02	6.15-02	7.98-02	9.22-02	1.10-01	1.13-01
Tl	81	7.03-02	4.58-02	4.25-02	4.94-02	6.16-02	8.00-02	9.24-02	1.10-01	1.14-01
Pb	82	7.10-02	4.61-02	4.27-02	4.97-02	6.21-02	8.06-02	9.31-02	1.11-01	1.15-01
Bi	83	7.21-02	4.66-02	4.32-02	5.03-02	6.28-02	8.15-02	9.42-02	1.12-01	1.16-01
Po	84	7.39-02	4.75-02	4.40-02	5.12-02	6.40-02	8.32-02	9.61-02	1.15-01	1.18-01
At	85	7.54-02	4.82-02	4.46-02	5.20-02	6.49-02	8.44-02	9.76-02	1.16-01	1.20-01
Rn	86	7.30-02	4.65-02	4.30-02	5.01-02	6.26-02	8.14-02	9.42-02	1.12-01	1.16-01
Fr	87	7.45-02	4.72-02	4.36-02	5.08-02	6.35-02	8.26-02	9.56-02	1.14-01	1.18-01
Ra	88	7.53-02	4.75-02	4.38-02	5.10-02	6.38-02	8.31-02	9.61-02	1.15-01	1.19-01
Ac	89	7.69-02	4.82-02	4.44-02	5.17-02	6.47-02	8.43-02	9.75-02	1.16-01	1.20-01
Th	90	7.71-02	4.81-02	4.42-02	5.15-02	6.45-02	8.40-02	9.72-02	1.16-01	1.20-01
Pa	91	7.94-02	4.93-02	4.52-02	5.26-02	6.59-02	8.60-02	9.95-02	1.19-01	1.23-01
U	92	7.90-02	4.88-02	4.46-02	5.19-02	6.51-02	8.49-02	9.83-02	1.17-01	1.21-01
Np	93	8.13-02	4.99-02	4.56-02	5.30-02	6.65-02	8.68-02	1.01-01	1.20-01	1.24-01
Pu	94	8.26-02	5.05-02	4.60-02	5.34-02	6.71-02	8.76-02	1.01-01	1.21-01	1.25-01
Am	95	8.33-02	5.06-02	4.60-02	5.34-02	6.70-02	8.77-02	1.02-01	1.21-01	1.25-01
Cm	96	8.41-02	5.08-02	4.60-02	5.34-02	6.70-02	8.77-02	1.02-01	1.21-01	1.26-01
Bk	97	8.62-02	5.18-02	4.68-02	5.42-02	6.81-02	8.92-02	1.03-01	1.24-01	1.28-01
Cf	98	8.70-02	5.20-02	4.68-02	5.42-02	6.81-02	8.92-02	1.04-01	1.24-01	1.28-01
Es	99	8.89-02	5.28-02	4.74-02	5.48-02	6.89-02	9.04-02	1.05-01	1.25-01	1.29-01
Fm	100	8.94-02	5.28-02	4.72-02	5.45-02	6.86-02	9.00-02	1.05-01	1.25-01	1.29-01

CLASSIFICATION OF ELECTROMAGNETIC RADIATION

Hans Dolezalek

Basic Conversions: $c = \lambda\nu = \nu/k$; $\nu = c/\lambda = ck$; $\lambda = c/\nu = 1/k$; $k = \nu/c = 1/\lambda$

c = speed of light = 2.99792458×10^8 m/s

Frequency (ν)	Wavelength (λ)	Wave number (k)	Names of bands	Approximate photon energies
$3 \times 10^0 - 3 \times 10^1$ Hz 3 — 30 Hz	$10^8 - 10^7$ m 100 — 10 Mm	$10^{-8} - 10^{-7}$ m^{-1} 10 — 100 Gm^{-1}	ELF-(ELF 1), ITU band no. 1	
$3 \times 10^1 - 3 \times 10^2$ Hz 30 — 300 Hz	$10^7 - 10^6$ m 10 — 1 Mm	$10^{-7} - 10^{-6}$ m^{-1} 100 Gm^{-1} — 1 Mm^{-1}	SLF-(ELF 2), ITU band no. 2, megameter waves	
$3 \times 10^2 - 3 \times 10^3$ Hz 300 Hz — 3 kHz	$10^6 - 10^5$ m 1 Mm — 100 km	$10^{-6} - 10^{-5}$ m^{-1} 1 — 10 Mm^{-1}	ULF-(ELF 3), ITU band no. 3	
$3 \times 10^3 - 3 \times 10^4$ Hz 3 — 30 kHz	$10^5 - 10^4$ m 100 — 10 km	$10^{-5} - 10^{-4}$ m^{-1} 10 — 100 Mm^{-1}	VLF, ITU band no. 4, myriameter waves	
$3 \times 10^4 - 3 \times 10^5$ Hz 30 — 300 kHz	$10^4 - 10^3$ m 10 — 1 km	$10^{-4} - 10^{-3}$ m^{-1} 100 Mm^{-1} — 1 km^{-1}	LF, ITU band no. 5, kilometer waves	
$3 \times 10^5 - 3 \times 10^6$ Hz 300 kHz — 3 MHz	$10^3 - 10^2$ m 1 km — 100 m	$10^{-3} - 10^{-2}$ m^{-1} 1 — 10 km^{-1}	MF, ITU band no. 6, hectometer waves	
$3 \times 10^6 - 3 \times 10^7$ Hz 3 — 30 MHz	$10^2 - 10^1$ m 100 — 10 m	$10^{-2} - 10^{-1}$ m^{-1} 10 — 100 km^{-1}	HF, ITU band no. 7, decameter waves	
$3 \times 10^7 - 3 \times 10^8$ Hz 30 — 300 MHz	$10^1 - 10^0$ m 10 — 1 m	$10^{-1} - 10^0$ m^{-1} 100 km^{-1} — 1 m^{-1}	VHF, ITU band no. 8, meter waves	
$3 \times 10^8 - 3 \times 10^9$ Hz 300 MHz — 3 GHz	$10^0 - 10^{-1}$ m 1 m — 100 mm	$10^0 - 10^1$ m^{-1} 1 — 10 m^{-1}	UHF, ITU band no. 9, decimeter waves[a]	
$3 \times 10^9 - 3 \times 10^{10}$ Hz 3 — 30 GHz	$10^{-1} - 10^{-2}$ m 100 — 10 mm	$10^1 - 10^2$ m^{-1} 10 — 100 m^{-1}	SHF, ITU band no. 10, centimeter waves[a]	
$3 \times 10^{10} - 3 \times 10^{11}$ Hz 30 — 300 GHz	$10^{-2} - 10^{-3}$ m 10 — 1 mm	$10^2 - 10^3$ m^{-1} 100 m^{-1} — 1 mm^{-1} (1 — 10 cm^{-1})	EHF, ITU band no. 11, millimeter waves	
$3 \times 10^{11} - 3 \times 10^{12}$ Hz 300 GHz — 3 THz	$10^{-3} - 10^{-4}$ m 1 mm — 100 μm	$10^3 - 10^4$ m^{-1} 1 — 10 mm^{-1} (10 — 100 cm^{-1})	Part of micrometer waves, includes part of far or thermal infrared; ITU band no. 12	
$3 \times 10^{12} - 3 \times 10^{13}$ Hz 3 — 30 THz	$10^{-4} - 10^{-5}$ m 100 — 10 μm	$10^4 - 10^5$ m^{-1} 10 — 100 mm^{-1} (100 — 1000 cm^{-1})	Part of micrometer waves includes part of far (thermal) infrared	
$3 \times 10^{13} - 3 \times 10^{14}$ Hz 30 — 300 THz	$10^{-5} - 10^{-6}$ m 10 — 1 μm (100,000 — 10,000 Å)	$10^5 - 10^6$ m^{-1} 100 mm^{-1} — 1 μm^{-1}	Part of μm waves, part of infrared	(1.6—16) × 10^{-20} joule {0.1 — 1 eV}
$3 \times 10^{14} - 3 \times 10^{15}$ Hz 300 THz — 3 PHz	$10^{-6} - 10^{-7}$ m 1 μm — 100 nm (10,000 — 1000 Å)	$10^6 - 10^7$ m^{-1} 1 — 10 μm^{-1}	Near infrared, visible, near ultraviolet	(1.6—16) × 10^{-19} joule {1 — 10 eV}
$3 \times 10^{15} - 3 \times 10^{16}$ Hz 3 — 30 PHz	$10^{-7} - 10^{-8}$ m 100 — 10 nm (1000 — 100 Å)	$10^7 - 10^8$ m^{-1} 10 — 100 μm^{-1}	Part of "vacuum" - ultraviolet	(1.6—16) × 10^{-18} joule {10 — 100 eV}
$3 \times 10^{16} - 3 \times 10^{17}$ Hz 30 — 300 PHz	$10^{-8} - 10^{-9}$ m 10 — 1 nm (100 — 10 Å)	$10^8 - 10^9$ m^{-1} 100 μm^{-1} — 1 nm^{-1}	Part of soft X-rays	(1.6—16) × 10^{-17} joule {100 — 1000 eV)}
$3 \times 10^{17} - 3 \times 10^{18}$ Hz 300 PHz — 3 EHz	$10^{-9} - 10^{-10}$ m 1 nm — 100 pm (10 — 1 Å)	$10^9 - 10^{10}$ m^{-1} 1 — 10 nm^{-1}	Part of soft X-rays	(1.6—16) × 10^{-16} joule {1 — 10 keV}
$3 \times 10^{18} - 3 \times 10^{19}$ Hz 3 — 30 EHz	$10^{-10} - 10^{-11}$ m 100 — 10 pm (1 — 0.1 Å)	$10^{10} - 10^{11}$ m^{-1} 10 — 100 nm^{-1}	Hard X-rays and part of soft γ-rays	(1.6—16) × 10^{-15} joule {10 — 100 keV}
$3 \times 10^{19} - 3 \times 10^{20}$ Hz 30 — 300 EHz	$10^{-11} - 10^{-12}$ m 10 — 1 pm (0.1 — 0.01 Å)	$10^{11} - 10^{12}$ m^{-1} 100 nm^{-1} — 1 pm^{-1}	Part of soft and part of hard γ-rays (limit at 510 keV)	(1.6—16) × 10^{-14} joule {100 keV — 1 MeV}
$3 \times 10^{20} - 3 \times 10^{21}$ Hz 300 — 3000 EHz	$10^{-12} - 10^{-13}$ m 1 pm — 100 fm (0.01 — 0.001 Å)	$10^{12} - 10^{13}$ m^{-1} 1 — 10 pm^{-1}	Part of hard γ-rays and part of "cosmic" γ-rays	(1.6—16) × 10^{-13} joule {1 — 10 MeV}
$3 \times 10^{21} - 3 \times 10^{22}$ Hz 3000 — 30,000 EHz	$10^{-13} - 10^{-14}$ m 100 — 10 fm (0.001 — 0.0001 Å)	$10^{13} - 10^{14}$ m^{-1} 10 — 100 pm^{-1}	γ-rays produced by cosmic rays	(1.6—16) × 10^{-12} joule {10 — 100 MeV}

Note: Abbreviations used in this table: Å—ångstrom (1 Å = 10^{-10} m); EHz—exahertz (10^{18} hertz); EHF—extremely high frequency; ELF—extremely low frequency; eV—electron volt (1 eV = 1.60219×10^{-19} joule); PHz—petahertz (10^{15} hertz); fm—femtometer (10^{-15} m); GHz—gigahertz (10^{9} hertz); Gm—gigameter (10^{9} m); HF—high frequency; Hz—hertz (s^{-1}); ITU—International Telecommunications Union; keV—kiloelectron volt (10^{3} eV); km—kilometer (10^{3} m); LF—low frequency; m—meter; MeV—megaelectron volt (10^{6} eV); MF—medium frequency; MHz—megahertz (10^{6} hertz); Mm—megameter (10^{6} meter); mm—millimeter (10^{-3} meter); μm—micrometer (10^{-6} meter); nm—nanometer (10^{-9} meter); pm—picometer (10^{-12} meter); SHF—super high frequency; SLF—super low frequency; THz—terahertz; UHF—ultra high frequency; ULF—ultra low frequency; VHF—very high frequency; VLF—very low frequency.

[a] Also called "microwaves"; not to be confused with "micrometer waves".

LETTER DESIGNATIONS OF MICROWAVE BANDS

Frequency (GHz)	Wavelength (cm)	Wavenumber (cm^{-1})	Band
1—2	30—15	0.033—0.067	L-Band
1—4	15—7.5	0.067—0.133	S-Band
4—8	7.5—3.7	0.133—0.267	C-Band
8—12	3.7—2.5	0.267—0.4	X-Band
12—18	2.5—1.7	0.4—0.6	Ku-Band
18—27	1.7—1.1	0.6—0.9	K-Band
27—40	1.1—0.75	0.9—1.33	Ka-Band

BLACK BODY RADIATION

The total power radiated from an ideal black body and the wavelength corresponding to maximum power are given here as a function of absolute temperature. Constants used in the calculation are taken from the table "Fundamental Physical Constants" in Section 1. The radiated power in a band $\Delta\lambda$ at λ_{max} may be calculated from:

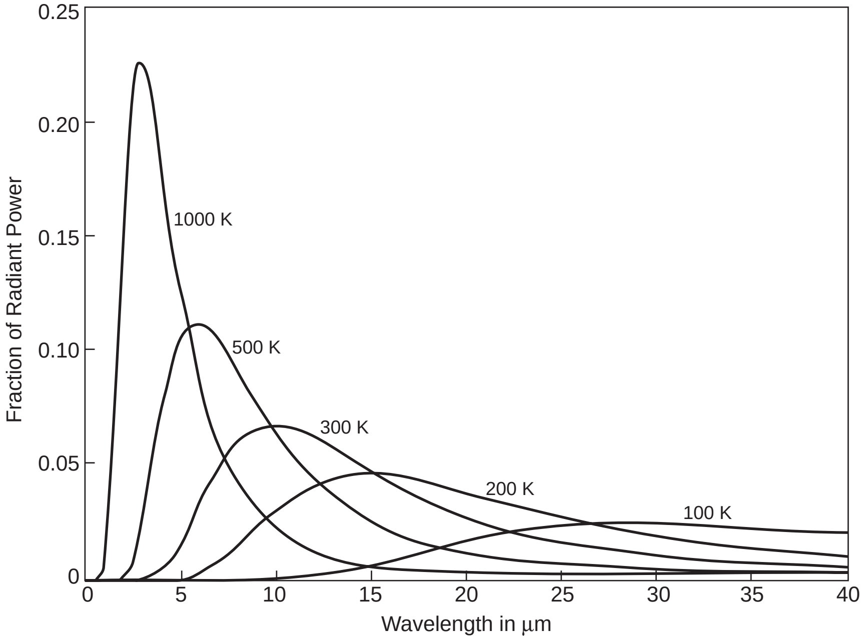
$$P_{max} = 0.657548\ (\Delta\lambda/\lambda_{max})\ P_{tot}$$

***T*/K**	***P*$_{tot}$**	**λ_{max}/μm**	***T*/K**	***P*$_{tot}$**	**λ_{max}/μm**	***T*/K**	***P*$_{tot}$**	**λ_{max}/μm**
50	0.354 W/m^2	57.955	740	17.004	3.916	1520	302.689	1.906
100	5.671	28.978	750	17.942	3.864	1540	318.937	1.882
150	28.707	19.318	760	18.918	3.813	1560	335.831	1.858
200	90.728	14.489	770	19.934	3.763	1580	353.387	1.834
250	221.504	11.591	780	20.989	3.715	1600	371.623	1.811
273	314.973	10.614	790	22.087	3.668	1620	390.555	1.789
280	348.541	10.349	800	23.226	3.622	1640	410.202	1.767
290	401.064	9.992	810	24.410	3.577	1660	430.581	1.746
300	459.311	9.659	820	25.638	3.534	1680	451.710	1.725
310	523.684	9.348	830	26.911	3.491	1700	473.607	1.705
320	594.596	9.055	840	28.232	3.450	1720	496.290	1.685
330	672.478	8.781	850	29.600	3.409	1740	519.779	1.665
340	757.771	8.523	860	31.018	3.369	1760	544.093	1.646
350	850.931	8.279	870	32.486	3.331	1780	569.249	1.628
360	952.428	8.049	880	34.006	3.293	1800	595.267	1.610
370	1.063 kW/m^2	7.832	890	35.578	3.256	1820	622.168	1.592
380	1.182	7.626	900	37.204	3.220	1840	649.970	1.575
390	1.312	7.430	910	38.886	3.184	1860	678.694	1.558
400	1.452	7.244	920	40.623	3.150	1880	708.359	1.541
410	1.602	7.068	930	42.418	3.116	1900	738.987	1.525
420	1.764	6.899	940	44.272	3.083	1920	770.597	1.509
430	1.939	6.739	950	46.187	3.050	1940	803.210	1.494
440	2.125	6.586	960	48.162	3.018	1960	836.848	1.478
450	2.325	6.439	970	50.201	2.987	1980	871.531	1.464
460	2.539	6.299	980	52.303	2.957	2000	907.282	1.449
470	2.767	6.165	990	54.471	2.927	2020	944.121	1.435
480	3.010	6.037	1000	56.705	2.898	2040	982.071	1.420
490	3.269	5.914	1020	61.379	2.841	2060	1.021 MW/m^2	1.407
500	3.544	5.796	1040	66.337	2.786	2080	1.061	1.393
510	3.836	5.682	1060	71.589	2.734	2100	1.103	1.380
520	4.146	5.573	1080	77.147	2.683	2120	1.145	1.367
530	4.474	5.467	1100	83.022	2.634	2140	1.189	1.354
540	4.822	5.366	1120	89.227	2.587	2160	1.234	1.342
550	5.189	5.269	1140	95.773	2.542	2180	1.281	1.329
560	5.577	5.175	1160	102.672	2.498	2200	1.328	1.317
570	5.986	5.084	1180	109.939	2.456	2220	1.377	1.305
580	6.417	4.996	1200	117.584	2.415	2240	1.428	1.294
590	6.871	4.911	1220	125.621	2.375	2260	1.479	1.282
600	7.349	4.830	1240	134.063	2.337	2280	1.532	1.271
610	7.851	4.750	1260	142.924	2.300	2300	1.587	1.260
620	8.379	4.674	1280	152.217	2.264	2320	1.643	1.249
630	8.933	4.600	1300	161.955	2.229	2340	1.700	1.238
640	9.514	4.528	1320	172.154	2.195	2360	1.759	1.228
650	10.122	4.458	1340	182.827	2.163	2380	1.819	1.218
660	10.760	4.391	1360	193.989	2.131	2400	1.881	1.207
670	11.427	4.325	1380	205.655	2.100	2420	1.945	1.197
680	12.124	4.261	1400	217.838	2.070	2440	2.010	1.188
690	12.853	4.200	1420	230.556	2.041	2460	2.077	1.178
700	13.615	4.140	1440	243.822	2.012	2480	2.145	1.168
710	14.410	4.081	1460	257.652	1.985	2500	2.215	1.159
720	15.239	4.025	1480	272.063	1.958	2550	2.398	1.136
730	16.103	3.970	1500	287.070	1.932	2600	2.591	1.115

BLACK BODY RADIATION (continued)

T/K	P_{tot}	λ_{max}/μm	T/K	P_{tot}	λ_{max}/μm	T/K	P_{tot}	λ_{max}/μm
2650	2.796	1.093	3600	9.524	0.805	5100	38.362	0.568
2700	3.014	1.073	3650	10.065	0.794	5200	41.461	0.557
2750	3.243	1.054	3700	10.627	0.783	5300	44.743	0.547
2800	3.485	1.035	3750	11.214	0.773	5400	48.217	0.537
2850	3.741	1.017	3800	11.824	0.763	5500	51.889	0.527
2900	4.011	0.999	3850	12.458	0.753	5600	55.767	0.517
2950	4.294	0.982	3900	13.118	0.743	5700	59.858	0.508
3000	4.593	0.966	3950	13.804	0.734	5800	64.170	0.500
3050	4.907	0.950	4000	14.517	0.724	5900	68.712	0.491
3100	5.237	0.935	4100	16.024	0.707	6000	73.490	0.483
3150	5.583	0.920	4200	17.645	0.690	6500	101.222	0.446
3200	5.946	0.906	4300	19.386	0.674	7000	136.149	0.414
3250	6.326	0.892	4400	21.254	0.659	7500	179.418	0.386
3300	6.725	0.878	4500	23.253	0.644	8000	232.264	0.362
3350	7.142	0.865	4600	25.389	0.630	8500	296.004	0.341
3400	7.578	0.852	4700	27.670	0.617	9000	372.042	0.322
3450	8.033	0.840	4800	30.101	0.604	9500	461.867	0.305
3500	8.509	0.828	4900	32.689	0.591	10000	567.051	0.290
3550	9.006	0.816	5000	35.441	0.580			

The curves below show, for various temperatures, the fraction of radiant power as a function of wavelength. The function plotted is $P_\lambda/\Delta\lambda\ P_{tot}$, where P_λ is the power at wavelength λ in a small interval Δλ (in μm), and P_{tot} is the total power.

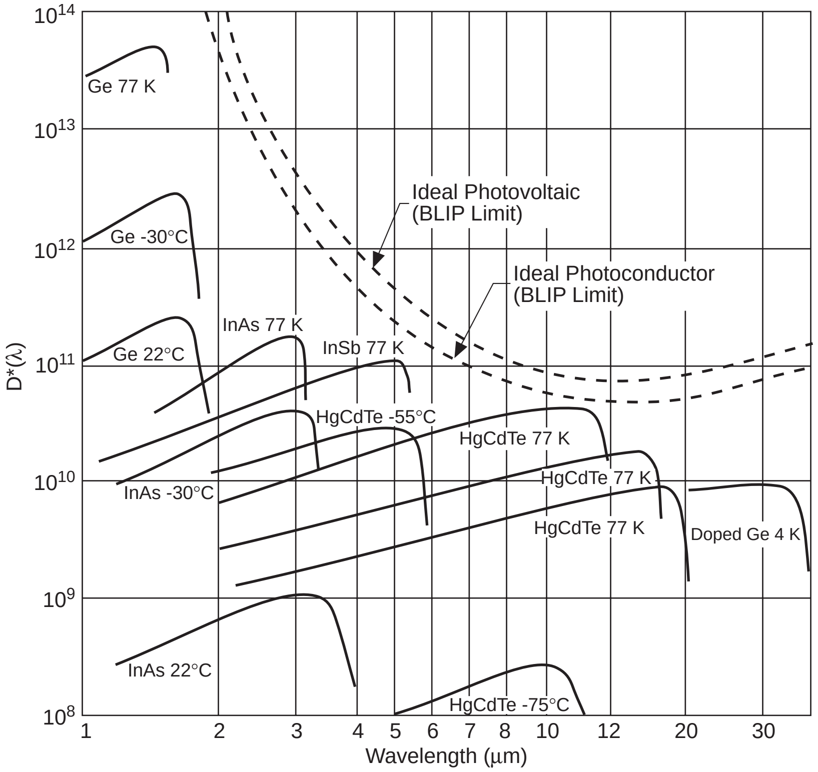


CHARACTERISTICS OF INFRARED DETECTORS

This graph summarizes the wavelength response of some semiconductors used as detectors for infrared radiation. The quantity $D^*(\lambda)$ is the signal to noise ratio for an incident radiant power density of 1 W/cm^2 and a bandwidth of 1 Hz (60° field of view). The Ge, InAs, and InSb detectors are photovoltaics, while the HgCdTe series are photoconductive devices. The cutoff wavelength of the latter can be varied by adjusting the relative amounts of Hg, Cd, and Te (three examples are shown at 77 K). The graph also shows the theoretical background limited sensitivity for ideal detectors which introduce no intrinsic noise.

REFERENCE

Infrared Detectors 1995, EG&G Judson, Montgomeryville, PA.



REFRACTIVE INDEX AND TRANSMITTANCE OF REPRESENTATIVE GLASSES

Typical values of the index of refraction and internal transmittance (fraction of light transmitted through a one centimeter thickness) are tabulated here for selected types of glasses, as well as for synthetic fused (vitreous) silica. Nominal compositions are given in the first part of the table. The second part gives the index of refraction, relative to air, and the internal transmittance for representative samples of each glass at wavelengths in the infrared, visible, and near-ultraviolet regions. It should be emphasized that wide variation of these parameters may be found among subtypes of each glass. More detailed data may be found in Reference 3.

Assuming that the Lambert-Beer Law is followed, the transmittance of a glass plate of thickness *d* (in centimeters) can be obtained by raising the transmittance value in the table to the power *d*.

REFERENCES

1. Weber, M.J., *CRC Handbook of Laser Science and Technology*, Vol. IV, Part 2, CRC Press, Boca Raton, FL ,1988.
2. Gray, D.E., Ed., *American Institute of Physics Handbook, Third Edition*, McGraw Hill, New York, 1972.
3. *Schott Optical Glass*, Schott Glass Technologies, Inc., 400 York Ave., Duryea, PA 18642.
4. Kaye, G.W.C., and Laby, T.H., *Tables of Physical and Chemical Constants, 15th Edition,* Longman, London, 1986.

		Composition in percent by mass									
Type	**Name**	**SiO_2**	**B_2O_3**	**Al_2O_3**	**Na_2O**	**K_2O**	**CaO**	**BaO**	**ZnO**	**PbO**	**P_2O_5**
PK	Phosphate crown		3	10		12	5				70
PSK	Dense phosphate crown		3	5			4	28			60
BK	Borosilicate crown	70	10		8	8	1	3			
K	Crown	74			9	11	6				
ZK	Zinc crown	71			17				12		
BaK	Barium crown	60	3		3	10		19	5		
SK	Dense crown	39	15	5				41			
KF	Crown flint	67		2	16				3	12	
BaLF	Barium light flint	51			6	5		20	14	4	
SSK	Extra dense crown	35	10	5				42	8		
LLF	Extra light flint	63			5	8				24	
BaF	Barium flint	46				8		16	8	22	
LF	Light flint	53			5	8				34	
F	Flint	47			2	7				44	
BaSF	Dense barium flint	43			1	7		11	5	33	
SF	Dense flint	33				5				62	
KzFS	Short flint										
SiO_2	Fused silica	100									

	Index of refraction				Transmittance of 1 cm plate			
Type	**1.060 μm**	**546.1 nm**	**365.0 nm**	**312.6 nm**	**1.060 μm**	**546.1 nm**	**365.0 nm**	**310 nm**
PK	1.51519	1.52736	1.54503	1.5574	0.997	0.998	0.987	0.46
PSK	1.54154	1.55440	1.57342	1.5868	0.996	0.998	0.984	0.46
BK	1.50669	1.51872	1.53627	1.5486	0.999	0.998	0.987	0.35
K	1.50091	1.51314	1.53189	1.5454	0.998	0.998	0.988	0.40
ZK	1.52220	1.53534	1.55588	1.5708	0.996	0.998	0.976	0.27
BaK	1.55695	1.57124	1.59407	1.6108	0.998	0.997	0.986	0.28
SK	1.59490	1.60994	1.63398		0.998	0.998	0.959	0.28
KF	1.50586	1.51978	1.54251	1.5600	0.998	0.996	0.989	0.49
BaLF	1.57579	1.59166	1.61804		0.996	0.998	0.933	0.010
SSK	1.60402	1.61993	1.64595		0.999	0.998	0.915	0.010
LaK	1.69710	1.71616	1.74573		0.999	0.998	0.882	0.17
LLF	1.52775	1.54344	1.57038		0.998	0.997	0.990	0.32
BaF	1.56873	1.58565	1.61524		0.999	0.997	0.992	0.004
LF	1.56594	1.58482	1.61926		0.999	0.998	0.981	0.008
F	1.58636	1.60718	1.64606		0.997	0.998	0.959	
BaSF	1.60889	1.62987	1.66926		0.999	0.998	0.857	
SF	1.71350	1.74620	1.8145		0.998	0.997	0.650	
KzFS	1.59680	1.61639	1.64849	1.6739		0.998	0.672	0.012
SiO_2	1.44968	1.46008	1.47435[a]	1.53430[b]				

[a] At 366.3 nm.
[b] At 213.9 nm.

INDEX OF REFRACTION OF WATER

This table gives the index of refraction of liquid water at atmospheric pressure, relative to a vacuum, at several temperatures and wavelengths. It is generated from the formulation in Reference 1, which covers a wide range of temperature, pressure, and wavelength.The wavelengths listed here correspond to prominent lines of cadmium (226.50 and 361.05 nm), potassium (404.41 nm), sodium (589.00 nm), Ne (632.80 nm, from a helium - neon laser), and mercury (1.01398 μm).

REFERENCES

1. Schiebener, P., Straub, J., Levelt Sengers, J.M.H., and Gallagher, J.S., *J. Phys. Chem. Ref. Data*, 19, 677 (1990); 19, 1617, 1990.
2. Marsh, K.N., Editor, *Recommended Reference Materials for the Realization of Physicochemical Properties*, Blackwell Scientific Publications, Oxford, 1987.

***T*/°C**	**226.50 nm**	**361.05 nm**	**404.41 nm**	**589.00 nm**	**632.80 nm**	**1.01398 μm**
0	1.39450	1.34896	1.34415	1.33432	1.33306	1.32612
10	1.39422	1.34870	1.34389	1.33408	1.33282	1.32591
20	1.39336	1.34795	1.34315	1.33336	1.33211	1.32524
30	1.39208	1.34682	1.34205	1.33230	1.33105	1.32424
40	1.39046	1.34540	1.34065	1.33095	1.32972	1.32296
50	1.38854	1.34373	1.33901	1.32937	1.32814	1.32145
60	1.38636	1.34184	1.33714	1.32757	1.32636	1.31974
70	1.38395	1.33974	1.33508	1.32559	1.32438	1.31784
80	1.38132	1.33746	1.33284	1.32342	1.32223	1.31576
90	1.37849	1.33501	1.33042	1.32109	1.31991	1.31353
100	1.37547	1.33239	1.32784	1.31861	1.31744	1.31114

INDEX OF REFRACTION OF LIQUIDS FOR CALIBRATION PURPOSES

This table gives the index of refraction of six liquids which are available in highly pure form and whose index of refraction has been accurately measured as a function of wavelength and temperature. They are therefore useful for calibration of refractometers. The estimated uncertainty in the values is:

2,2,4-Trimethylpentane	±0.00003
Hexadecane	±0.00008
trans-Bicyclo[4.0.0]decane	±0.00008
1-Methylnaphthalene	±0.00008
Toluene	±0.00003
Methylcyclohexane	±0.00003

Full details are given in the references. This table is reprinted from Reference 1 by permission of the International Union of Pure and Applied Chemistry.

REFERENCES

1. Marsh, K. N., Editor, *Recommended Reference Materials for the Realization of Physicochemical Properties,* Blackwell Scientific Publications, Oxford, 1987.
2. Tilton, L. W., J. *Opt. Soc. Am.*, 32, 71, 1941.

λ	**2,2,4-Trimethylpentane**			**Hexadecane**		
nm	**20°C**	**25°C**	**30°C**	**20°C**	**25°C**	**30°C**
667.81	1.38916	1.38670	1.38424	1.43204	1.43001	1.42798
656.28	1.38945	1.38698	1.38452	1.43235	1.43032	1.42829
589.26	1.39145	1.38898	1.38650	1.43453	1.43250	1.43047
546.07	1.39316	1.39068	1.38820	1.43640	1.43436	1.43232
501.57	1.39544	1.39294	1.39044	1.43888	1.43684	1.43480
486.13	1.39639	1.39389	1.39138	1.43993	1.43788	1.43583
435.83	1.40029	1.39776	1.39523	1.44419	1.44213	1.44007

λ	***trans*-Bicyclo[4.4.0]decane**			**1-Methylnaphthalene**		
nm	**20°C**	**25°C**	**30°C**	**20°C**	**25°C**	**30°C**
667.81	1.46654	1.46438	1.46222	1.60828	1.60592	1.60360
656.28	1.46688	1.46472	1.46256	1.60940	1.60703	1.60471
589.26	1.46932	1.46715	1.46498	1.61755	1.61512	1.61278
546.07	1.47141	1.46923	1.46705	1.62488	1.62240	1.62005
501.57	1.47420	1.47200	1.46980	1.63513	1.63259	1.63022
486.13	1.47535	1.47315	1.47095	1.63958	1.63701	1.63463
435.83	1.48011	1.47789	1.47567		1.65627	1.65386

λ	**Toluene**			**Methylcyclohexane**		
nm	**20°C**	**25°C**	**30°C**	**20°C**	**25°C**	**30°C**
667.81	1.49180	1.48903	1.48619	1.42064	1.41812	1.41560
656.28	1.49243	1.48966	1.48682	1.42094	1.41842	1.41591
589.26	1.49693	1.49413	1.49126	1.42312	1.42058	1.41806
546.07	1.50086	1.49803	1.49514	1.42497	1.42243	1.41989
501.57	1.50620	1.50334	1.50041	1.42744	1.42488	1.42233
486.13	1.50847	1.50559	1.50265	1.42847	1.42590	1.42334
435.83	1.51800	1.51506	1.51206	1.43269	1.43010	1.42752

INDEX OF REFRACTION OF AIR

This is a table of the index of refraction n of dry air at 15°C and a pressure of 101.325 kPa and containing 0.03% by volume of carbon dioxide (“standard air”). The index of refraction is defined by $n = \lambda_{vac} / \lambda_{air}$, where λ is the wavelength of the radiation. The index is calculated from the expression:

$$(n - 1) \times 10^8 = 8342.13 + 2406030(130 - \sigma^2)^{-1} + 15997(38.9 - \sigma^2)^{-1}$$

where $\sigma = 1/\lambda_{vac}$ and λ_{vac} has units of μm. The equation is valid for λ_{vac} from 200 nm to 2 μm.
The table also gives the correction $(n - 1)\lambda_{air}$ which must be added to the wavelength in air to obtain λ_{vac}.
If the air is at a temperature t in °C and a pressure p in pascals, a value of $(n - 1)$ from this table should be multiplied by

$$\frac{p\left[1 + p(61.3 - t) \times 10^{-10}\right]}{96095.4(1 + 0.003661t)}$$

REFERENCE

Edlen, B., *Metrologia*, 2, 71, 1966.

λ_{vac}	$(n - 1) \times 10^8$	$\lambda_{vac} - \lambda_{air}$	λ_{vac}	$(n - 1) \times 10^8$	$\lambda_{vac} - \lambda_{air}$	λ_{vac}	$(n - 1) \times 10^8$	$\lambda_{vac} - \lambda_{air}$
200 nm	32408	0.0648 nm	540	27803	0.1501	880	27461	0.2416
210	31746	0.0666	550	27782	0.1528	890	27457	0.2443
220	31224	0.0687	560	27763	0.1554	900	27452	0.2470
230	30799	0.0708	570	27745	0.1581	910	27448	0.2497
240	30445	0.0730	580	27728	0.1608	920	27444	0.2524
250	30146	0.0753	590	27712	0.1635	930	27440	0.2551
260	29890	0.0777	600	27697	0.1661	940	27436	0.2578
270	29669	0.0801	610	27682	0.1688	950	27432	0.2605
280	29475	0.0825	620	27669	0.1715	960	27429	0.2632
290	29306	0.0850	630	27656	0.1742	970	27425	0.2660
300	29155	0.0874	640	27643	0.1769	980	27422	0.2687
310	29022	0.0899	650	27631	0.1796	990 nm	27419	0.2714 nm
320	28902	0.0925	660	27620	0.1822			
330	28795	0.0950	670	27609	0.1849	1.00 μm	27416	0.000274 μm
340	28698	0.0975	680	27599	0.1876	1.05	27401	0.000288
350	28611	0.1001	690	27589	0.1903	1.10	27389	0.000301
360	28531	0.1027	700	27579	0.1930	1.15	27378	0.000315
370	28458	0.1053	710	27570	0.1957	1.20	27368	0.000328
380	28392	0.1079	720	27562	0.1984	1.25	27360	0.000342
390	28331	0.1105	730	27553	0.2011	1.30	27352	0.000355
400	28275	0.1131	740	27545	0.2038	1.35	27346	0.000369
410	28223	0.1157	750	27538	0.2065	1.40	27340	0.000383
420	28175	0.1183	760	27530	0.2092	1.45	27334	0.000396
430	28131	0.1209	770	27523	0.2119	1.50	27330	0.000410
440	28090	0.1236	780	27516	0.2146	1.55	27325	0.000423
450	28052	0.1262	790	27510	0.2173	1.60	27321	0.000437
460	28016	0.1288	800	27504	0.2200	1.65	27318	0.000451
470	27983	0.1315	810	27498	0.2227	1.70	27314	0.000464
480	27952	0.1341	820	27492	0.2254	1.75	27311	0.000478
490	27923	0.1368	830	27486	0.2281	1.80	27309	0.000491
500	27896	0.1394	840	27481	0.2308	1.85	27306	0.000505
510	27870	0.1421	850	27476	0.2335	1.90	27304	0.000519
520	27846	0.1448	860	27471	0.2362	1.95	27302	0.000532
530	27824	0.1474	870	27466	0.2389	2.00 μm	27300	0.000546 μm

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CHARACTERISTICS OF LASER SOURCES

William F. Krupke

Light Amplification by Stimulated Emission of Radiation was first demonstrated by Maiman in 1960, the result of a population inversion produced between energy levels of chromium ions in a ruby crystal when irradiated with a xenon flashlamp. Since then population inversions and coherent emission have been generated in literally thousands of substances (neutral and ionized gases, liquids, and solids) using a variety of incoherent excitation techniques (optical pumping, electrical discharges, gas-dynamic flow, electron-beams, chemical reactions, nuclear decay).

The extrema of laser output parameters which have been demonstrated to date and the laser media used are summarized in Table 1. Note that the extreme power and energy parameters listed in this table were attained with laser *systems* rather than with simple laser oscillators.

Laser sources are commonly classified in terms of the state-of-matter of the active medium: gas, liquid, and solid. Each of these classes is further subdivided into one or more types as shown in Table 2. A well-known representative example of each type of laser is also given in Table 2 together with its nominal operation wavelength and the methods by which it is pumped.

The various lasers together cover a wide spectral range from the far ultraviolet to the far infrared. The particular wavelength of emission (usually a narrow line) is presented for some six dozen lasers in Figures 1A and 1B.

By suitably designing the excitation source and/or by controlling the laser resonator structure, laser systems can provide continuous or pulsed radiation as shown in Table 3.

Besides the method of excitation and the temporal behavior of a laser, there are many other parameters that characterize its operation and efficiency, as shown in Tables 4 and 5.

Although many lasers only emit in one or more narrow spectral "lines", an increasing number of lasers can be tuned by changing the composition or the pressure of the medium, or by varying the wavelength of the pump bands. The spectral regions in which these tunable lasers operate are presented in Figure 2.

REFERENCE

Krupke, W. F., in *Handbook of Laser Science and Technology*, Vol. I, Weber, M. J., Ed., CRC Press, Boca Raton, FL, 1986.

TABLE 1
Extrema of Output Parameters of Laser Devices or Systems

Parameter	Value	Laser medium
Peak power	1×10^{14} W (collimated)	Nd:glass
Peak power density	10^{18} W/cm^2 (focused)	Nd:glass
Pulse energy	$>10^5$ J	CO_2, Nd:glass
Average power	10^5 W	CO_2
Pulse duration	3×10^{-15} s continuous wave (cw)	Rh6G dye; various gases, liquids, solids
Wavelength	60 nm $\leftrightarrow$ 385 μm	Many required
Efficiency (nonlaser pumped)	70%	CO
Beam quality	Diffraction limited	Various gases, liquids, solids
Spectral linewidth	20 Hz (for 10^{-1} s)	Neon-helium
Spatial coherence	10 m	Ruby

TABLE 2
Classes, Types, and Representative Examples of Laser Sources

Class	Type (characteristic)	Representative example	Nominal operating wavelength (nm)	Method(s) of excitation
Gas	Atom, neutral (electronic transition)	Neon-Helium (Ne-He)	633	Glow discharge
	Atom, ionic (electronic transition)	Argon (Ar^+)	488	Arc discharge
	Molecule, neutral (electronic transition)	Krypton fluoride (KrF)	248	Glow discharge; e-beam
	Molecule, neutral (vibrational transition)	Carbon dioxide (CO_2)	10600	Glow discharge; gas-dynamic flow
	Molecule, neutral (rotational transition)	Methyl fluoride (CH_3F)	496000	Laser pumping
	Molecule, ionic (electronic transition)	Nitrogen ion (N_2^+)	420	E-beam
Liquid	Organic solvent (dye-chromophore)	Rhodamine dye (Rh6G)	580–610	Flashlamp; laser pumping
	Organic solvent (rare earth chelate)	Europium:TTF	612	Flashlamp
	Inorganic solvent (trivalent rare earth ion)	Neodymium:$POCl_4$	1060	Flashlamp
Solid	Insulator, crystal (impurity)	Neodymium:YAG	1064	Flashlamp, arc lamp
	Insulator, crystal (stoichiometric)	Neodymium:UP(NdP_5O_{14})	1052	Flashlamp
	Insulator, crystal (color center)	F_2^-:LiF	1120	Laser pumping
	Insulator, amorphous (impurity)	Neodymium:glass	1061	Flashlamp
	Semiconductor (p-n junction)	GaAs	820	Injection current
	Semiconductor (electron-hole plasma)	GaAs	890	E-beam, laser pumping

Table 3
Temporal Characteristics of Lasers and Laser Systems

Form	Technique	Pulse width range (s)
Continuous wave	Excitation is continuous; resonator Q is held constant at some moderate value	∞
Pulsed	Excitation is pulsed; resonator Q is held constant at some moderate value	10^{-8}–10^{-3}
Q-Switched	Excitation is continuous or pulsed; resonator Q is switched from a very low value to a moderate value	10^{-8}–10^{-6}
Cavity dumped	Excitation is continuous or pulsed; resonator Q is switched from a very high value to a low value	10^{-7}–10^{-5}
Mode locked	Excitation is continuous or pulsed; phase or loss of the resonator modes is modulated at a rate related to the resonator transit time	10^{-12}–10^{-9}

Table 4
Properties and Performance of Some Continuous Wave (CW) Lasers

		Gas			Liquid	Solid	
Parameter	**Unit**	**Neon helium**	**Argon ion**	**Carbon dioxide**	**Rhodamine 6G dye**	**Nd:YAG**	**GaAs**
Excitation method		DC discharge	DC discharge	DC discharge	Ar^+ laser pump	Krypton arc lamp	DC injection
Gain medium composition		Neon:helium	Argon	CO_2:N_2:He	Rh 6G:H_2O	Nd:YAG	p:n:GaAs
Gain medium density	Torr	0.1:1.0	0.4	0.4:0.8:5.0			
	ions/cm^3				2(18):2(22)	1.5(20):2(22)	2(19):3(18):3(22)
Wavelength	nm	633	488	10600	590	1064	810
Laser cross-section	cm^{-2}	3(-13)	1.6(-12)	1.5(-16)	1.8(-16)	7(-19)	; 6(-15)
Radiative lifetime (upper level)	s	; 1(-7)	7.5(-9)	4(-3)	6.5(-9)	2.6(-4)	; 1(-9)
Decay lifetime (upper level)	s	; 1(-7)	; 5.0(-9)	; 4(-3)	6.0(-9)	2.3(-4)	; 1(-9)
Gain bandwidth	nm	2(-3)	5(-3)	1.6(-2)	80	0.5	10
Type, gain saturation		Inhomogeneous	Inhomogeneous	Homogeneous	Homogeneous	Homogeneous	Homogeneous
Homogeneous saturation flux	W cm^{-2}			; 20	3(5)	2.3(3)	; 2(4)
Decay lifetime (lower level)	s	; 1(-8)	; 4(-10)	; 5(-6)[b]	<1(-12)	<1(-7)	<1(-12)
Inversion density	cm^{-3}	; 1(9)	2(10)	2(15)	2(16)	6(16)	1(16)
Small signal gain coefficient	cm^{-1}	; 1(-3)	; 3(-2)	1(-2)	4	5(-2)	40
Pump power density	W cm^{-3}	3	900	0.15	1(6)	150	7(7)
Output power density	W cm^{-3}	2.6(-3)	; 1	2(-2)	3(5)	95	5(6)
Laser size (diameter:length)	cm:cm	0.5:100	0.3:100	5.0:600	1(-3):0.3	0.6:10	5(-4):7(-3);2(-2)[a]
Excitation current/voltage	A/V	3(-2):2(3)	30:300	0.1:1.5(4)		90:125	1.0/1.7
Excitation current density	A cm^{-2}	0.15	600	6(-3)		140	4.5(3)
Excitation power	W	60	9(3)	1.5(3)	4	1.1(4)	1.7
Output power	W	0.06	10	240	0.3	300	0.12
Efficiency	%	0.1	0.1	13	7	2.6	7

[a] Junction thickness:width:length.
[b] Pressure dependent.

Table 5
Properties and Performance of Some Pulsed Lasers

Parameter	Unit	Gas				Liquid	Solid	
		Carbon dixoxide		Krypton fluoride		Rhodamine 6G	Nd:YAG	Nd:glass
Excitation method		TEA-discharge	E-beam/sust.	Glow discharge	E-beam	Xenon flashlamp	Xenon flashlamp	Xenon flashlamp
Gain medium composition		CO_2:N_2:He	CO_2:N_2:He	He:Kr:F_2	Ar:Kr:F_2	Rh6G:alcohol	Nd:YAG	Nd:Glass
Gain medium density	torr	100:50:600	240:240:320	1070:70:3	1235:52:3			-
	ions/cm^3					1(18):1.5(22)	1.5(20):1(22)	3(20):2(22)
Wavelength	nm	10600	10600	249	249	590	1064	1061
Laser cross-section	cm^{-2}	2(-18)	2(-18)	2(-16)	2(-16)	1.8(-16)	7(-19)	2.8(-20)
Radiative lifetime (upper level)	s	4(-3)	4(-3)	7(-9)	7(-9)	6.5(-9)	2.6(-4)	4.1(-4)
Decay lifetime (upper level)	s	; 1(-4)	5(-5)	2(-9)	3(-9)	6.0(-9)	2.3(-4)	3.7(-4)
Gain bandwidth	nm	1	1	2	2	80	0.5	26
Homogeneous saturation fluence	J/cm^2	0.2	0.2	4(-3)	4(-3)	2(-3)	0.6	; 5
Decay lifetime (lower level)	s	5(-8)[a]	1(-8)[a]	<1(-12)	<1(-12)	<1(-12)	<1(-7)	<1(-8)
Inversion density	cm^{-3}	3(17)	6(17)	4(14)	2(14)	2(16)	4(17)	3(18)
Small signal gain coefficient	cm^{-1}	2(-2)	4(-2)	8–92)	4(-2)	4	0.3	8(-2)
Medium excitation energy density	J/cm^3	0.1	0.36	0.15	0.13	2.8	0.15	0.6
Output energy density	J/cm^3	2(-2)	1.8(-2)	1.5(-3)	1.2(-2)	0.85	5(-2)	2(-2)
Laser dimensions	cm:cm:cm	4.5:4.5:87	10:10:100	1.5:4.5:100	8.5:10:100	1.2ϕ25	0.6ϕ7.5	0.6ϕ8.3
Excitation current/voltage	A/V	6(4)/3.3(3)	2.4(4)/4(4)	2.5(4)/1.5(5)	1.2(4)/2.5(5)	2(5)/2.5(4)		
Excitation current density	A cm^2	8.5	22	170	11.5	2.6(3)		
Excitation peak power	W	2(8)	9(8)	4(9)	3(9)	5.4(9)	4(4)	9(4)
Output pulse energy	J	35	180	1	102	32	0.1	1.0
Output pulse length	s	1(-6)	4(-6)	2.5(-8)	6(-7)	3.2(-6)	2(-8)	1(-4)
Output pulse power	W	3.5(7)	4(7)	4(7)	2(8)	1(7)	5(6)	1(4)
Efficiency	%	17	5	1	10[b]	0.2	1.5	3.7

[a] Pressure dependent.

[b] Intrinsic efficiency ≡ energy output/energy deposited in gas.

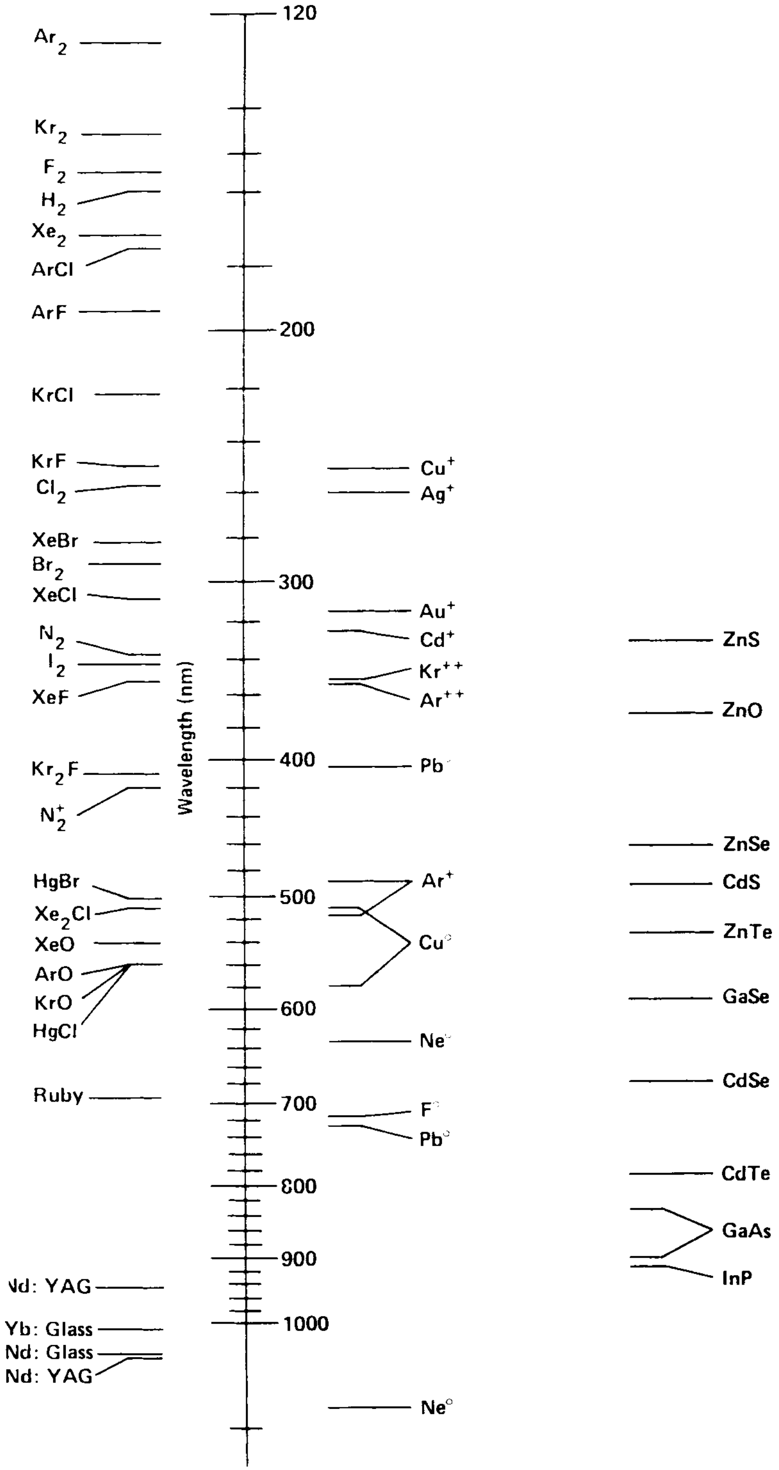

FIGURE 1A. Wavelengths of lasers operating in the 120 to 1200 nm spectral region.

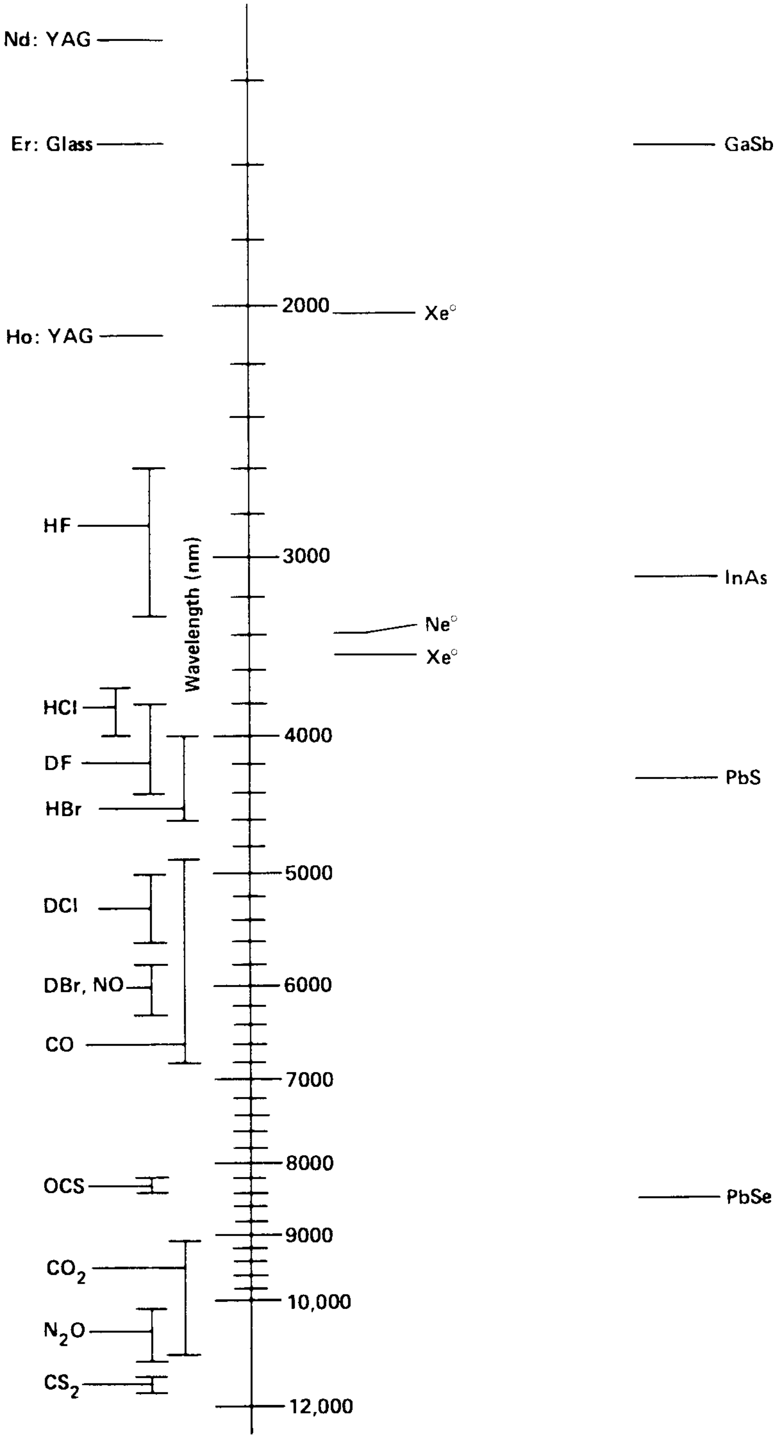

FIGURE 1B. Wavelength of lasers operating in the 1300 to 12,000 nm spectral region.

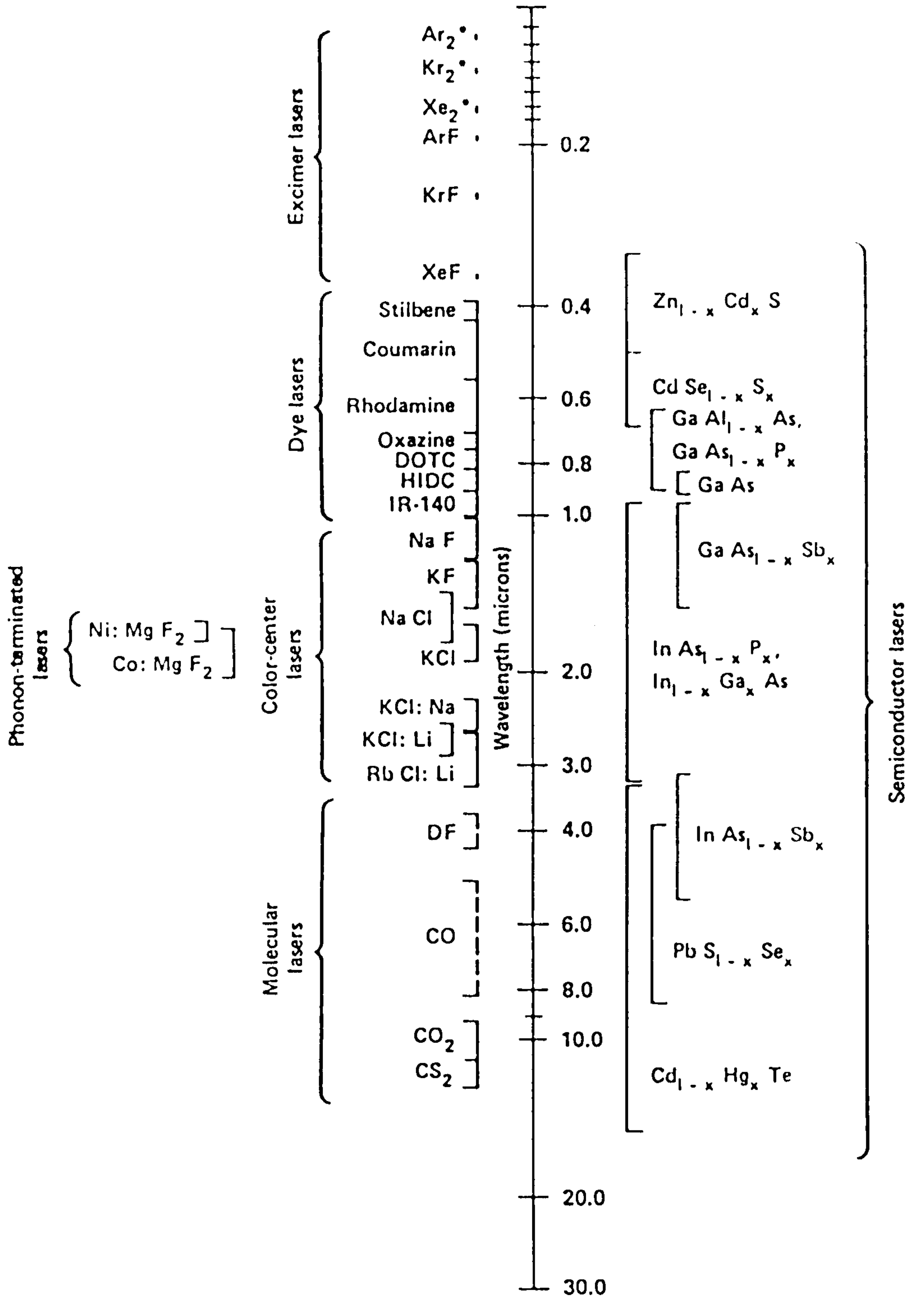

FIGURE 2. Spectral tuning ranges of various types of tunable lasers.

INFRARED LASER FREQUENCIES
Arthur Maki

The CO_2 laser has been the subject of a number of very accurate frequency measurements. Most of the earlier measurements are given by Bradley et al.[1] That analysis was based on a single absolute frequency measurement and many laser frequency differences. New measurements of the methane frequency[2-4] have made it necessary to slightly revise that single absolute frequency measurement. In addition, there have been several other absolute frequency measurements[5-7] that have been used here to improve the accuracy of the present tables. New frequency difference measurements have also been added to the database used for the present tables.[8]

REFERENCES

1. Bradley, L. C., Soohoo, K. L., and Freed, C., *IEEE J. Quantum Electron.*, QE-22, 234-267, 1986.
2. Clairon, A., Dahmani, B., Filimon, A., and Rutman, J., *IEEE Trans. Inst. Meas.*, IM-34, 265-268, 1985.
3. Weiss, C. O., Kramer, G., Lipphardt, B., and Garcia, E., *IEEE J. Quantum Electron.*, QE-24, 1970-1972, 1988.
4. Bagayev, S. N., Baklanov, A. E., Chebotayev, V. P., and Dychkov, A. S., *Appl. Phys.*, B-48, 31-35, 1989.
5. Blaney, T. G., Bradley, C. C., Edwards, G. J., Jolliffe, B. W., Knight, D. J. E., Rowley, W. R. C., Shotten, K. C., and Woods, P. T., *Proc. R. Soc. Lond.*, A-355, 61-88, 1977.
6. Chardonnet, Ch., Van Lerberghe, A., and Bordé, Ch. J., *Opt. Comm.*, 58, 333-337, 1986.
7. Clairon, A., Acef, O., Chardonnet, Ch., and Bordé, Ch. J., *Frequency Standards and Metrology*, De Marchi, A., Ed., Springer-Verlag, Berlin, Heidelberg, 1989, p. 212.
8. Evenson, K., private communication.

Frequencies for the 00°1-(10°0,02°0)$_I$ and 00°1-(10°0,02°0)$_{II}$ Bands of $^{12}C^{16}O_2$ with the Estimated 2-σ Uncertainties

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
P(70)	26721305.4647	0.1680	P(70)	29789856.3783	0.0308
P(68)	26794232.6712	0.1217	P(68)	29861850.7690	0.0192
P(66)	26866318.8073	0.0867	P(66)	29933216.1760	0.0122
P(64)	26937571.7234	0.0606	P(64)	30003944.2861	0.0086
P(62)	27007998.9216	0.0415	P(62)	30074026.9127	0.0072
P(60)	27077607.5643	0.0279	P(60)	30143456.0039	0.0066
P(58)	27146404.4834	0.0185	P(58)	30212223.6504	0.0061
P(56)	27214396.1873	0.0121	P(56)	30280322.0930	0.0055
P(54)	27281588.8696	0.0081	P(54)	30347743.7306	0.0049
P(52)	27347988.4161	0.0057	P(52)	30414481.1273	0.0044
P(50)	27413600.4119	0.0043	P(50)	30480527.0196	0.0041
P(48)	27478430.1487	0.0036	P(48)	30545874.3239	0.0039
P(46)	27542482.6310	0.0032	P(46)	30610516.1429	0.0039
P(44)	27605762.5826	0.0030	P(44)	30674445.7724	0.0039
P(42)	27668274.4525	0.0028	P(42)	30737656.7080	0.0039
P(40)	27730022.4206	0.0027	P(40)	30800142.6511	0.0039
P(38)	27791010.4036	0.0026	P(38)	30861897.5150	0.0038
P(36)	27851242.0594	0.0025	P(36)	30922915.4310	0.0037
P(34)	27910720.7927	0.0024	P(34)	30983190.7534	0.0037
P(32)	27969449.7593	0.0023	P(32)	31042718.0652	0.0037
P(30)	28027431.8708	0.0022	P(30)	31101492.1833	0.0036
P(28)	28084669.7981	0.0021	P(28)	31159508.1631	0.0037
P(26)	28141165.9762	0.0020	P(26)	31216761.3029	0.0037
P(24)	28196922.6067	0.0019	P(24)	31273247.1487	0.0037
P(22)	28251941.6622	0.0017	P(22)	31328961.4978	0.0037
P(20)	28306224.8888	0.0016	P(20)	31383900.4028	0.0037
P(18)	28359773.8090	0.0014	P(18)	31438060.1749	0.0037
P(16)	28412589.7245	0.0012	P(16)	31491437.3872	0.0036
P(14)	28464673.7184	0.0011	P(14)	31544028.8776	0.0036
P(12)	28516026.6574	0.0009	P(12)	31595831.7516	0.0036
P(10)	28566649.1935	0.0008	P(10)	31646843.3843	0.0035
P(8)	28616541.7661	0.0008	P(8)	31697061.4225	0.0035
P(6)	28665704.6027	0.0008	P(6)	31746483.7868	0.0035

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
P(4)	28714137.7205	0.0008	P(4)	31795108.6724	0.0035
P(2)	28761840.9272	0.0008	P(2)	31842934.5511	0.0035
R(0)	28832026.2198	0.0008	R(0)	31913172.5691	0.0035
R(2)	28877902.4382	0.0007	R(2)	31958996.0621	0.0034
R(4)	28923046.4303	0.0006	R(4)	32004017.3822	0.0034
R(6)	28967457.0657	0.0005	R(6)	32048236.2498	0.0034
R(8)	29011133.0054	0.0003	R(8)	32091652.6619	0.0034
R(10)	29054072.7010	0.0001	R(10)	32134266.8917	0.0034
R(12)	29096274.3935	0.0003	R(12)	32176079.4878	0.0034
R(14)	29137736.1129	0.0005	R(14)	32217091.2721	0.0035
R(16)	29178455.6759	0.0007	R(16)	32257303.3386	0.0036
R(18)	29218430.6852	0.0009	R(18)	32296717.0510	0.0037
R(20)	29257658.5269	0.0010	R(20)	32335334.0408	0.0038
R(22)	29296136.3689	0.0011	R(22)	32373156.2044	0.0039
R(24)	29333861.1583	0.0012	R(24)	32410185.7003	0.0041
R(26)	29370829.6191	0.0011	R(26)	32446424.9459	0.0042
R(28)	29407038.2491	0.0011	R(28)	32481876.6140	0.0042
R(30)	29442483.3168	0.0011	R(30)	32516543.6293	0.0042
R(32)	29477160.8582	0.0012	R(32)	32550429.1641	0.0042
R(34)	29511066.6733	0.0013	R(34)	32583536.6340	0.0042
R(36)	29544196.3221	0.0015	R(36)	32615869.6937	0.0041
R(38)	29576545.1205	0.0017	R(38)	32647432.2320	0.0040
R(40)	29608108.1360	0.0019	R(40)	32678228.3665	0.0039
R(42)	29638880.1831	0.0022	R(42)	32708262.4386	0.0038
R(44)	29668855.8183	0.0024	R(44)	32737539.0081	0.0039
R(46)	29698029.3350	0.0027	R(46)	32766062.8469	0.0041
R(48)	29726394.7582	0.0032	R(48)	32793838.9334	0.0045
R(50)	29753945.8385	0.0037	R(50)	32820872.4463	0.0055
R(52)	29780676.0464	0.0042	R(52)	32847168.7576	0.0071
R(54)	29806578.5659	0.0047	R(54)	32872733.4269	0.0099
R(56)	29831646.2878	0.0052	R(56)	32897572.1935	0.0141
R(58)	29855871.8032	0.0058	R(58)	32921690.9701	0.0202
R(60)	29879247.3960	0.0074	R(60)	32945095.8355	0.0288
R(62)	29901765.0357	0.0113	R(62)	32967793.0268	0.0407
R(64)	29923416.3695	0.0186	R(64)	32989788.9322	0.0567
R(66)	29944192.7145	0.0302	R(66)	33011090.0831	0.0780
R(68)	29964085.0488	0.0475	R(68)	33031703.1467	0.1060
R(70)	29983084.0036	0.0720	R(70)	33051634.9172	0.1423

Frequencies for the 00°1-(10°0,02°0)$_I$ and 00°1-(10°0,02°0)$_{II}$ Bands of $^{13}C^{16}O_2$ with the Estimated 2-σ Uncertainties

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
P(66)	25523832.1808	0.7836	P(66)	28512082.5283	1.2894
P(64)	25590013.4703	0.5415	P(64)	28585121.9396	0.9194
P(62)	25655543.6502	0.3629	P(62)	28657449.4180	0.6420
P(60)	25720428.2487	0.2339	P(60)	28729056.6374	0.4375
P(58)	25784672.4840	0.1430	P(58)	28799935.4147	0.2897
P(56)	25848281.2771	0.0810	P(56)	28870077.7187	0.1853
P(54)	25911259.2627	0.0405	P(54)	28939475.6771	0.1135
P(52)	25973610.8005	0.0157	P(52)	29008121.5846	0.0659
P(50)	26035339.9857	0.0045	P(50)	29076007.9109	0.0357
P(48)	26096450.6582	0.0079	P(48)	29143127.3077	0.0180
P(46)	26156946.4123	0.0101	P(46)	29209472.6164	0.0090

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
P(44)	26216830.6053	0.0101	P(44)	29275036.8754	0.0058
P(42)	26276106.3655	0.0090	P(42)	29339813.3270	0.0050
P(40)	26334776.6003	0.0077	P(40)	29403795.4243	0.0044
P(38)	26392844.0030	0.0068	P(38)	29466976.8383	0.0037
P(36)	26450311.0599	0.0063	P(36)	29529351.4635	0.0032
P(34)	26507180.0565	0.0061	P(34)	29590913.4252	0.0029
P(32)	26563453.0836	0.0060	P(32)	29651657.0844	0.0028
P(30)	26619132.0428	0.0058	P(30)	29711577.0447	0.0028
P(28)	26674218.6515	0.0055	P(28)	29770668.1566	0.0031
P(26)	26728714.4479	0.0054	P(26)	29828925.5239	0.0035
P(24)	26782620.7952	0.0054	P(24)	29886344.5074	0.0041
P(22)	26835938.8858	0.0054	P(22)	29942920.7308	0.0046
P(20)	26888669.7451	0.0055	P(20)	29998650.0838	0.0051
P(18)	26940814.2347	0.0055	P(18)	30053528.7271	0.0054
P(16)	26992373.0555	0.0055	P(16)	30107553.0955	0.0055
P(14)	27043346.7508	0.0054	P(14)	30160719.9016	0.0055
P(12)	27093735.7083	0.0052	P(12)	30213026.1388	0.0054
P(10)	27143540.1624	0.0051	P(10)	30264469.0839	0.0054
P(8)	27192760.1962	0.0049	P(8)	30315046.2994	0.0054
P(6)	27241395.7431	0.0048	P(6)	30364755.6359	0.0055
P(4)	27289446.5880	0.0047	P(4)	30413595.2335	0.0056
P(2)	27336912.3682	0.0046	P(2)	30461563.5231	0.0057
R(0)	27407012.8882	0.0045	P(0)	30531879.5415	0.0057
R(2)	27453013.4589	0.0043	P(2)	30577664.6138	0.0056
R(4)	27498426.5430	0.0040	P(4)	30622575.1885	0.0054
R(6)	27543251.1200	0.0037	P(6)	30666611.0128	0.0051
R(8)	27587486.0225	0.0034	P(8)	30709772.1257	0.0047
R(10)	27631129.9356	0.0031	P(10)	30752058.8571	0.0045
R(12)	27674181.3963	0.0029	P(12)	30793471.8269	0.0044
R(14)	27716638.7917	0.0029	P(14)	30834011.9425	0.0043
R(16)	27758500.3577	0.0029	P(16)	30873680.3976	0.0044
R(18)	27799764.1770	0.0029	P(18)	30912478.6694	0.0044
R(20)	27840428.1773	0.0030	P(20)	30950408.5159	0.0044
R(22)	27880490.1283	0.0029	P(22)	30987471.9732	0.0043
R(24)	27919947.6395	0.0029	P(24)	31023671.3517	0.0042
R(26)	27958798.1567	0.0028	P(26)	31059009.2327	0.0042
R(28)	27997038.9591	0.0028	P(28)	31093488.4642	0.0042
R(30)	28034667.1551	0.0027	P(30)	31127112.1569	0.0043
R(32)	28071679.6785	0.0027	P(32)	31159883.6793	0.0045
R(34)	28108073.2842	0.0026	P(34)	31191806.6529	0.0046
R(36)	28143844.5432	0.0026	P(36)	31222884.9469	0.0048
R(38)	28178989.8377	0.0026	P(38)	31253122.6730	0.0053
R(40)	28213505.3554	0.0028	P(40)	31282524.1795	0.0061
R(42)	28247387.0838	0.0033	P(42)	31311094.0452	0.0077
R(44)	28280630.8035	0.0046	P(44)	31338837.0736	0.0108
R(46)	28313232.0818	0.0083	P(46)	31365758.2858	0.0173
R(48)	28345186.2652	0.0161	P(48)	31391862.9147	0.0295
R(50)	28376488.4720	0.0301	P(50)	31417156.3972	0.0505
R(52)	28407133.5839	0.0531	P(52)	31441644.3679	0.0845
R(54)	28437116.2372	0.0887	P(54)	31465332.6516	0.1366
R(56)	28466430.8141	0.1419	P(56)	31488227.2557	0.2138
R(58)	28495071.4324	0.2188	P(58)	31510334.3631	0.3247
R(60)	28523031.9357	0.3271	P(60)	31531660.3243	0.4800
R(62)	28550305.8819	0.4763	P(62)	31552211.6497	0.6932
R(64)	28576886.5323	0.6781	P(64)	31571995.0017	0.9805
R(66)	28602766.8393	0.9467	P(66)	31591017.1868	1.3619

INFRARED LASER FREQUENCIES (continued)

Frequencies for the $00^{\circ}1$-$(10^{\circ}0,02^{\circ}0)_I$ and $00^{\circ}1$-$(10^{\circ}0,02^{\circ}0)_{II}$ Bands of $^{12}C^{18}O_2$ with the Estimated 2-σ Uncertainties

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
P(70)	27045326.3119	0.4540	P(70)	30695237.5856	0.0858
P(68)	27114914.0922	0.3324	P(68)	30755520.2231	0.0570
P(66)	27183635.7945	0.2392	P(66)	30815311.4928	0.0364
P(64)	27251496.4118	0.1688	P(64)	30874607.2084	0.0223
P(62)	27318500.7361	0.1165	P(62)	30933403.2309	0.0131
P(60)	27384653.3618	0.0783	P(60)	30991695.4724	0.0075
P(58)	27449958.6881	0.0510	P(58)	31049479.9009	0.0049
P(56)	27514420.9224	0.0319	P(56)	31106752.5446	0.0041
P(54)	27578044.0828	0.0191	P(54)	31163509.4964	0.0040
P(52)	27640832.0010	0.0108	P(52)	31219746.9183	0.0040
P(50)	27702788.3248	0.0059	P(50)	31275461.0455	0.0039
P(48)	27763916.5206	0.0035	P(48)	31330648.1908	0.0039
P(46)	27824219.8762	0.0028	P(46)	31385304.7490	0.0039
P(44)	27883701.5029	0.0026	P(44)	31439427.2006	0.0039
P(42)	27942364.3379	0.0025	P(42)	31493012.1163	0.0038
P(40)	28000211.1464	0.0024	P(40)	31546056.1605	0.0038
P(38)	28057244.5242	0.0022	P(38)	31598556.0954	0.0037
P(36)	28113466.8992	0.0021	P(36)	31650508.7847	0.0037
P(34)	28168880.5335	0.0020	P(34)	31701911.1970	0.0037
P(32)	28223487.5256	0.0019	P(32)	31752760.4093	0.0037
P(30)	28277289.8118	0.0017	P(30)	31803053.6105	0.0037
P(28)	28330289.1679	0.0016	P(28)	31852788.1043	0.0038
P(26)	28382487.2111	0.0015	P(26)	31901961.3125	0.0038
P(24)	28433885.4012	0.0013	P(24)	31950570.7773	0.0038
P(22)	28484485.0420	0.0012	P(22)	31998614.1649	0.0038
P(20)	28534287.2828	0.0011	P(20)	32046089.2669	0.0037
P(18)	28583293.1193	0.0010	P(18)	32092994.0036	0.0037
P(16)	28631503.3952	0.0010	P(16)	32139326.4254	0.0036
P(14)	28678918.8025	0.0009	P(14)	32185084.7154	0.0036
P(12)	28725539.8830	0.0010	P(12)	32230267.1907	0.0036
P(10)	28771367.0288	0.0010	P(10)	32274872.3041	0.0037
P(8)	28816400.4829	0.0010	P(8)	32318898.6455	0.0038
P(6)	28860640.3403	0.0011	P(6)	32362344.9434	0.0039
P(4)	28904086.5477	0.0011	P(4)	32405210.0652	0.0041
P(2)	28946738.9048	0.0011	P(2)	32447493.0185	0.0041
R(0)	29009228.1702	0.0010	P(0)	32509824.0580	0.0042
R(2)	29049894.0586	0.0010	P(2)	32550648.1723	0.0042
R(4)	29089764.2368	0.0009	P(4)	32590887.7542	0.0042
R(6)	29128837.8426	0.0008	P(6)	32630542.4457	0.0041
R(8)	29167113.8668	0.0008	P(8)	32669612.0295	0.0041
R(10)	29204591.1529	0.0009	P(10)	32708096.4282	0.0040
R(12)	29241268.3964	0.0010	P(12)	32745995.7040	0.0040
R(14)	29277144.1444	0.0011	P(14)	32783310.0573	0.0040
R(16)	29312216.7955	0.0012	P(16)	32820039.8258	0.0040
R(18)	29346484.5984	0.0012	P(18)	32856185.4827	0.0040
R(20)	29379945.6517	0.0013	P(20)	32891747.6358	0.0040
R(22)	29412597.9024	0.0013	P(22)	32926727.0254	0.0040
R(24)	29444439.1458	0.0013	P(24)	32961124.5220	0.0040
R(26)	29475467.0236	0.0014	P(26)	32994941.1249	0.0040
R(28)	29505679.0230	0.0015	P(28)	33028177.9594	0.0040
R(30)	29535072.4755	0.0016	P(30)	33060836.2743	0.0040
R(32)	29563644.5557	0.0018	P(32)	33092917.4394	0.0041
R(34)	29591392.2794	0.0020	P(34)	33124422.9429	0.0043
R(36)	29618312.5023	0.0023	P(36)	33155354.3878	0.0046
R(38)	29644401.9182	0.0028	P(38)	33185713.4894	0.0049

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
R(40)	29669657.0575	0.0036	P(40)	33215502.0716	0.0056
R(42)	29694074.2853	0.0053	P(42)	33244722.0637	0.0068
R(44)	29717649.7992	0.0082	P(44)	33273375.4969	0.0092
R(46)	29740379.6276	0.0128	P(46)	33301464.5003	0.0134
R(48)	29762259.6274	0.0200	P(48)	33328991.2976	0.0199
R(50)	29783285.4820	0.0307	P(50)	33355958.2027	0.0294
R(52)	29803452.6988	0.0461	P(52)	33382367.6161	0.0427
R(54)	29822756.6072	0.0681	P(54)	33408222.0209	0.0607
R(56)	29841192.3558	0.0985	P(56)	33433523.9780	0.0848
R(58)	29858754.9100	0.1401	P(58)	33458276.1228	0.1165
R(60)	29875439.0495	0.1960	P(60)	33482481.1601	0.1576
R(62)	29891239.3658	0.2702	P(62)	33506141.8605	0.2104
R(64)	29906150.2589	0.3673	P(64)	33529261.0556	0.2775
R(66)	29920165.9352	0.4930	P(66)	33551841.6335	0.3621
R(68)	29933280.4042	0.6540	P(68)	33573886.5352	0.4679
R(70)	29945487.4756	0.8581	P(70)	33595398.7493	0.5992

Frequencies for the 00°1-(10°0,02°0)$_I$ and 00°1-(10°0,02°0)$_{II}$ Bands of $^{13}C^{18}O_2$ with the Estimated 2-σ Uncertainties

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
P(70)	25967863.7652	1.1146	P(70)	28960476.2278	0.4069
P(68)	26033448.2798	0.8152	P(68)	29022326.9578	0.2861
P(66)	26098273.9159	0.5860	P(66)	29083661.3546	0.1961
P(64)	26162346.4813	0.4129	P(64)	29144473.5795	0.1303
P(62)	26225671.5466	0.2844	P(62)	29204757.8761	0.0833
P(60)	26288254.4494	0.1906	P(60)	29264508.5768	0.0507
P(58)	26350100.2984	0.1237	P(58)	29323720.1086	0.0290
P(56)	26411213.9778	0.0772	P(56)	29382386.9988	0.0152
P(54)	26471600.1504	0.0459	P(54)	29440503.8809	0.0073
P(52)	26531263.2618	0.0258	P(52)	29498065.4997	0.0038
P(50)	26590207.5442	0.0138	P(50)	29555066.7172	0.0032
P(48)	26648437.0195	0.0077	P(48)	29611502.5178	0.0031
P(46)	26705955.5026	0.0057	P(46)	29667368.0132	0.0031
P(44)	26762766.6051	0.0055	P(44)	29722658.4475	0.0034
P(42)	26818873.7378	0.0055	P(42)	29777369.2022	0.0039
P(40)	26874280.1143	0.0056	P(40)	29831495.8006	0.0044
P(38)	26928988.7531	0.0056	P(38)	29885033.9125	0.0049
P(36)	26983002.4809	0.0056	P(36)	29937979.3584	0.0053
P(34)	27036323.9351	0.0055	P(34)	29990328.1139	0.0054
P(32)	27088955.5657	0.0054	P(32)	30042076.3132	0.0055
P(30)	27140899.6384	0.0051	P(30)	30093220.2534	0.0055
P(28)	27192158.2363	0.0049	P(28)	30143756.3978	0.0054
P(26)	27242733.2620	0.0047	P(26)	30193681.3793	0.0053
P(24)	27292626.4396	0.0044	P(24)	30242992.0038	0.0052
P(22)	27341839.3165	0.0042	P(22)	30291685.2529	0.0051
P(20)	27390373.2651	0.0040	P(20)	30339758.2870	0.0049
P(18)	27438229.4843	0.0037	P(18)	30387208.4477	0.0048
P(16)	27485409.0008	0.0035	P(16)	30434033.2603	0.0046
P(14)	27531912.6704	0.0033	P(14)	30480230.4356	0.0045
P(12)	27577741.1795	0.0031	P(12)	30525797.8725	0.0044
P(10)	27622895.0455	0.0031	P(10)	30570733.6593	0.0043
P(8)	27667374.6182	0.0031	P(8)	30615036.0750	0.0043
P(6)	27711180.0803	0.0033	P(6)	30658703.5912	0.0044
P(4)	27754311.4480	0.0034	P(4)	30701734.8727	0.0045

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
P(2)	27796768.5718	0.0036	P(2)	30744128.7785	0.0045
R(0)	27859189.3155	0.0036	P(0)	30806522.5414	0.0045
R(2)	27899959.0889	0.0035	P(2)	30847319.2956	0.0044
R(4)	27940052.7921	0.0033	P(4)	30887476.2168	0.0043
R(6)	27979469.5315	0.0031	P(6)	30926993.0424	0.0042
R(8)	28018208.2478	0.0028	P(8)	30965869.7046	0.0041
R(10)	28056267.7161	0.0026	P(10)	31004106.3298	0.0040
R(12)	28093646.5448	0.0025	P(12)	31041703.2379	0.0040
R(14)	28130343.1757	0.0025	P(14)	31078660.9408	0.0040
R(16)	28166355.8825	0.0025	P(16)	31114980.1420	0.0040
R(18)	28201682.7706	0.0025	P(18)	31150661.7340	0.0041
R(20)	28236321.7757	0.0025	P(20)	31185706.7976	0.0042
R(22)	28270270.6628	0.0024	P(22)	31220116.5992	0.0043
R(24)	28303527.0249	0.0024	P(24)	31253892.5891	0.0043
R(26)	28336088.2817	0.0023	P(26)	31287036.3991	0.0044
R(28)	28367951.6781	0.0024	P(28)	31319549.8396	0.0043
R(30)	28399114.2823	0.0025	P(30)	31351434.8973	0.0043
R(32)	28429572.9843	0.0026	P(32)	31382693.7318	0.0042
R(34)	28459324.4940	0.0028	P(34)	31413328.6728	0.0042
R(36)	28488365.3390	0.0029	P(36)	31443342.2165	0.0041
R(38)	28516691.8625	0.0029	P(38)	31472737.0219	0.0040
R(40)	28544300.2211	0.0031	P(40)	31501515.9074	0.0039
R(42)	28571186.3823	0.0032	P(42)	31529681.8467	0.0040
R(44)	28597346.1222	0.0032	P(44)	31557237.9646	0.0042
R(46)	28622775.0223	0.0038	P(46)	31584187.5329	0.0046
R(48)	28647468.4672	0.0071	P(48)	31610533.9656	0.0057
R(50)	28671421.6417	0.0148	P(50)	31636280.8146	0.0088
R(52)	28694629.5272	0.0286	P(52)	31661431.7650	0.0151
R(54)	28717086.8993	0.0510	P(54)	31685990.6298	0.0261
R(56)	28738788.3239	0.0852	P(56)	31709961.3449	0.0434
R(58)	28759728.1540	0.1355	P(58)	31733347.9642	0.0693
R(60)	28779900.5263	0.2075	P(60)	31756154.6537	0.1068
R(62)	28799299.3572	0.3078	P(62)	31778385.6867	0.1594
R(64)	28817918.3393	0.4447	P(64)	31800045.4375	0.2317
R(66)	28835750.9374	0.6283	P(66)	31821138.3761	0.3291
R(68)	28852790.3843	0.8707	P(68)	31841669.0622	0.4581
R(70)	28869029.6768	1.1863	P(70)	31861642.1394	0.6268

Frequencies for the $01^{1e}1$-$(11^{1e}0,03^{1e}0)_I$ and $01^{1e}1$-$(11^{1e}0,03^{1e}0)_{II}$ Bands of $^{12}C^{16}O_2$ with the Estimated 2-σ Uncertainties

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
P(59)	26125213.2723	1.6633	P(59)	30427055.2899	0.1962
P(57)	26191576.6703	1.0880	P(57)	30494640.3229	0.1332
P(55)	26257240.7898	0.6844	P(55)	30561557.5929	0.0865
P(53)	26322208.2302	0.4094	P(53)	30627802.0344	0.0530
P(51)	26386481.4313	0.2286	P(51)	30693368.7014	0.0306
P(49)	26450062.6783	0.1155	P(49)	30758252.7710	0.0175
P(47)	26512954.1076	0.0498	P(47)	30822449.5469	0.0123
P(45)	26575157.7109	0.0191	P(45)	30885954.4624	0.0114
P(43)	26636675.3402	0.0160	P(43)	30948763.0834	0.0109
P(41)	26697508.7115	0.0182	P(41)	31010871.1119	0.0100
P(39)	26757659.4084	0.0177	P(39)	31072274.3882	0.0091
P(37)	26817128.8857	0.0160	P(37)	31132968.8940	0.0091
P(35)	26875918.4726	0.0144	P(35)	31192950.7549	0.0102

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
P(33)	26934029.3751	0.0131	P(33)	31252216.2430	0.0118
P(31)	26991462.6787	0.0119	P(31)	31310761.7788	0.0134
P(29)	27048219.3509	0.0106	P(29)	31368583.9339	0.0147
P(27)	27104300.2431	0.0096	P(27)	31425679.4328	0.0155
P(25)	27159706.0925	0.0093	P(25)	31482045.1550	0.0157
P(23)	27214437.5237	0.0097	P(23)	31537678.1367	0.0154
P(21)	27268495.0505	0.0104	P(21)	31592575.5725	0.0147
P(19)	27321879.0769	0.0108	P(19)	31646734.8172	0.0137
P(17)	27374589.8987	0.0108	P(17)	31700153.3868	0.0127
P(15)	27426627.7040	0.0104	P(15)	31752828.9602	0.0119
P(13)	27477992.5747	0.0098	P(13)	31804759.3803	0.0113
P(11)	27528684.4867	0.0096	P(11)	31855942.6551	0.0113
P(9)	27578703.3113	0.0101	P(9)	31906376.9582	0.0116
P(7)	27628048.8151	0.0113	P(7)	31956060.6304	0.0122
P(5)	27676720.6609	0.0127	P(5)	32004992.1796	0.0129
P(3)	27724718.4080	0.0141	P(3)	32053170.2819	0.0136
R(1)	27841759.7696	0.0152	P(1)	32170312.0391	0.0149
R(3)	27887393.2105	0.0146	P(3)	32215845.0845	0.0151
R(5)	27932349.2934	0.0135	P(5)	32260620.8121	0.0152
R(7)	27976627.0108	0.0124	P(7)	32304638.8261	0.0152
R(9)	28020225.2521	0.0115	P(9)	32347898.8990	0.0150
R(11)	28063142.8031	0.0110	P(11)	32390400.9714	0.0148
R(13)	28105378.3457	0.0109	P(13)	32432145.1513	0.0145
R(15)	28146930.4576	0.0109	P(15)	32473131.7137	0.0142
R(17)	28187797.6116	0.0107	P(17)	32513361.0997	0.0140
R(19)	28227978.1750	0.0103	P(19)	32552833.9153	0.0140
R(21)	28267470.4088	0.0099	P(21)	32591550.9309	0.0141
R(23)	28306272.4666	0.0099	P(23)	32629513.0796	0.0143
R(25)	28344382.3939	0.0107	P(25)	32666721.4564	0.0144
R(27)	28381798.1267	0.0122	P(27)	32703177.3164	0.0142
R(29)	28418517.4902	0.0141	P(29)	32738882.0732	0.0136
R(31)	28454538.1976	0.0165	P(31)	32773837.2976	0.0136
R(33)	28489857.8477	0.0213	P(33)	32808044.7156	0.0174
R(35)	28524473.9240	0.0312	P(35)	32841506.2063	0.0279
R(37)	28558383.7917	0.0486	P(37)	32874223.8000	0.0462
R(39)	28591584.6963	0.0754	P(39)	32906199.6761	0.0735
R(41)	28624073.7602	0.1131	P(41)	32937436.1606	0.1114
R(43)	28655847.9806	0.1644	P(43)	32967935.7238	0.1624
R(45)	28686904.2261	0.2328	P(45)	32997700.9775	0.2292
R(47)	28717239.2334	0.3239	P(47)	33026734.6728	0.3151
R(49)	28746849.6038	0.4465	P(49)	33055039.6965	0.4238
R(51)	28775731.7988	0.6142	P(51)	33082619.0689	0.5595
R(53)	28803882.1361	0.8465	P(53)	33109475.9403	0.7272

Frequencies for the $01^{1f}1$-$(11^{1f}0,03^{1f}0)_I$ and $01^{1f}1$-$(11^{1f}0,03^{1f}0)_{II}$ Bands of $^{12}C^{16}O_2$ with the Estimated 2-σ Uncertainties

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
P(60)	26051570.0104	4.4521	P(60)	30355115.0204	0.2752
P(58)	26120964.4932	3.0629	P(58)	30425283.5969	0.1926
P(56)	26189552.8496	2.0516	P(56)	30494732.8293	0.1301
P(54)	26257339.6006	1.3305	P(54)	30563455.6325	0.0840
P(52)	26324329.0344	0.8289	P(52)	30631445.1076	0.0512
P(50)	26390525.2136	0.4901	P(50)	30698694.5456	0.0292
P(48)	26455931.9824	0.2698	P(48)	30765197.4310	0.0163

INFRARED LASER FREQUENCIES (continued)

Line	Band I Frequency (MHz)	Uncertainty (MHz)	Line	Band II Frequency (MHz)	Uncertainty (MHz)
P(46)	26520552.9722	0.1334	P(46)	30830947.4444	0.0111
P(44)	26584391.6075	0.0551	P(44)	30895938.4662	0.0104
P(42)	26647451.1105	0.0181	P(42)	30960164.5794	0.0105
P(40)	26709734.5057	0.0151	P(40)	31023620.0723	0.0105
P(38)	26771244.6242	0.0174	P(38)	31086299.4415	0.0107
P(36)	26831984.1067	0.0157	P(36)	31148197.3941	0.0114
P(34)	26891955.4069	0.0126	P(34)	31209308.8510	0.0126
P(32)	26951160.7945	0.0105	P(32)	31269628.9481	0.0138
P(30)	27009602.3576	0.0096	P(30)	31329153.0395	0.0147
P(28)	27067282.0045	0.0092	P(28)	31387876.6994	0.0151
P(26)	27124201.4662	0.0090	P(26)	31445795.7236	0.0149
P(24)	27180362.2977	0.0089	P(24)	31502906.1318	0.0141
P(22)	27235765.8792	0.0090	P(22)	31559204.1695	0.0128
P(20)	27290413.4182	0.0093	P(20)	31614686.3091	0.0113
P(18)	27344305.9494	0.0096	P(18)	31669349.2515	0.0098
P(16)	27397444.3368	0.0097	P(16)	31723189.9280	0.0086
P(14)	27449829.2733	0.0096	P(14)	31776205.5007	0.0081
P(12)	27501461.2824	0.0096	P(12)	31828393.3642	0.0085
P(10)	27552340.7179	0.0101	P(10)	31879751.1463	0.0095
P(8)	27602467.7649	0.0111	P(8)	31930276.7092	0.0107
P(6)	27651842.4399	0.0125	P(6)	31979968.1497	0.0120
P(4)	27700464.5912	0.0139	P(4)	32028823.8002	0.0131
P(2)	27748333.8988	0.0148	P(2)	32076842.2290	0.0139
R(2)	27864709.8633	0.0146	P(2)	32193218.1935	0.0150
R(4)	27909939.2762	0.0135	P(4)	32238298.4853	0.0151
R(6)	27954412.3294	0.0122	P(6)	32282538.0393	0.0153
R(8)	27998127.7801	0.0112	P(8)	32325936.7244	0.0153
R(10)	28041084.2173	0.0107	P(10)	32368494.6458	0.0154
R(12)	28083280.0620	0.0108	P(12)	32410212.1438	0.0155
R(14)	28124713.5668	0.0110	P(14)	32451089.7941	0.0155
R(16)	28165382.8151	0.0112	P(16)	32491128.4063	0.0154
R(18)	28205285.7213	0.0111	P(18)	32530329.0234	0.0152
R(20)	28244420.0302	0.0110	P(20)	32568692.9211	0.0149
R(22)	28282783.3158	0.0114	P(22)	32606221.6061	0.0147
R(24)	28320372.9812	0.0129	P(24)	32642916.8154	0.0144
R(26)	28357186.2574	0.0149	P(26)	32678780.5147	0.0140
R(28)	28393220.2023	0.0168	P(28)	32713814.8971	0.0133
R(30)	28428471.6994	0.0175	P(30)	32748022.3813	0.0120
R(32)	28462937.4565	0.0165	P(32)	32781405.6101	0.0106
R(34)	28496614.0042	0.0142	P(34)	32813967.4482	0.0122
R(36)	28529497.6934	0.0163	P(36)	32845710.9809	0.0212
R(38)	28561584.6939	0.0309	P(38)	32876639.5111	0.0385
R(40)	28592870.9914	0.0593	P(40)	32906756.5580	0.0646
R(42)	28623352.3850	0.1054	P(42)	32936065.8540	0.1015
R(44)	28653024.4839	0.1779	P(44)	32964571.3426	0.1518
R(46)	28681882.7038	0.2907	P(46)	32992277.1760	0.2184
R(48)	28709922.2632	0.4635	P(48)	33019187.7118	0.3048
R(50)	28737138.1785	0.7231	P(50)	33045307.5105	0.4152

INFRARED AND FAR-INFRARED ABSORPTION FREQUENCY STANDARDS
Arthur Maki

Aside from the CO_2 laser transitions, the absorption spectrum of CO has been more accurately and thoroughly measured than any other spectrum. A bibliography of earlier measurements on CO is given by Maki and Wells,[1] and the present tables were calculated from the measurements referred to in that work. In addition, some new and very accurate frequency measurements[2,3] have been made and were incorporated in the present tables. The frequencies of the rotational transitions of HF and HCl were calculated from constants obtained from fitting the measurements of Evenson et al.[4,5] and Jennings and Wells.[6]

A new report on infrared wavenumber standards from the International Union of Pure and Applied Chemistry, Commission on Molecular Structure and Spectroscopy, may be found in Reference 7.

REFERENCES

1. Maki, A. G. and Wells, J. S., *Wavenumber Calibration Tables from Heterodyne Frequency Measurements*, NIST Special Publication 821, U.S. Dept. of Commerce, Washington, D.C., 1991.
2. Evenson, K. and Stroh, F., private communication.
3. George, T., Urban, W., and co-workers, private communication.
4. Jennings, D. A., Evenson, K. M., Zink, L. R., Demuynck, C., Destombes, J. L., Lemoine, B., and Johns, J. W. C., *J. Mol. Spectrosc.*, 122, 477-480, 1987.
5. Nolt, I. G., Radostitz, J. V., DiLonardo, G., Evenson, K. M., Jennings, D. A., Leopold, K. R., Vanek, M. D., Zink, L. R., Hinz, A., and Chance, K. V., *J. Mol. Spectrosc.*, 125, 274-287, 1987.
6. Jennings, D. A. and Wells, J. S., *J. Mol. Spectrosc.*, 130, 267-268, 1988.
7. *High Resolution Wavenumber Standards for the Infrared, Pure Appl. Chemistry,* 68, 193, 1996.

Wavenumbers for the *v* = 1-0 Band of CO

Wavenumber (unc)* cm^{-1}	Transition	Wavenumber (unc) cm^{-1}	Transition
		2147.081132(01)	R(0)
2139.426071(01)	P(1)	2150.856006(01)	R(1)
2135.546178(01)	P(2)	2154.595581(01)	R(2)
2131.631574(01)	P(3)	2158.299710(01)	R(3)
2127.682404(01)	P(4)	2161.968245(01)	R(4)
2123.698816(01)	P(5)	2165.601041(01)	R(5)
2119.680957(01)	P(6)	2169.197949(01)	R(6)
2115.628973(01)	P(7)	2172.758824(01)	R(7)
2111.543012(01)	P(8)	2176.283519(01)	R(8)
2107.423221(01)	P(9)	2179.771887(01)	R(9)
2103.269746(01)	P(10)	2183.223782(01)	R(10)
2099.082734(01)	P(11)	2186.639057(01)	R(11)
2094.862333(01)	P(12)	2190.017565(01)	R(12)
2090.608688(01)	P(13)	2193.359161(01)	R(13)
2086.321947(01)	P(14)	2196.663698(01)	R(14)
2082.002256(01)	P(15)	2199.931030(01)	R(15)
2077.649762(01)	P(16)	2203.161010(01)	R(16)
2073.264612(01)	P(17)	2206.353492(01)	R(17)
2068.846952(01)	P(18)	2209.508331(02)	R(18)
2064.396929(01)	P(19)	2212.625379(02)	R(19)
2059.914688(02)	P(20)	2215.704492(02)	R(20)
2055.400377(02)	P(21)	2218.745522(02)	R(21)
2050.854140(02)	P(22)	2221.748326(03)	R(22)
2046.276126(03)	P(23)	2224.712755(03)	R(23)
2041.666479(03)	P(24)	2227.638666(03)	R(24)
2037.025345(03)	P(25)	2230.525912(04)	R(25)
2032.352870(04)	P(26)	2233.374349(04)	R(26)
2027.649200(04)	P(27)	2236.183829(04)	R(27)
2022.914480(04)	P(28)	2238.954210(05)	R(28)
2018.148857(05)	P(29)	2241.685344(05)	R(29)
2013.352474(05)	P(30)	2244.377088(06)	R(30)
2008.525477(06)	P(31)	2247.029296(07)	R(31)
2003.668012(06)	P(32)	2249.641824(08)	R(32)
1998.780224(07)	P(33)	2252.214527(10)	R(33)
1993.862257(09)	P(34)	2254.747262(14)	R(34)

Wavenumber (unc)* cm^{-1}	Transition	Wavenumber (unc) cm^{-1}	Transition
1988.914257(11)	P(35)	2257.239883(18)	R(35)
1983.936367(14)	P(36)	2259.692248(24)	R(36)
1978.928733(18)	P(37)	2262.104213(33)	R(37)
1973.891500(25)	P(38)	2264.475634(45)	R(38)
1968.824811(34)	P(39)	2266.806368(61)	R(39)
1963.728813(46)	P(40)	2269.096273(81)	R(40)
1958.603648(61)	P(41)	2271.345206(106)	R(41)
1953.449462(82)	P(42)	2273.553027(139)	R(42)

* The uncertainty in the last digits (twice the standard error) is given in parentheses.

Wavenumbers for the *v* = 2-0 Band of CO

Wavenumber (unc)* cm^{-1}	Transition	Wavenumber (unc) cm^{-1}	Transition
		4263.837198(02)	R(0)
4256.217140(02)	P(1)	4267.542066(02)	R(1)
4252.302244(02)	P(2)	4271.176630(02)	R(2)
4248.317633(02)	P(3)	4274.740746(02)	R(3)
4244.263453(02)	P(4)	4278.234264(02)	R(4)
4240.139852(02)	P(5)	4281.657039(02)	R(5)
4235.946975(02)	P(6)	4285.008924(02)	R(6)
4231.684972(02)	P(7)	4288.289772(02)	R(7)
4227.353987(02)	P(8)	4291.499437(02)	R(8)
4222.954169(02)	P(9)	4294.637773(02)	R(9)
4218.485665(02)	P(10)	4297.704631(02)	R(10)
4213.948620(02)	P(11)	4300.699868(02)	R(11)
4209.343182(02)	P(12)	4303.623334(02)	R(12)
4204.669499(02)	P(13)	4306.474886(02)	R(13)
4199.927716(02)	P(14)	4309.254375(02)	R(14)
4195.117980(02)	P(15)	4311.961657(02)	R(15)
4190.240439(02)	P(16)	4314.596584(02)	R(16)
4185.295239(02)	P(17)	4317.159011(02)	R(17)
4180.282526(02)	P(18)	4319.648791(02)	R(18)
4175.202447(02)	P(19)	4322.065779(03)	R(19)
4170.055149(03)	P(20)	4324.409829(03)	R(20)
4164.840777(03)	P(21)	4326.680794(03)	R(21)
4159.559478(03)	P(22)	4328.878530(03)	R(22)
4154.211398(03)	P(23)	4331.002889(04)	R(23)
4148.796683(04)	P(24)	4333.053728(04)	R(24)
4143.315479(04)	P(25)	4335.030899(05)	R(25)
4137.767932(04)	P(26)	4336.934259(06)	R(26)
4132.154187(05)	P(27)	4338.763661(07)	R(27)
4126.474391(06)	P(28)	4340.518961(09)	R(28)
4120.728689(07)	P(29)	4342.200014(11)	R(29)
4114.917226(09)	P(30)	4343.806675(16)	R(30)
4109.040148(12)	P(31)	4345.338799(21)	R(31)
4103.097600(16)	P(32)	4346.796243(29)	R(32)
4097.089728(21)	P(33)	4348.178862(40)	R(33)
4091.016676(29)	P(34)	4349.486513(54)	R(34)
4084.878591(40)	P(35)	4350.719052(73)	R(35)
4078.675618(54)	P(36)	4351.876336(96)	R(36)
4072.407901(73)	P(37)	4352.958224(127)	R(37)
4066.075588(97)	P(38)	4353.964572(166)	R(38)
4059.678822(127)	P(39)	4354.895240(214)	R(39)

* The uncertainty in the last digits (twice the standard error) is given in parentheses.

Wavenumbers for the *v* = 3-0 Band of CO

Wavenumber (unc)* cm^{-1}	Transition	Wavenumber (unc) cm^{-1}	Transition
		6354.179057(13)	R(0)
6346.594000(13)	P(1)	6357.813923(13)	R(1)
6342.644103(13)	P(2)	6361.343487(13)	R(2)
6338.589491(13)	P(3)	6364.767599(13)	R(3)
6334.430309(13)	P(4)	6368.086115(13)	R(4)
6330.166705(13)	P(5)	6371.298887(13)	R(5)
6325.798826(13)	P(6)	6374.405768(12)	R(6)
6321.326819(13)	P(7)	6377.406611(12)	R(7)
6316.750831(12)	P(8)	6380.301271(12)	R(8)
6312.071008(12)	P(9)	6383.089600(12)	R(9)
6307.287498(12)	P(10)	6385.771452(12)	R(10)
6302.400447(12)	P(11)	6388.346680(13)	R(11)
6297.410003(12)	P(12)	6390.815139(13)	R(12)
6292.316311(13)	P(13)	6393.176681(13)	R(13)
6287.119520(13)	P(14)	6395.431160(13)	R(14)
6281.819775(13)	P(15)	6397.578430(13)	R(15)
6276.417224(13)	P(16)	6399.618344(13)	R(16)
6270.912012(13)	P(17)	6401.550757(13)	R(17)
6265.304287(13)	P(18)	6403.375523(13)	R(18)
6259.594194(13)	P(19)	6405.092495(14)	R(19)
6253.781880(13)	P(20)	6406.701527(14)	R(20)
6247.867492(14)	P(21)	6408.202474(14)	R(21)
6241.851176(14)	P(22)	6409.595189(15)	R(22)
6235.733077(14)	P(23)	6410.879527(15)	R(23)
6229.513342(15)	P(24)	6412.055343(16)	R(24)
6223.192117(15)	P(25)	6413.122491(17)	R(25)
6216.769547(16)	P(26)	6414.080825(19)	R(26)
6210.245778(17)	P(27)	6414.930201(23)	R(27)
6203.620957(19)	P(28)	6415.670474(28)	R(28)
6196.895229(23)	P(29)	6416.301500(37)	R(29)
6190.068739(28)	P(30)	6416.823133(50)	R(30)
6183.141633(37)	P(31)	6417.235231(67)	R(31)
6176.114058(50)	P(32)	6417.537649(90)	R(32)
6168.986159(67)	P(33)		
6161.758082(90)	P(34)		

* The uncertainty in the last digits (twice the standard error) is given in parentheses.

Frequencies and Wavenumbers for the Rotational Lines of CO

Frequency MHz	Uncertainty* MHz	*J′*	*J″*	Wavenumber cm^{-1}	Uncertainty* cm^{-1}
115271.2029	0.0004	1	0	3.84503345	0.00000001
230538.0016	0.0008	2	1	7.68991999	0.00000003
345795.9923	0.0012	3	2	11.53451273	0.00000004
461040.7712	0.0016	4	3	15.37866477	0.00000005
576267.9350	0.0019	5	4	19.22222923	0.00000006
691473.0809	0.0021	6	5	23.06505926	0.00000007
806651.8065	0.0023	7	6	26.90700800	0.00000008
921799.7104	0.0025	8	7	30.74792863	0.00000008
1036912.3919	0.0027	9	8	34.58767438	0.00000009
1151985.4515	0.0029	10	9	38.42609848	0.00000010
1267014.4906	0.0031	11	10	42.26305422	0.00000010
1381995.1119	0.0034	12	11	46.09839491	0.00000011
1496922.9195	0.0038	13	12	49.93197392	0.00000013

Frequency MHz	Uncertainty* MHz	J′	J″	Wavenumber cm^{-1}	Uncertainty* cm^{-1}
1611793.5189	0.0042	14	13	53.76364468	0.00000014
1726602.5173	0.0047	15	14	57.59326065	0.00000016
1841345.5237	0.0052	16	15	61.42067535	0.00000017
1956018.1486	0.0057	17	16	65.24574239	0.00000019
2070616.0050	0.0061	18	17	69.06831542	0.00000020
2185134.7075	0.0065	19	18	72.88824816	0.00000022
2299569.8733	0.0069	20	19	76.70539441	0.00000023
2413917.1217	0.0071	21	20	80.51960806	0.00000024
2528172.0747	0.0073	22	21	84.33074306	0.00000024
2642330.3567	0.0074	23	22	88.13865346	0.00000025
2756387.5949	0.0075	24	23	91.94319341	0.00000025
2870339.4194	0.0077	25	24	95.74421713	0.00000026
2984181.4631	0.0080	26	25	99.54157896	0.00000027
3097909.3621	0.0085	27	26	103.33513334	0.00000028
3211518.7558	0.0090	28	27	107.12473480	0.00000030
3325005.2869	0.0096	29	28	110.91023800	0.00000032
3438364.6013	0.0102	30	29	114.69149772	0.00000034
3551592.3489	0.0107	31	30	118.46836884	0.00000036
3664684.1829	0.0111	32	31	122.24070637	0.00000037
3777635.7608	0.0118	33	32	126.00836545	0.00000039
3890442.7435	0.0137	34	33	129.77120137	0.00000046
4003100.7965	0.0179	35	34	133.52906952	0.00000060
4115605.5892	0.0254	36	35	137.28182546	0.00000085
4227952.7954	0.0370	37	36	141.02932487	0.00000123
4340138.0932	0.0531	38	37	144.77142361	0.00000177
4452157.1657	0.0746	39	38	148.50797766	0.00000249
4564005.7001	0.1025	40	39	152.23884318	0.00000342

* The uncertainty given is twice the standard error.

Frequencies and Wavenumbers for the Rotational Lines of HF

Frequency MHz	Uncertainty* MHz	J′	J″	Wavenumber cm^{-1}	Uncertainty* cm^{-1}
1232476.21	0.12	1	0	41.110981	0.000004
2463428.09	0.19	2	1	82.171116	0.000006
3691334.81	0.25	3	2	123.129676	0.000008
4914682.58	0.51	4	3	163.936165	0.000017
6131968.11	1.10	5	4	204.540439	0.000037
7341702.00	2.00	6	5	244.892818	0.000067
8542412.1	3.21	7	6	284.944197	0.000107
9732646.8	4.72	8	7	324.646153	0.000157
10910978.2	6.51	9	8	363.951056	0.000217
12076004.8	8.55	10	9	402.81216	0.000285
13226355.2	10.81	11	10	441.18372	0.000361
14360689.8	13.25	12	11	479.02105	0.00044
15477704.4	15.86	13	12	516.28065	0.00053
16576131.8	18.61	14	13	552.92024	0.00062
17654744.4	21.48	15	14	588.89888	0.00072
18712356.5	24.44	16	15	624.17703	0.00082
19747825.6	27.43	17	16	658.71656	0.00092
20760054.3	30.32	18	17	692.4809	0.00101
21747991.7	32.91	19	18	725.4349	0.00110
22710634.7	34.94	20	19	757.5452	0.00117
23647028.7	36.08	21	20	788.7800	0.00120
24556268.8	35.93	22	21	819.1090	0.00120
25437499.9	34.12	23	22	848.5037	0.00114

Frequency MHz	Uncertainty* MHz	*J′*	*J″*	Wavenumber cm^{-1}	Uncertainty* cm^{-1}
26289917.4	30.32	24	23	876.9373	0.00101
27112767.2	24.41	25	24	904.38457	0.00081
27905345.6	16.88	26	25	930.82214	0.00056
28666999.3	10.80	27	26	956.22817	0.00036
29397124.8	14.65	28	27	980.58253	0.00049
30095168.2	24.62	29	28	1003.86676	0.00082
30760624.2	33.36	30	29	1026.0640	0.00111
31393035.7	36.17	31	30	1047.1590	0.00121

* The uncertainty given is twice the standard error.

Frequencies and Wavenumbers for the Rotational Lines of $H^{35}Cl$

Frequency MHz	Uncertainty* MHz	*J′*	*J″*	Wavemumber cm^{-1}	Uncertainty* cm^{-1}
1876226.517	0.065	3	2	62.584180	0.000002
2499864.439	0.066	4	3	83.386502	0.000002
3121986.563	0.064	5	4	104.138262	0.000002
3742216.601	0.076	6	5	124.826909	0.000003
4360180.042	0.098	7	6	145.439951	0.000003
4975504.51	0.11	8	7	165.964966	0.000004
5587820.10	0.12	9	8	186.389615	0.000004
6196759.76	0.22	10	9	206.701656	0.000007
6801959.63	0.50	11	10	226.888951	0.000017
7403059.41	1.02	12	11	246.939481	0.000034
7999702.7	1.8	13	12	266.841359	0.000062
8591537.3	3.1	14	13	286.582837	0.000103
9178215.8	4.8	15	14	306.152324	0.000161

* The uncertainty given is twice the standard error.

Frequencies and Wavenumbers for the Rotational Lines of $H^{37}Cl$

Frequency MHz	Uncertainty* MHz	*J′*	*J″*	Wavenumber cm^{-1}	Uncertainty* cm^{-1}
1873410.72	0.05	3	2	62.490255	0.000002
2496115.33	0.05	4	3	83.261445	0.000002
3117308.69	0.05	5	4	103.982225	0.000002
3736615.64	0.06	6	5	124.640082	0.000002
4353662.84	0.08	7	6	145.222561	0.000003
4968079.04	0.09	8	7	165.717279	0.000003
5579495.53	0.10	9	8	186.111938	0.000003
6187546.42	0.19	10	9	206.394332	0.000006
6791869.04	0.45	11	10	226.552365	0.000015
7392104.3	0.9	12	11	246.574057	0.000030
7987896.9	1.6	13	12	266.447561	0.000054
8578896.1	2.7	14	13	286.161170	0.000089

* The uncertainty given is twice the standard error.

SUMMARY TABLES OF PARTICLE PROPERTIES

Extracted from the Particle Listings of the

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GAUGE AND HIGGS BOSONS

γ

$I(J^{PC}) = 0,1(1^{--})$

Mass $m < 2 \times 10^{-16}$ eV
Charge $q < 5 \times 10^{-30}$ e
Mean life τ = Stable

g or gluon

$I(J^{P}) = 0(1^{-})$

Mass $m = 0$ [a]
SU(3) color octet

W

$J = 1$

Charge = ± 1 e
Mass $m = 80.41 \pm 0.10$ GeV
$m_Z - m_W = 10.78 \pm 0.10$ GeV
$m_{W^+} - m_{W^-} = -0.2 \pm 0.6$ GeV
Full width $\Gamma = 2.06 \pm 0.06$ GeV

W^- modes are charge conjugates of the modes below.

W^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\ell^+\nu$	[b]	(10.74 ± 0.33) %		–
$e^+\nu$		(10.9 ± 0.4) %		40205
$\mu^+\nu$		(10.2 ± 0.5) %		40205
$\tau^+\nu$		(11.3 ± 0.8) %		40185
hadrons		(67.8 ± 1.0) %		–
$\pi^+\gamma$		$< 2.2 \times 10^{-4}$	95%	40205

Z

$J = 1$

Charge = 0
Mass $m = 91.187 \pm 0.007$ GeV [c]
Full width $\Gamma = 2.490 \pm 0.007$ GeV
$\Gamma(\ell^+ \ell^-) = 83.83 \pm 0.27$ MeV [b]
$\Gamma(\text{invisible}) = 498.3 \pm 4.2$ MeV [d]
$\Gamma(\text{hadrons}) = 1740.7 \pm 5.9$ MeV
$\Gamma(\mu^+ \mu^-)/\Gamma(e^+ e^-) = 1.000 \pm 0.005$
$\Gamma(\tau^+ \tau^-)/\Gamma(e^+ e^-) = 0.998 \pm 0.005$ [e]

Average charged multiplicity

$\langle N_{charged} \rangle = 21.00 \pm 0.13$

Couplings to leptons

$g^{\ell}_V = -0.0377 \pm 0.0007$
$g^{\ell}_A = -0.5008 \pm 0.0008$
$g^{\nu_e} = 0.53 \pm 0.09$
$g^{\nu_\mu} = 0.502 \pm 0.017$

Asymmetry parameters [f]

$A_e = 0.1519 \pm 0.0034$
$A_\mu = 0.102 \pm 0.034$
$A_\tau = 0.143 \pm 0.008$
$A_c = 0.59 \pm 0.19$
$A_b = 0.89 \pm 0.11$

Charge asymmetry (%) at *Z* pole

$A^{(0\ell)}_{FB} = 1.59 \pm 0.18$
$A^{(0u)}_{FB} = 4.0 \pm 7.3$
$A^{(0s)}_{FB} = 9.9 \pm 3.1$ (S = 1.2)
$A^{(0c)}_{FB} = 7.32 \pm 0.58$
$A^{(0b)}_{FB} = 10.02 \pm 0.28$

Z DECAY MODES			Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
e^+e^-			(3.366±0.008) %		45594
$\mu^+\mu^-$			(3.367±0.013) %		45593
$\tau^+\tau^-$			(3.360±0.015) %		45559
$\ell^+\ell^-$		[b]	(3.366±0.006) %		–
invisible			(20.01 ±0.16) %		–
hadrons			(69.90 ±0.15) %		–
$(u\overline{u}+c\overline{c})/2$			(10.1 ±1.1) %		–
$(d\overline{d}+s\overline{s}+b\overline{b})/3$			(16.6 ±0.6) %		–
$c\overline{c}$			(12.4 ±0.6) %		–
$b\overline{b}$			(15.16 ±0.09) %		–
ggg			< 1.1 %	95%	–
$\pi^0\gamma$			< 5.2 $\times 10^{-5}$	95%	45593
$\eta\gamma$			< 5.1 $\times 10^{-5}$	95%	45592
$\omega\gamma$			< 6.5 $\times 10^{-4}$	95%	45590
$\eta'(958)\gamma$			< 4.2 $\times 10^{-5}$	95%	45588
$\gamma\gamma$			< 5.2 $\times 10^{-5}$	95%	45594
$\gamma\gamma\gamma$			< 1.0 $\times 10^{-5}$	95%	45594
$\pi^\pm W^\mp$		[g]	< 7 $\times 10^{-5}$	95%	10139
$\rho^\pm W^\mp$		[g]	< 8.3 $\times 10^{-5}$	95%	10114
$J/\psi(1S)$X			(3.66 ±0.23) $\times 10^{-3}$		–
$\psi(2S)$X			(1.60 ±0.29) $\times 10^{-3}$		–
$\chi_{c1}(1P)$X			(2.9 ±0.7) $\times 10^{-3}$		–
$\chi_{c2}(1P)$X			< 3.2 $\times 10^{-3}$	90%	–
$\Upsilon(1S)$ X $+\Upsilon(2S)$ X $+\Upsilon(3S)$ X			(1.0 ±0.5) $\times 10^{-4}$		–
$\Upsilon(1S)$X			< 5.5 $\times 10^{-5}$	95%	–
$\Upsilon(2S)$X			< 1.39 $\times 10^{-4}$	95%	–
$\Upsilon(3S)$X			< 9.4 $\times 10^{-5}$	95%	–
$(D^0/\overline{D}^0)$ X			(20.7 ±2.0) %		–
$D^\pm$X			(12.2 ±1.7) %		–
$D^*(2010)^\pm$X		[g]	(11.4 ±1.3) %		–
B^0_sX			seen		–
anomalous $\gamma+$ hadrons		[h]	< 3.2 $\times 10^{-3}$	95%	–
$e^+e^-\gamma$		[h]	< 5.2 $\times 10^{-4}$	95%	45594
$\mu^+\mu^-\gamma$		[h]	< 5.6 $\times 10^{-4}$	95%	45593
$\tau^+\tau^-\gamma$		[h]	< 7.3 $\times 10^{-4}$	95%	45559
$\ell^+\ell^-\gamma\gamma$		[i]	< 6.8 $\times 10^{-6}$	95%	–
$q\overline{q}\gamma\gamma$		[i]	< 5.5 $\times 10^{-6}$	95%	–
$\nu\overline{\nu}\gamma\gamma$		[i]	< 3.1 $\times 10^{-6}$	95%	45594
$e^\pm\mu^\mp$	*LF*	[g]	< 1.7 $\times 10^{-6}$	95%	45593
$e^\pm\tau^\mp$	*LF*	[g]	< 9.8 $\times 10^{-6}$	95%	45576
$\mu^\pm\tau^\mp$	*LF*	[g]	< 1.2 $\times 10^{-5}$	95%	45576

Higgs Bosons — H^0 and $H^{\pm}$, Searches for

H^0 Mass $m >$ 77.5 GeV, CL = 95%

H_1^0 in Supersymmetric Models ($m_{H_1^0} < m_{H_2^0}$)

Mass $m >$ 62.5 GeV, CL = 95%

A^0 Pseudoscalar Higgs Boson in Supersymmetric Models [j]

Mass $m >$ 62.5 GeV, CL = 95% $\tan\beta > 1$

$H^{\pm}$ Mass $m >$ 54.5 GeV, CL = 95%

See the Particle Listings for a Note giving details of Higgs Bosons.

Heavy Bosons Other Than Higgs Bosons, Searches for

Additional *W* Bosons

W_R — right-handed W
Mass $m >$ 549 GeV
(assuming light right-handed neutrino)

W' with standard couplings decaying to $e\nu$, $\mu\nu$
Mass $m >$ 720 GeV, CL = 95%

Additional *Z* Bosons

Z'_{SM} with standard couplings
Mass $m >$ 690 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 779 GeV, CL = 95% (electroweak fit)

Z_{LR} of $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R \times \mathrm{U}(1)$
(with $g_L = g_R$)
Mass $m >$ 630 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 389 GeV, CL = 95% (electroweak fit)

Z_χ of $\mathrm{SO}(10) \to \mathrm{SU}(5) \times \mathrm{U}(1)_\chi$
(coupling constant derived from G.U.T.)
Mass $m >$ 595 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 321 GeV, CL = 95% (electroweak fit)

Z_ψ of $E_6 \to \mathrm{SO}(10) \times \mathrm{U}(1)_\psi$
(coupling constant derived from G.U.T.)
Mass $m >$ 590 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 160 GeV, CL = 95% (electroweak fit)

Z_η of $E_6 \to \mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1) \times \mathrm{U}(1)_\eta$
(coupling constant derived from G.U.T.);
charges are $Q_\eta = \sqrt{3/8} Q_\chi - \sqrt{5/8} Q_\psi$)
Mass $m >$ 620 GeV, CL = 95% ($p\overline{p}$ direct search)
Mass $m >$ 182 GeV, CL = 95% (electroweak fit)

Scalar Leptoquarks

Mass $m >$ 225 GeV, CL = 95% (1st generation, pair prod.)
Mass $m >$ 237 GeV, CL = 95% (1st gener., single prod.)
Mass $m >$ 119 GeV, CL = 95% (2nd gener., pair prod.)
Mass $m >$ 73 GeV, CL = 95% (2nd gener., single prod.)
Mass $m >$ 99 GeV, CL = 95% (3rd gener., pair prod.)

(See the Particle Listings for assumptions on leptoquark quantum numbers and branching fractions.)

Axions (A^0) and Other Very Light Bosons, Searches for

The standard Peccei-Quinn axion is ruled out. Variants with reduced couplings or much smaller masses are constrained by various data. The Particle Listings in the full *Review* contain a Note discussing axion searches.

The best limit for the half-life of neutrinoless double beta decay with Majoron emission is $> 7.2 \times 10^{24}$ years (CL = 90%).

NOTES

[*a*] Theoretical value. A mass as large as a few MeV may not be precluded.

[*b*] ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

[*c*] The Z-boson mass listed here corresponds to a Breit-Wigner resonance parameter. It lies approximately 34 MeV above the real part of the position of the pole (in the energy-squared plane) in the Z-boson propagator.

[*d*] This partial width takes into account Z decays into $\nu\overline{\nu}$ and any other possible undetected modes.

[*e*] This ratio has not been corrected for the τ mass.

[*f*] Here $A \equiv 2g_V g_A/(g_V^2+g_A^2)$.

[*g*] The value is for the sum of the charge states of particle/antiparticle states indicated.

[*h*] See the Z Particle Listings for the γ energy range used in this measurement.

[*i*] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.

[*j*] The limits assume no invisible decays.

LEPTONS

e

$J = \frac{1}{2}$

Mass $m = 0.51099907 \pm 0.00000015$ MeV [a]

$= (5.485799111 \pm 0.000000012) \times 10^{-4}$ u

$(m_{e^+} - m_{e^-})/m < 4 \times 10^{-8}$, CL = 90%

$\left|q_{e^+} + q_{e^-}\right|/e < 4 \times 10^{-8}$

Magnetic moment $\mu = 1.001159652193 \pm 0.000000000010\ \mu_B$

$(g_{e^+} - g_{e^-}) \ / \ g_{\text{average}} = (-0.5 \pm 2.1) \times 10^{-12}$

Electric dipole moment $d = (0.18 \pm 0.16) \times 10^{-26}\ e\,\text{cm}$

Mean life $\tau > 4.3 \times 10^{23}$ yr, CL = 68% [b]

μ

$J = \frac{1}{2}$

Mass $m = 105.658389 \pm 0.000034$ MeV [c]
$= 0.113428913 \pm 0.000000017$ u
Mean life $\tau = (2.19703 \pm 0.00004) \times 10^{-6}$ s
$\tau_{\mu^+}/\tau_{\mu^-} = 1.00002 \pm 0.00008$
$c\tau = 658.654$ m
Magnetic moment $\mu = 1.0011659230 \pm 0.0000000084\ e\hbar/2m_\mu$
$(g_{\mu^+} - g_{\mu^-})\ /\ g_{\text{average}} = (-2.6 \pm 1.6) \times 10^{-8}$
Electric dipole moment $d = (3.7 \pm 3.4) \times 10^{-19}\ e\,$cm

Decay parameters [d]

$\rho = 0.7518 \pm 0.0026$
$\eta = -0.007 \pm 0.013$
$\delta = 0.749 \pm 0.004$
$\xi P_\mu = 1.003 \pm 0.008$ [e]
$\xi P_\mu \delta/\rho > 0.99682$, CL = 90% [e]
$\xi' = 1.00 \pm 0.04$
$\xi'' = 0.7 \pm 0.4$
$\alpha/A = (0 \pm 4) \times 10^{-3}$
$\alpha'/A = (0 \pm 4) \times 10^{-3}$
$\beta/A = (4 \pm 6) \times 10^{-3}$
$\beta'/A = (2 \pm 6) \times 10^{-3}$
$\overline{\eta} = 0.02 \pm 0.08$

μ^+ modes are charge conjugates of the modes below.

μ^- DECAY MODES			Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$e^- \overline{\nu}_e \nu_\mu$			$\approx 100\%$		53
$e^- \overline{\nu}_e \nu_\mu \gamma$		[f]	(1.4 ± 0.4) %		53
$e^- \overline{\nu}_e \nu_\mu e^+ e^-$		[g]	$(3.4\pm0.4) \times 10^{-5}$		53
Lepton Family number (*LF*) violating modes					
$e^- \nu_e \overline{\nu}_\mu$	*LF*	[h]	< 1.2 %	90%	53
$e^- \gamma$	*LF*		$< 4.9 \times 10^{-11}$	90%	53
$e^- e^+ e^-$	*LF*		$< 1.0 \times 10^{-12}$	90%	53
$e^- 2\gamma$	*LF*		$< 7.2 \times 10^{-11}$	90%	53

τ

$J = \frac{1}{2}$

Mass $m = 1777.05^{+0.29}_{-0.26}$ MeV
Mean life $\tau = (290.0 \pm 1.2) \times 10^{-15}$ s
$c\tau = 86.93\ \mu$m
Magnetic moment anomaly > -0.052 and < 0.058, CL = 95%
Electric dipole moment $d > -3.1$ and $< 3.1 \times 10^{-16}\ e\,$cm, CL = 95%

Weak dipole moment

$\mathrm{Re}(d^w_\tau) <\ 0.56 \times 10^{-17}\ e\,$cm, CL = 95%
$\mathrm{Im}(d^w_\tau) <\ 1.5 \times 10^{-17}\ e\,$cm, CL = 95%

Weak anomalous magnetic dipole moment

$\mathrm{Re}(\alpha^w_\tau) <\ 4.5 \times 10^{-3}$, CL = 90%
$\mathrm{Im}(\alpha^w_\tau) <\ 9.9 \times 10^{-3}$, CL = 90%

Decay parameters

See the τ Particle Listings for a note concerning τ-decay parameters.

$\rho^\tau(e \text{ or } \mu) = 0.748 \pm 0.010$
$\rho^\tau(e) = 0.745 \pm 0.012$
$\rho^\tau(\mu) = 0.741 \pm 0.030$
$\xi^\tau(e \text{ or } \mu) = 1.01 \pm 0.04$
$\xi^\tau(e) = 0.98 \pm 0.05$
$\xi^\tau(\mu) = 1.07 \pm 0.08$
$\eta^\tau(e \text{ or } \mu) = 0.01 \pm 0.07$
$\eta^\tau(\mu) = -0.10 \pm 0.18$
$(\delta\xi)^\tau(e \text{ or } \mu) = 0.749 \pm 0.026$
$(\delta\xi)^\tau(e) = 0.733 \pm 0.033$
$(\delta\xi)^\tau(\mu) = 0.78 \pm 0.05$
$\xi^\tau(\pi) = 0.99 \pm 0.05$
$\xi^\tau(\rho) = 0.996 \pm 0.010$
$\xi^\tau(a_1) = 1.02 \pm 0.04$
$\xi^\tau(\text{all hadronic modes}) = 0.997 \pm 0.009$

τ^+ modes are charge conjugates of the modes below. "$h^\pm$" stands for $\pi^\pm$ or $K^\pm$. "ℓ" stands for e or μ. "Neutral" means neutral hadron whose decay products include γ's and/or π^0's.

τ^- DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Modes with one charged particle				
particle$^-$ ≥ 0 neutrals $\geq 0 K^0_L \nu_\tau$ ("1-prong")		$(84.71\pm\ 0.13)$ %	S=1.2	–
particle$^-$ ≥ 0 neutrals $\geq 0 K^0 \nu_\tau$		$(85.30\pm\ 0.13)$ %	S=1.2	–
$\mu^- \overline{\nu}_\mu \nu_\tau$	[i]	$(17.37\pm\ 0.09)$ %		885
$\mu^- \overline{\nu}_\mu \nu_\tau \gamma$	[g]	$(\ 3.0\ \pm\ 0.6\ ) \times 10^{-3}$		–
$e^- \overline{\nu}_e \nu_\tau$	[i]	$(17.81\pm\ 0.07)$ %		889
$h^- \geq 0$ neutrals $\geq 0 K^0_L\ \nu_\tau$		$(49.52\pm\ 0.16)$ %	S=1.2	–
$h^- \geq 0 K^0_L\ \nu_\tau$		$(12.32\pm\ 0.12)$ %	S=1.5	–
$h^- \nu_\tau$		$(11.79\pm\ 0.12)$ %	S=1.5	–
$\pi^- \nu_\tau$	[i]	$(11.08\pm\ 0.13)$ %	S=1.4	883
$K^- \nu_\tau$	[i]	$(\ 7.1\ \pm\ 0.5\ ) \times 10^{-3}$		820
$h^- \geq 1$ neutrals ν_τ		$(36.91\pm\ 0.17)$ %	S=1.2	–
$h^- \pi^0 \nu_\tau$		$(25.84\pm\ 0.14)$ %	S=1.1	–
$\pi^- \pi^0 \nu_\tau$	[i]	$(25.32\pm\ 0.15)$ %	S=1.1	878
$\pi^- \pi^0$ non-$\rho(770) \nu_\tau$		$(\ 3.0\ \pm\ 3.2\ ) \times 10^{-3}$		878
$K^- \pi^0 \nu_\tau$	[i]	$(\ 5.2\ \pm\ 0.5\ ) \times 10^{-3}$		814
$h^- \geq 2\pi^0 \nu_\tau$		$(10.79\pm\ 0.16)$ %	S=1.2	–
$h^- 2\pi^0 \nu_\tau$		$(\ 9.39\pm\ 0.14)$ %	S=1.2	–
$h^- 2\pi^0 \nu_\tau$ (ex.K^0)		$(\ 9.23\pm\ 0.14)$ %	S=1.2	–
$\pi^- 2\pi^0 \nu_\tau$ (ex.K^0)	[i]	$(\ 9.15\pm\ 0.15)$ %	S=1.2	862
$K^- 2\pi^0 \nu_\tau$ (ex.K^0)	[i]	$(\ 8.0\ \pm\ 2.7\ ) \times 10^{-4}$		796
$h^- \geq 3\pi^0 \nu_\tau$		$(\ 1.40\pm\ 0.11)$ %	S=1.1	–
$h^- 3\pi^0 \nu_\tau$		$(\ 1.23\pm\ 0.10)$ %	S=1.1	–
$\pi^- 3\pi^0 \nu_\tau$ (ex.K^0)	[i]	$(\ 1.11\pm\ 0.14)$ %		836
$K^- 3\pi^0 \nu_\tau$ (ex.K^0)	[i]	$(\ 4.3\ ^{+10.0}_{-\ 2.9}\ ) \times 10^{-4}$		766
$h^- 4\pi^0 \nu_\tau$ (ex.K^0)		$(\ 1.7\ \pm\ 0.6\ ) \times 10^{-3}$		–
$h^- 4\pi^0 \nu_\tau$ (ex.K^0,η)	[i]	$(\ 1.1\ \pm\ 0.6\ ) \times 10^{-3}$		–
$K^- \geq 0\pi^0\ \geq 0 K^0\ \nu_\tau$		$(\ 1.66\pm\ 0.10)$ %		–
$K^- \geq 1\ (\pi^0$ or $K^0)\ \nu_\tau$		$(\ 9.5\ \pm\ 1.0\ ) \times 10^{-3}$		–

Modes with K^0's

K^0 (particles)$^-$ ν_τ		(1.66± 0.09) %	S=1.4	–
$h^- \overline{K}^0 \geq 0$ neutrals $\geq 0 K^0_L \nu_\tau$		(1.62± 0.09) %	S=1.4	–
$h^- \overline{K}^0 \nu_\tau$		(9.9 ± 0.8) $\times 10^{-3}$	S=1.5	–
$\pi^- \overline{K}^0 \nu_\tau$	[i]	(8.3 ± 0.8) $\times 10^{-3}$	S=1.4	812
$\pi^- \overline{K}^0$ (non-$K^*(892)^-$) ν_τ		< 1.7 $\times 10^{-3}$	CL=95%	812
$K^- K^0 \nu_\tau$	[i]	(1.59± 0.24) $\times 10^{-3}$		737
$h^- \overline{K}^0 \pi^0 \nu_\tau$		(5.5 ± 0.5) $\times 10^{-3}$		–
$\pi^- \overline{K}^0 \pi^0 \nu_\tau$	[i]	(3.9 ± 0.5) $\times 10^{-3}$		794
$\overline{K}^0 \rho^- \nu_\tau$		(1.9 ± 0.7) $\times 10^{-3}$		–
$K^- K^0 \pi^0 \nu_\tau$	[i]	(1.51± 0.29) $\times 10^{-3}$		685
$\pi^- \overline{K}^0 \pi^0 \pi^0 \nu_\tau$		(6 ± 4) $\times 10^{-4}$		–
$K^- K^0 \pi^0 \pi^0 \nu_\tau$		< 3.9 $\times 10^{-4}$	CL=95%	–
$\pi^- K^0 \overline{K}^0 \nu_\tau$	[i]	(1.21± 0.21) $\times 10^{-3}$	S=1.2	682
$\pi^- K^0_S K^0_S \nu_\tau$		(3.0 ± 0.5) $\times 10^{-4}$	S=1.2	–
$\pi^- K^0_S K^0_L \nu_\tau$		(6.0 ± 1.0) $\times 10^{-4}$	S=1.2	–
$\pi^- K^0_S K^0_S \pi^0 \nu_\tau$		< 2.0 $\times 10^{-4}$	CL=95%	–
$\pi^- K^0_S K^0_L \pi^0 \nu_\tau$		(3.1 ± 1.2) $\times 10^{-4}$		–
$K^- K^0 \geq 0$ neutrals ν_τ		(3.1 ± 0.4) $\times 10^{-3}$		–
$K^0 h^+ h^- h^- \geq 0$ neutrals ν_τ		< 1.7 $\times 10^{-3}$	CL=95%	–
$K^0 h^+ h^- h^- \nu_\tau$		(2.3 ± 2.0) $\times 10^{-4}$		–

Modes with three charged particles

$h^- h^- h^+ \geq 0$neut. ν_τ ("3-prong")		(15.18± 0.13) %	S=1.2	–
$h^- h^- h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \to \pi^+ \pi^-$)		(14.60± 0.13) %	S=1.2	–
$\pi^- \pi^+ \pi^- \geq 0$ neutrals ν_τ		(14.60± 0.14) %		–
$h^- h^- h^+ \nu_\tau$		(9.96± 0.10) %	S=1.1	–
$h^- h^- h^+ \nu_\tau$ (ex.K^0)		(9.62± 0.10) %	S=1.1	–
$h^- h^- h^+ \nu_\tau$ (ex.K^0,ω)		(9.57± 0.10) %	S=1.1	–
$\pi^- \pi^+ \pi^- \nu_\tau$		(9.56± 0.11) %	S=1.1	–
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex.K^0)		(9.52± 0.11) %	S=1.1	–
$\pi^- \pi^+ \pi^- \nu_\tau$ (ex.K^0,ω)	[i]	(9.23± 0.11) %	S=1.1	–
$h^- h^- h^+ \geq 1$ neutrals ν_τ		(5.18± 0.11) %	S=1.2	–

$h^- h^- h^+ \geq 1$ neutrals ν_τ (ex. $K^0_S \to \pi^+ \pi^-$)		(4.98± 0.11) %		S=1.2	–
$h^- h^- h^+ \pi^0 \nu_\tau$		(4.50± 0.09) %		S=1.1	–
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex.K^0)		(4.31± 0.09) %		S=1.1	–
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0, ω)		(2.59± 0.09) %			–
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$		(4.35± 0.10) %			–
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0)		(4.22± 0.10) %			–
$\pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0,ω)	[i]	(2.49± 0.10) %			–
$h^- (\rho\pi)^0 \nu_\tau$		(2.88± 0.35) %			–
$(a_1(1260) h)^- \nu_\tau$		< 2.0 %		CL=95%	–
$h^- \rho \pi^0 \nu_\tau$		(1.35± 0.20) %			–
$h^- \rho^+ h^- \nu_\tau$		(4.5 ± 2.2)	$\times 10^{-3}$		–
$h^- \rho^- h^+ \nu_\tau$		(1.17± 0.23) %			–
$h^- h^- h^+ 2\pi^0 \nu_\tau$		(5.4 ± 0.4)	$\times 10^{-3}$		–
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex.K^0)		(5.3 ± 0.4)	$\times 10^{-3}$		–
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex.K^0,ω,η)	[i]	(1.1 ± 0.4)	$\times 10^{-3}$		–
$h^- h^- h^+ \geq 3\pi^0 \nu_\tau$	[i]	($1.4 ^{+0.9}_{-0.7}$)	$\times 10^{-3}$	S=1.5	–
$h^- h^- h^+ 3\pi^0 \nu_\tau$		(2.9 ± 0.8)	$\times 10^{-4}$		–
$K^- h^+ h^- \geq 0$ neutrals ν_τ		(5.4 ± 0.7)	$\times 10^{-3}$	S=1.1	–
$K^- \pi^+ \pi^- \geq 0$ neutrals ν_τ		(3.1 ± 0.6)	$\times 10^{-3}$	S=1.1	–
$K^- \pi^+ \pi^- \nu_\tau$		(2.3 ± 0.4)	$\times 10^{-3}$		–
$K^- \pi^+ \pi^- \nu_\tau$ (ex.K^0)	[i]	(1.8 ± 0.5)	$\times 10^{-3}$		–
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$		(8 ± 4)	$\times 10^{-4}$		–
$K^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0)	[i]	($2.4 ^{+4.3}_{-1.6}$)	$\times 10^{-4}$		–
$K^- \pi^+ K^- \geq 0$ neut. ν_τ		< 9	$\times 10^{-4}$	CL=95%	–
$K^- K^+ \pi^- \geq 0$ neut. ν_τ		(2.3 ± 0.4)	$\times 10^{-3}$		–
$K^- K^+ \pi^- \nu_\tau$	[i]	(1.61± 0.26)	$\times 10^{-3}$		685
$K^- K^+ \pi^- \pi^0 \nu_\tau$	[i]	(6.9 ± 3.0)	$\times 10^{-4}$		–
$K^- K^+ K^- \geq 0$ neut. ν_τ		< 2.1	$\times 10^{-3}$	CL=95%	–
$K^- K^+ K^- \nu_\tau$		< 1.9	$\times 10^{-4}$	CL=90%	–
$\pi^- K^+ \pi^- \geq 0$ neut. ν_τ		< 2.5	$\times 10^{-3}$	CL=95%	–
$e^- e^- e^+ \overline{\nu}_e \nu_\tau$		(2.8 ± 1.5)	$\times 10^{-5}$		889
$\mu^- e^- e^+ \overline{\nu}_\mu \nu_\tau$		< 3.6	$\times 10^{-5}$	CL=90%	885

Modes with five charged particles

$3h^- 2h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \to \pi^- \pi^+$) ("5-prong")		(9.7 ± 0.7)	$\times 10^{-4}$		–
$3h^- 2h^+ \nu_\tau$ (ex.K^0)	[i]	(7.5 ± 0.7)	$\times 10^{-4}$		–
$3h^- 2h^+ \pi^0 \nu_\tau$ (ex.K^0)	[i]	(2.2 ± 0.5)	$\times 10^{-4}$		–
$3h^- 2h^+ 2\pi^0 \nu_\tau$		< 1.1	$\times 10^{-4}$	CL=90%	–

Miscellaneous other allowed modes

$(5\pi)^- \nu_\tau$		$(7.4 \pm 0.7) \times 10^{-3}$		–
$4h^- 3h^+ \geq 0$ neutrals ν_τ ("7-prong")		$< 2.4 \times 10^{-6}$	CL=90%	–
$K^*(892)^- \geq 0(h^0 \neq K^0_S)\nu_\tau$		(1.94 ± 0.31) %		–
$K^*(892)^- \geq 0$ neutrals ν_τ		(1.33 ± 0.13) %		–
$K^*(892)^- \nu_\tau$		(1.28 ± 0.08) %		665
$K^*(892)^0 K^- \geq 0$ neutrals ν_τ		$(3.2 \pm 1.4) \times 10^{-3}$		–
$K^*(892)^0 K^- \nu_\tau$		$(2.1 \pm 0.4) \times 10^{-3}$		539
$\overline{K}^*(892)^0 \pi^- \geq 0$ neutrals ν_τ		$(3.8 \pm 1.7) \times 10^{-3}$		–
$\overline{K}^*(892)^0 \pi^- \nu_\tau$		$(2.2 \pm 0.5) \times 10^{-3}$		653
$(\overline{K}^*(892)\pi)^- \nu_\tau \rightarrow \pi^- \overline{K}^0 \pi^0 \nu_\tau$		$(1.1 \pm 0.5) \times 10^{-3}$		–
$K_1(1270)^- \nu_\tau$		$(4 \pm 4) \times 10^{-3}$		433
$K_1(1400)^- \nu_\tau$		$(8 \pm 4) \times 10^{-3}$		335
$K_2^*(1430)^- \nu_\tau$		$< 3 \times 10^{-3}$	CL=95%	317
$\eta \pi^- \nu_\tau$		$< 1.4 \times 10^{-4}$	CL=95%	798
$\eta \pi^- \pi^0 \nu_\tau$	[i]	$(1.74 \pm 0.24) \times 10^{-3}$		778
$\eta \pi^- \pi^0 \pi^0 \nu_\tau$		$(1.4 \pm 0.7) \times 10^{-4}$		746
$\eta K^- \nu_\tau$		$(2.7 \pm 0.6) \times 10^{-4}$		720
$\eta \pi^+ \pi^- \pi^- \geq 0$ neutrals ν_τ		$< 3 \times 10^{-3}$	CL=90%	–
$\eta \pi^- \pi^+ \pi^- \nu_\tau$		$(3.4 \pm 0.8) \times 10^{-4}$		–
$\eta a_1(1260)^- \nu_\tau \rightarrow \eta \pi^- \rho^0 \nu_\tau$		$< 3.9 \times 10^{-4}$	CL=90%	–
$\eta \eta \pi^- \nu_\tau$		$< 1.1 \times 10^{-4}$	CL=95%	637
$\eta \eta \pi^- \pi^0 \nu_\tau$		$< 2.0 \times 10^{-4}$	CL=95%	559
$\eta'(958) \pi^- \nu_\tau$		$< 7.4 \times 10^{-5}$	CL=90%	–
$\eta'(958) \pi^- \pi^0 \nu_\tau$		$< 8.0 \times 10^{-5}$	CL=90%	–
$\phi \pi^- \nu_\tau$		$< 2.0 \times 10^{-4}$	CL=90%	585
$\phi K^- \nu_\tau$		$< 6.7 \times 10^{-5}$	CL=90%	–
$f_1(1285) \pi^- \nu_\tau$		$(5.8 \pm 2.3) \times 10^{-4}$		–
$f_1(1285) \pi^- \nu_\tau \rightarrow \eta \pi^- \pi^+ \pi^- \nu_\tau$		$(1.9 \pm 0.7) \times 10^{-4}$		–
$h^- \omega \geq 0$ neutrals ν_τ		(2.36 ± 0.08) %		–
$h^- \omega \nu_\tau$	[i]	(1.93 ± 0.06) %		–
$h^- \omega \pi^0 \nu_\tau$	[i]	$(4.3 \pm 0.5) \times 10^{-3}$		–
$h^- \omega 2\pi^0 \nu_\tau$		$(1.9 \pm 0.8) \times 10^{-4}$		–

Lepton Family number (LF), Lepton number (L), or Baryon number (B) violating modes (In the modes below, ℓ means a sum over e and μ modes)

L means lepton number violation (*e.g.* $\tau^- \to e^+\pi^-\pi^-$). Following common usage, LF means lepton family violation *and not* lepton number violation (*e.g.* $\tau^- \to e^-\pi^+\pi^-$). B means baryon number violation.

$e^-\gamma$	LF	$<$	2.7	$\times 10^{-6}$	CL=90%	888
$\mu^-\gamma$	LF	$<$	3.0	$\times 10^{-6}$	CL=90%	885
$e^-\pi^0$	LF	$<$	3.7	$\times 10^{-6}$	CL=90%	883
$\mu^-\pi^0$	LF	$<$	4.0	$\times 10^{-6}$	CL=90%	880
e^-K^0	LF	$<$	1.3	$\times 10^{-3}$	CL=90%	819
μ^-K^0	LF	$<$	1.0	$\times 10^{-3}$	CL=90%	815
$e^-\eta$	LF	$<$	8.2	$\times 10^{-6}$	CL=90%	804
$\mu^-\eta$	LF	$<$	9.6	$\times 10^{-6}$	CL=90%	800
$e^-\rho^0$	LF	$<$	2.0	$\times 10^{-6}$	CL=90%	722
$\mu^-\rho^0$	LF	$<$	6.3	$\times 10^{-6}$	CL=90%	718
$e^-K^*(892)^0$	LF	$<$	5.1	$\times 10^{-6}$	CL=90%	663
$\mu^-K^*(892)^0$	LF	$<$	7.5	$\times 10^{-6}$	CL=90%	657
$e^-\overline{K}^*(892)^0$	LF	$<$	7.4	$\times 10^{-6}$	CL=90%	663
$\mu^-\overline{K}^*(892)^0$	LF	$<$	7.5	$\times 10^{-6}$	CL=90%	657
$e^-\phi$	LF	$<$	6.9	$\times 10^{-6}$	CL=90%	596
$\mu^-\phi$	LF	$<$	7.0	$\times 10^{-6}$	CL=90%	590
$\pi^-\gamma$	L	$<$	2.8	$\times 10^{-4}$	CL=90%	883
$\pi^-\pi^0$	L	$<$	3.7	$\times 10^{-4}$	CL=90%	878
$e^-e^+e^-$	LF	$<$	2.9	$\times 10^{-6}$	CL=90%	888
$e^-\mu^+\mu^-$	LF	$<$	1.8	$\times 10^{-6}$	CL=90%	882
$e^+\mu^-\mu^-$	LF	$<$	1.5	$\times 10^{-6}$	CL=90%	882
$\mu^-e^+e^-$	LF	$<$	1.7	$\times 10^{-6}$	CL=90%	885
$\mu^+e^-e^-$	LF	$<$	1.5	$\times 10^{-6}$	CL=90%	885
$\mu^-\mu^+\mu^-$	LF	$<$	1.9	$\times 10^{-6}$	CL=90%	873
$e^-\pi^+\pi^-$	LF	$<$	2.2	$\times 10^{-6}$	CL=90%	877
$e^+\pi^-\pi^-$	L	$<$	1.9	$\times 10^{-6}$	CL=90%	877
$\mu^-\pi^+\pi^-$	LF	$<$	8.2	$\times 10^{-6}$	CL=90%	866
$\mu^+\pi^-\pi^-$	L	$<$	3.4	$\times 10^{-6}$	CL=90%	866
$e^-\pi^+K^-$	LF	$<$	6.4	$\times 10^{-6}$	CL=90%	814
$e^-\pi^-K^+$	LF	$<$	3.8	$\times 10^{-6}$	CL=90%	814
$e^+\pi^-K^-$	L	$<$	2.1	$\times 10^{-6}$	CL=90%	814
$e^-K^+K^-$	LF	$<$	6.0	$\times 10^{-6}$	CL=90%	739
$e^+K^-K^-$	L	$<$	3.8	$\times 10^{-6}$	CL=90%	739
$\mu^-\pi^+K^-$	LF	$<$	7.5	$\times 10^{-6}$	CL=90%	800
$\mu^-\pi^-K^+$	LF	$<$	7.4	$\times 10^{-6}$	CL=90%	800
$\mu^+\pi^-K^-$	L	$<$	7.0	$\times 10^{-6}$	CL=90%	800

$\mu^- K^+ K^-$	*LF*	$<$	1.5	$\times 10^{-5}$	CL=90%	699
$\mu^+ K^- K^-$	*L*	$<$	6.0	$\times 10^{-6}$	CL=90%	699
$e^- \pi^0 \pi^0$	*LF*	$<$	6.5	$\times 10^{-6}$	CL=90%	878
$\mu^- \pi^0 \pi^0$	*LF*	$<$	1.4	$\times 10^{-5}$	CL=90%	867
$e^- \eta\eta$	*LF*	$<$	3.5	$\times 10^{-5}$	CL=90%	700
$\mu^- \eta\eta$	*LF*	$<$	6.0	$\times 10^{-5}$	CL=90%	654
$e^- \pi^0 \eta$	*LF*	$<$	2.4	$\times 10^{-5}$	CL=90%	798
$\mu^- \pi^0 \eta$	*LF*	$<$	2.2	$\times 10^{-5}$	CL=90%	784
$\overline{p}\gamma$	*L,B*	$<$	2.9	$\times 10^{-4}$	CL=90%	641
$\overline{p}\pi^0$	*L,B*	$<$	6.6	$\times 10^{-4}$	CL=90%	632
$\overline{p}\eta$	*L,B*	$<$	1.30	$\times 10^{-3}$	CL=90%	476
e^- light boson	*LF*	$<$	2.7	$\times 10^{-3}$	CL=95%	–
μ^- light boson	*LF*	$<$	5	$\times 10^{-3}$	CL=95%	–

Heavy Charged Lepton Searches

$L^\pm$ – charged lepton

Mass $m >$ 80.2 GeV, CL = 95% $m_\nu \approx 0$

$L^\pm$ – stable charged heavy lepton

Mass $m >$ 84.2 GeV, CL = 95%

Neutrinos

See the Particle Listings for a Note "Neutrino Mass" giving details of neutrinos, masses, mixing, and the status of experimental searches.

ν_e

$J = \frac{1}{2}$

Mass m: Unexplained effects have resulted in significantly negative m^2 in the new, precise tritium beta decay experiments. It is felt that a real neutrino mass as large as 10–15 eV would cause observable spectral distortions even in the presence of the end-point count excesses.

Mean life/mass, $\tau/m_{\nu_e} > 7 \times 10^9$ s/eV   (solar)

Mean life/mass, $\tau/m_{\nu_e} >$ 300 s/eV, CL = 90%   (reactor)

Magnetic moment $\mu < 1.8 \times 10^{-10}\ \mu_B$, CL = 90%

ν_μ

$J = \frac{1}{2}$

Mass $m <$ 0.17 MeV, CL = 90%
Mean life/mass, $\tau/m_{\nu_\mu} >$ 15.4 s/eV, CL = 90%
Magnetic moment $\mu < 7.4 \times 10^{-10}\ \mu_B$, CL = 90%

ν_τ

$J = \frac{1}{2}$

Mass $m <$ 18.2 MeV, CL = 95%
Magnetic moment $\mu < 5.4 \times 10^{-7}\ \mu_B$, CL = 90%
Electric dipole moment $d < 5.2 \times 10^{-17}\ e\,\text{cm}$, CL = 95%

Number of Light Neutrino Types

(including ν_e, ν_μ, and ν_τ)
Number $N = 2.994 \pm 0.012$ (Standard Model fits to LEP data)
Number $N = 3.07 \pm 0.12$ (Direct measurement of invisible Z width)

Massive Neutrinos and Lepton Mixing, Searches for

For excited leptons, see Compositeness Limits below.

See the Particle Listings for a Note "Neutrino Mass" giving details of neutrinos, masses, mixing, and the status of experimental searches.

While no direct, uncontested evidence for massive neutrinos or lepton mixing has been obtained, suggestive evidence has come from solar neutrino observations, from anomalies in the relative fractions of ν_e and ν_μ observed in energetic cosmic-ray air showers, and possibly from a $\overline{\nu}_e$ appearance experiment at Los Alamos. Sample limits are:

Stable Neutral Heavy Lepton Mass Limits

Mass $m >$ 45.0 GeV, CL = 95% (Dirac)
Mass $m >$ 39.5 GeV, CL = 95% (Majorana)

Neutral Heavy Lepton Mass Limits

Mass $m >$ 69.0 GeV, CL = 95% (Dirac ν_L coupling to e, μ, τ with $|U_{\ell j}|^2 > 10^{-12}$)
Mass $m >$ 58.2 GeV, CL = 95% (Majorana ν_L coupling to e, μ, τ with $|U_{\ell j}|^2 > 10^{-12}$)

Solar Neutrinos

Detectors using gallium ($E_\nu \gtrsim 0.2$ MeV), chlorine ($E_\nu \gtrsim 0.8$ MeV), and Ĉerenkov effect in water ($E_\nu \gtrsim 7$ MeV) measure significantly lower neutrino rates than are predicted from solar models. The deficit in the solar neutrino flux compared with solar model calculations could be explained by oscillations with $\Delta m^2 \leq 10^{-5}$ eV^2 causing the disappearance of ν_e.

Atmospheric Neutrinos

Underground detectors observing neutrinos produced by cosmic rays in the atmosphere have measured a ν_μ/ν_e ratio much less than expected and also a deficiency of upward going ν_μ compared to downward. This could be explained by oscillations leading to the disappearance of ν_μ with $\Delta m^2 \approx 10^{-3}$ to 10^{-2} eV^2.

ν oscillation: $\overline{\nu}_e \not\to \overline{\nu}_e$ (θ = mixing angle)

$\Delta m^2 < 9 \times 10^{-4}$ eV^2, CL = 90% (if $\sin^2 2\theta = 1$)
$\sin^2 2\theta < 0.02$, CL = 90% (if $\Delta(m^2)$ is large)

ν oscillation: ν_μ ($\overline{\nu}_\mu$) $\to$ ν_e ($\overline{\nu}_e$) (any combination)

$\Delta m^2 < 0.075$ eV^2, CL = 90% (if $\sin^2 2\theta = 1$)
$\sin^2 2\theta < 1.8 \times 10^{-3}$, CL = 90% (if $\Delta(m^2)$ is large)

NOTES

[*a*] The uncertainty in the electron mass in unified atomic mass units (u) is ten times smaller than that given by the 1986 CODATA adjustment, quoted in the Table of Physical Constants (Section 1). The conversion to MeV via the factor 931.49432(28) MeV/u is more uncertain because of the electron charge uncertainty. Our value in MeV differs slightly from the 1986 CODATA result.

[*b*] This is the best "electron disappearance" limit. The best limit for the mode $e^- \rightarrow \nu\gamma$ is $> 2.35 \times 10^{25}$ yr (CL=68%).

[*c*] The muon mass is most precisely known in u (unified atomic mass units). The conversion factor to MeV via the factor 931.49432(28) MeV/u is more uncertain because of the electron charge uncertainty.

[*d*] See the "Note on Muon Decay Parameters" in the μ Particle Listings for definitions and details.

[*e*] P_μ is the longitudinal polarization of the muon from pion decay. In standard $V{-}A$ theory, $P_\mu = 1$ and $\rho = \delta = 3/4$.

[*f*] This only includes events with the γ energy > 10 MeV. Since the $e^- \overline{\nu}_e \nu_\mu$ and $e^- \overline{\nu}_e \nu_\mu \gamma$ modes cannot be clearly separated, we regard the latter mode as a subset of the former.

[*g*] See the μ Particle Listings for the energy limits used in this measurement.

[*h*] A test of additive vs. multiplicative lepton family number conservation.

[*i*] Basis mode for the τ.

QUARKS

The *u*-, *d*-, and *s*-quark masses are estimates of so-called "current-quark masses," in a mass-independent subtraction scheme such as $\overline{\text{MS}}$ at a scale $\mu \approx 2$ GeV. The *c*- and *b*-quark masses are estimated from charmonium, bottomonium, *D*, and *B* masses. They are the "running" masses in the $\overline{\text{MS}}$ scheme. These can be different from the heavy quark masses obtained in potential models.

u

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Mass $m = 1.5$ to 5 MeV [a] Charge $= \frac{2}{3}\,e$ $I_z = +\frac{1}{2}$

$m_u/m_d = 0.20$ to 0.70

d

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Mass $m = 3$ to 9 MeV [a] Charge $= -\frac{1}{3}\,e$ $I_z = -\frac{1}{2}$

$m_s/m_d = 17$ to 25

$\overline{m} = (m_u+m_d)/2 = 2$ to 6 MeV

s

$I(J^P) = 0(\frac{1}{2}^+)$

Mass $m = 60$ to 170 MeV [a] Charge $= -\frac{1}{3}\,e$ Strangeness $= -1$

$(m_s - (m_u + m_d)/2)/(m_d - m_u) = 34$ to 51

c

$I(J^P) = 0(\frac{1}{2}^+)$

Mass $m = 1.1$ to 1.4 GeV Charge $= \frac{2}{3}\,e$ Charm $= +1$

b

$I(J^P) = 0(\frac{1}{2}^+)$

Mass $m = 4.1$ to 4.4 GeV Charge $= -\frac{1}{3}\,e$ Bottom $= -1$

t

$I(J^P) = 0(\frac{1}{2}^+)$

Charge = $\frac{2}{3}$ e Top = $+1$

Mass $m = 173.8 \pm 5.2$ GeV (direct observation of top events)
Mass $m = 170 \pm 7$ $(+14)$ GeV (Standard Model electroweak fit, assuming $M_H = M_Z$. Number in parentheses is shift from changing M_H to 300 GeV.

b′ (4th Generation) Quark, Searches for

Mass $m >$ 128 GeV, CL = 95% ($p\overline{p}$, charged current decays)
Mass $m >$ 46.0 GeV, CL = 95% ($e^+ e^-$, all decays)

Free Quark Searches

All searches since 1977 have had negative results.

NOTES

[*a*] The ratios m_u/m_d and m_s/m_d are extracted from pion and kaon masses using chiral symmetry. The estimates of u and d masses are not without controversy and remain under active investigation. Within the literature there are even suggestions that the u quark could be essentially massless. The s-quark mass is estimated from SU(3) splittings in hadron masses.

LIGHT UNFLAVORED MESONS ($S = C = B = 0$)

For $I = 1$ (π, b, ρ, a): $u\overline{d}$, $(u\overline{u}-d\overline{d})/\sqrt{2}$, $d\overline{u}$;
for $I = 0$ (η, η', h, h', ω, ϕ, f, f'): $c_1(u\overline{u} + d\overline{d}) + c_2(s\overline{s})$

$\pi^{\pm}$

$I^G(J^P) = 1^-(0^-)$

Mass $m = 139.56995 \pm 0.00035$ MeV
Mean life $\tau = (2.6033 \pm 0.0005) \times 10^{-8}$ s (S = 1.2)
$c\tau = 7.8045$ m

$\pi^{\pm} \rightarrow \ell^{\pm}\nu\gamma$ form factors [a]

$F_V = 0.017 \pm 0.008$
$F_A = 0.0116 \pm 0.0016$ (S = 1.3)
$R = 0.059^{+0.009}_{-0.008}$

π^- modes are charge conjugates of the modes below.

π^+ DECAY MODES			Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\mu^+\nu_\mu$		[b]	(99.98770 ± 0.00004) %		30
$\mu^+\nu_\mu\gamma$		[c]	$(1.24 \pm 0.25) \times 10^{-4}$		30
$e^+\nu_e$		[b]	$(1.230 \pm 0.004) \times 10^{-4}$		70
$e^+\nu_e\gamma$		[c]	$(1.61 \pm 0.23) \times 10^{-7}$		70
$e^+\nu_e\pi^0$			$(1.025 \pm 0.034) \times 10^{-8}$		4
$e^+\nu_e e^+ e^-$			$(3.2 \pm 0.5) \times 10^{-9}$		70
$e^+\nu_e\nu\overline{\nu}$			$< 5 \times 10^{-6}$	90%	70
Lepton Family number (*LF*) or Lepton number (*L*) violating modes					
$\mu^+\overline{\nu}_e$	*L*	[d]	$< 1.5 \times 10^{-3}$	90%	30
$\mu^+\nu_e$	*LF*	[d]	$< 8.0 \times 10^{-3}$	90%	30
$\mu^- e^+ e^+ \nu$	*LF*		$< 1.6 \times 10^{-6}$	90%	30

π^0

$I^G(J^{PC}) = 1^-(0^{-+})$

Mass $m = 134.9764 \pm 0.0006$ MeV

$m_{\pi^\pm} - m_{\pi^0} = 4.5936 \pm 0.0005$ MeV

Mean life $\tau = (8.4 \pm 0.6) \times 10^{-17}$ s (S = 3.0)

$c\tau = 25.1$ nm

π^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
2γ		(98.798 ± 0.032) %	S=1.1	67
$e^+ e^- \gamma$		(1.198 ± 0.032) %	S=1.1	67
γ positronium		$(1.82 \pm 0.29) \times 10^{-9}$		67
$e^+ e^+ e^- e^-$		$(3.14 \pm 0.30) \times 10^{-5}$		67
$e^+ e^-$		$(7.5 \pm 2.0) \times 10^{-8}$		67
4γ		$< 2 \times 10^{-8}$	CL=90%	67
$\nu\overline{\nu}$		[e] $< 8.3 \times 10^{-7}$	CL=90%	67
$\nu_e \overline{\nu}_e$		$< 1.7 \times 10^{-6}$	CL=90%	67
$\nu_\mu \overline{\nu}_\mu$		$< 3.1 \times 10^{-6}$	CL=90%	67
$\nu_\tau \overline{\nu}_\tau$		$< 2.1 \times 10^{-6}$	CL=90%	67
Charge conjugation (C) or Lepton Family number (LF) violating modes				
3γ	C	$< 3.1 \times 10^{-8}$	CL=90%	67
$\mu^+ e^- + e^- \mu^+$	LF	$< 1.72 \times 10^{-8}$	CL=90%	26

η

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 547.30 \pm 0.12$ MeV
Full width $\Gamma = 1.18 \pm 0.11$ keV [f] (S = 1.8)

C-nonconserving decay parameters

$\pi^+\pi^-\pi^0$ Left-right asymmetry $= (0.09 \pm 0.17) \times 10^{-2}$
$\pi^+\pi^-\pi^0$ Sextant asymmetry $= (0.18 \pm 0.16) \times 10^{-2}$
$\pi^+\pi^-\pi^0$ Quadrant asymmetry $= (-0.17 \pm 0.17) \times 10^{-2}$
$\pi^+\pi^-\gamma$ Left-right asymmetry $= (0.9 \pm 0.4) \times 10^{-2}$
$\pi^+\pi^-\gamma$ β (D-wave) $= 0.05 \pm 0.06$ (S = 1.5)

Dalitz plot parameter

$\pi^0\pi^0\pi^0$ $\alpha = -0.039 \pm 0.015$

η DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Neutral modes				
neutral modes		(71.5 ± 0.6) %	S=1.4	–
2γ	[f]	(39.21 ± 0.34) %	S=1.4	274
$3\pi^0$		(32.2 ± 0.4) %	S=1.3	178
$\pi^0 2\gamma$		$(7.1 \pm 1.4) \times 10^{-4}$		257
other neutral modes		< 2.8 %	CL=90%	–
Charged modes				
charged modes		(28.5 ± 0.6) %	S=1.4	–
$\pi^+\pi^-\pi^0$		(23.1 ± 0.5) %	S=1.4	173
$\pi^+\pi^-\gamma$		(4.77 ± 0.13) %	S=1.3	235
$e^+e^-\gamma$		$(4.9 \pm 1.1) \times 10^{-3}$		274
$\mu^+\mu^-\gamma$		$(3.1 \pm 0.4) \times 10^{-4}$		252
e^+e^-		$< 7.7 \times 10^{-5}$	CL=90%	274
$\mu^+\mu^-$		$(5.8 \pm 0.8) \times 10^{-6}$		252
$\pi^+\pi^-e^+e^-$		$(1.3 ^{+1.2}_{-0.8}) \times 10^{-3}$		235
$\pi^+\pi^-2\gamma$		$< 2.1 \times 10^{-3}$		235
$\pi^+\pi^-\pi^0\gamma$		$< 6 \times 10^{-4}$	CL=90%	173
$\pi^0\mu^+\mu^-\gamma$		$< 3 \times 10^{-6}$	CL=90%	210
Charge conjugation (C), Parity (P), Charge conjugation × Parity (CP), or Lepton Family number (LF) violating modes				
$\pi^+\pi^-$	P,CP	$< 9 \times 10^{-4}$	CL=90%	235
3γ	C	$< 5 \times 10^{-4}$	CL=95%	274
$\pi^0 e^+e^-$	C [g]	$< 4 \times 10^{-5}$	CL=90%	257
$\pi^0\mu^+\mu^-$	C [g]	$< 5 \times 10^{-6}$	CL=90%	210
$\mu^+e^- + \mu^-e^+$	LF	$< 6 \times 10^{-6}$	CL=90%	263

$f_0(400\text{–}1200)$ [h] or σ

$I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = (400\text{–}1200)$ MeV
Full width $\Gamma = (600\text{–}1000)$ MeV

$f_0(400\text{–}1200)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	dominant	–
$\gamma\gamma$	seen	–

$\rho(770)$ [i]

$I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 770.0 \pm 0.8$ MeV (S = 1.8)
Full width $\Gamma = 150.7 \pm 1.1$ MeV
$\Gamma_{ee} = 6.77 \pm 0.32$ keV

$\rho(770)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi\pi$		$\sim$ 100 %		358
$\rho(770)^\pm$ decays				
$\pi^\pm\gamma$		$(4.5 \pm 0.5) \times 10^{-4}$	S=2.2	372
$\pi^\pm\eta$		$< 6 \times 10^{-3}$	CL=84%	146
$\pi^\pm\pi^+\pi^-\pi^0$		$< 2.0 \times 10^{-3}$	CL=84%	249
$\rho(770)^0$ decays				
$\pi^+\pi^-\gamma$		$(9.9 \pm 1.6) \times 10^{-3}$		358
$\pi^0\gamma$		$(6.8 \pm 1.7) \times 10^{-4}$		372
$\eta\gamma$		$(2.4 {+0.8 \atop -0.9}) \times 10^{-4}$	S=1.6	189
$\mu^+\mu^-$	[j]	$(4.60 \pm 0.28) \times 10^{-5}$		369
e^+e^-	[j]	$(4.49 \pm 0.22) \times 10^{-5}$		384
$\pi^+\pi^-\pi^0$		$< 1.2 \times 10^{-4}$	CL=90%	319
$\pi^+\pi^-\pi^+\pi^-$		$< 2 \times 10^{-4}$	CL=90%	246
$\pi^+\pi^-\pi^0\pi^0$		$< 4 \times 10^{-5}$	CL=90%	252

$\omega(782)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 781.94 \pm 0.12$ MeV (S = 1.5)
Full width $\Gamma = 8.41 \pm 0.09$ MeV
$\Gamma_{ee} = 0.60 \pm 0.02$ keV

ω(782) DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi^+\pi^-\pi^0$		(88.8 ±0.7) %		327
$\pi^0\gamma$		(8.5 ±0.5) %		379
$\pi^+\pi^-$		(2.21±0.30) %		365
neutrals (excluding $\pi^0\gamma$)		(5.3 $^{+8.7}_{-3.5}$) $\times 10^{-3}$		–
$\eta\gamma$		(6.5 ±1.0) $\times 10^{-4}$		199
$\pi^0 e^+ e^-$		(5.9 ±1.9) $\times 10^{-4}$		379
$\pi^0\mu^+\mu^-$		(9.6 ±2.3) $\times 10^{-5}$		349
e^+e^-		(7.07±0.19) $\times 10^{-5}$	S=1.1	391
$\pi^+\pi^-\pi^0\pi^0$		< 2 %	CL=90%	261
$\pi^+\pi^-\gamma$		< 3.6 $\times 10^{-3}$	CL=95%	365
$\pi^+\pi^-\pi^+\pi^-$		< 1 $\times 10^{-3}$	CL=90%	256
$\pi^0\pi^0\gamma$		(7.2 ±2.5) $\times 10^{-5}$		367
$\mu^+\mu^-$		< 1.8 $\times 10^{-4}$	CL=90%	376
3γ		< 1.9 $\times 10^{-4}$	CL=95%	391
Charge conjugation (C) violating modes				
$\eta\pi^0$	C	< 1 $\times 10^{-3}$	CL=90%	162
$3\pi^0$	C	< 3 $\times 10^{-4}$	CL=90%	329

$\eta'(958)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 957.78 \pm 0.14$ MeV
Full width $\Gamma = 0.203 \pm 0.016$ MeV (S = 1.3)

$\eta'(958)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi^+\pi^-\eta$		(43.8 ± 1.5) %	S=1.1	232
$\rho^0\gamma$ (including non-resonant $\pi^+\pi^-\gamma$)		(30.2 ± 1.3) %	S=1.1	169
$\pi^0\pi^0\eta$		(20.7 ± 1.3) %	S=1.2	239
$\omega\gamma$		(3.01 ± 0.30) %		160
$\gamma\gamma$		(2.11 ± 0.13) %	S=1.2	479
$3\pi^0$		$(1.54 \pm 0.26) \times 10^{-3}$		430
$\mu^+\mu^-\gamma$		$(1.03 \pm 0.26) \times 10^{-4}$		467
$\pi^+\pi^-\pi^0$		< 5 %	CL=90%	427
$\pi^0\rho^0$		< 4 %	CL=90%	118
$\pi^+\pi^+\pi^-\pi^-$		< 1 %	CL=90%	372
$\pi^+\pi^+\pi^-\pi^-$ neutrals		< 1 %	CL=95%	–
$\pi^+\pi^+\pi^-\pi^-\pi^0$		< 1 %	CL=90%	298
6π		< 1 %	CL=90%	189
$\pi^+\pi^-e^+e^-$		$< 6 \times 10^{-3}$	CL=90%	458
$\pi^0\gamma\gamma$		$< 8 \times 10^{-4}$	CL=90%	469
$4\pi^0$		$< 5 \times 10^{-4}$	CL=90%	379
e^+e^-		$< 2.1 \times 10^{-7}$	CL=90%	479
Charge conjugation (C) or Parity (P) violating modes				
$\pi^+\pi^-$	P,CP	< 2 %	CL=90%	458
$\pi^0\pi^0$	P,CP	$< 9 \times 10^{-4}$	CL=90%	459
$\pi^0e^+e^-$	C [g]	< 1.3 %	CL=90%	469
ηe^+e^-	C [g]	< 1.1 %	CL=90%	322
3γ	C	$< 1.0 \times 10^{-4}$	CL=90%	479
$\mu^+\mu^-\pi^0$	C [g]	$< 6.0 \times 10^{-5}$	CL=90%	445
$\mu^+\mu^-\eta$	C [g]	$< 1.5 \times 10^{-5}$	CL=90%	274

$f_0(980)$ [k]

$I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 980 \pm 10$ MeV
Full width $\Gamma = 40$ to 100 MeV

$f_0(980)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\pi\pi$	dominant		470
$K\overline{K}$	seen		–
$\gamma\gamma$	$(1.19\pm0.33) \times 10^{-5}$		490
e^+e^-	$< 3 \times 10^{-7}$	90%	490

$a_0(980)$ [k]

$I^G(J^{PC}) = 1^-(0^{++})$

Mass $m = 983.4 \pm 0.9$ MeV
Full width $\Gamma = 50$ to 100 MeV

$a_0(980)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\eta\pi$	dominant	321
$K\overline{K}$	seen	–
$\gamma\gamma$	seen	492

$\phi(1020)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 1019.413 \pm 0.008$ MeV
Full width $\Gamma = 4.43 \pm 0.05$ MeV

$\phi(1020)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
K^+K^-	(49.1 ± 0.8) %	S=1.3	127
$K^0_L K^0_S$	(34.1 ± 0.6) %	S=1.2	110
$\rho\pi + \pi^+\pi^-\pi^0$	(15.5 ± 0.7) %	S=1.5	–
$\eta\gamma$	(1.26 ± 0.06) %	S=1.1	363
$\pi^0\gamma$	$(1.31 \pm 0.13) \times 10^{-3}$		501
e^+e^-	$(2.99 \pm 0.08) \times 10^{-4}$	S=1.2	510
$\mu^+\mu^-$	$(2.5 \pm 0.4) \times 10^{-4}$		499
ηe^+e^-	$(1.3 ^{+0.8}_{-0.6}) \times 10^{-4}$		363
$\pi^+\pi^-$	$(8 ^{+5}_{-4}) \times 10^{-5}$	S=1.5	490
$\omega\gamma$	< 5 %	CL=84%	210
$\rho\gamma$	$< 7 \times 10^{-4}$	CL=90%	219
$\pi^+\pi^-\gamma$	$< 3 \times 10^{-5}$	CL=90%	490
$f_0(980)\gamma$	$< 1 \times 10^{-4}$	CL=90%	39
$\pi^0\pi^0\gamma$	$< 1 \times 10^{-3}$	CL=90%	492
$\pi^+\pi^-\pi^+\pi^-$	$< 8.7 \times 10^{-4}$	CL=90%	410
$\pi^+\pi^+\pi^-\pi^-\pi^0$	$< 1.5 \times 10^{-4}$	CL=95%	341
$\pi^0 e^+e^-$	$< 1.2 \times 10^{-4}$	CL=90%	501
$\pi^0\eta\gamma$	$< 2.5 \times 10^{-3}$	CL=90%	346
$a_0(980)\gamma$	$< 5 \times 10^{-3}$	CL=90%	36
$\eta'(958)\gamma$	$(1.2 ^{+0.7}_{-0.5}) \times 10^{-4}$		–
$\mu^+\mu^-\gamma$	$(2.3 \pm 1.0) \times 10^{-5}$		–

$h_1(1170)$

$I^G(J^{PC}) = 0^-(1^{+-})$

Mass $m = 1170 \pm 20$ MeV
Full width $\Gamma = 360 \pm 40$ MeV

$h_1(1170)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\rho\pi$	seen	310

$b_1(1235)$

$I^G(J^{PC}) = 1^+(1^{+-})$

Mass $m = 1229.5 \pm 3.2$ MeV (S = 1.6)
Full width $\Gamma = 142 \pm 9$ MeV (S = 1.2)

$b_1(1235)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\omega\pi$	dominant		348
[D/S amplitude ratio $= 0.29 \pm 0.04$]			
$\pi^\pm\gamma$	$(1.6\pm0.4)\times10^{-3}$		608
$\eta\rho$	seen		–
$\pi^+\pi^+\pi^-\pi^0$	< 50 %	84%	536
$(K\overline{K})^\pm\pi^0$	< 8 %	90%	248
$K^0_S K^0_L \pi^\pm$	< 6 %	90%	238
$K^0_S K^0_S \pi^\pm$	< 2 %	90%	238
$\phi\pi$	< 1.5 %	84%	146

$a_1(1260)$ [l]

$I^G(J^{PC}) = 1^-(1^{++})$

Mass $m = 1230 \pm 40$ MeV [m]
Full width $\Gamma = 250$ to 600 MeV

$a_1(1260)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\rho\pi$	dominant	356
[D/S amplitude ratio $= -0.100 \pm 0.028$]		
$\pi\gamma$	seen	607
$\pi(\pi\pi)_{S\text{-wave}}$	possibly seen	575

$f_2(1270)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 1275.0 \pm 1.2$ MeV
Full width $\Gamma = 185.5^{+3.8}_{-2.7}$ MeV (S = 1.5)

$f_2(1270)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi\pi$	$(84.6\ ^{+2.5}_{-1.3})$ %	S=1.3	622
$\pi^+\pi^-2\pi^0$	$(7.2\ ^{+1.5}_{-2.7})$ %	S=1.3	562
$K\overline{K}$	(4.6 ± 0.4) %	S=2.8	403
$2\pi^+2\pi^-$	(2.8 ± 0.4) %	S=1.2	559
$\eta\eta$	$(4.5 \pm 1.0) \times 10^{-3}$	S=2.4	327
$4\pi^0$	$(3.0 \pm 1.0) \times 10^{-3}$		564
$\gamma\gamma$	$(1.32^{+0.17}_{-0.16}) \times 10^{-5}$		637
$\eta\pi\pi$	$< 8 \times 10^{-3}$	CL=95%	475
$K^0K^-\pi^+$ + c.c.	$< 3.4 \times 10^{-3}$	CL=95%	293
e^+e^-	$< 9 \times 10^{-9}$	CL=90%	637

$f_1(1285)$

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 1281.9 \pm 0.6$ MeV (S = 1.7)
Full width $\Gamma = 24.0 \pm 1.2$ MeV (S = 1.4)

$(4\pi = \rho(\pi\pi)_{Pwave})$

$f_1(1285)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
4π	(35 ± 4) %	S=1.6	563
$\pi^0\pi^0\pi^+\pi^-$	(23.5 ± 3.0) %	S=1.6	566
$2\pi^+2\pi^-$	(11.7 ± 1.5) %	S=1.6	563
$\rho^0\pi^+\pi^-$	(11.7 ± 1.5) %	S=1.6	340
$4\pi^0$	$< 7 \times 10^{-4}$	CL=90%	568
$\eta\pi\pi$	(50 ± 18) %		479
$a_0(980)\pi$ [ignoring $a_0(980) \rightarrow K\overline{K}$]	(34 ± 8) %	S=1.2	234
$\eta\pi\pi$ [excluding $a_0(980)\pi$]	(15 ± 7) %	S=1.1	–
$K\overline{K}\pi$	(9.6 ± 1.2) %	S=1.5	308
$K\overline{K}^*(892)$	not seen		–
$\gamma\rho^0$	(5.4 ± 1.2) %	S=2.3	410
$\phi\gamma$	$(7.9 \pm 3.0) \times 10^{-4}$		236

$\eta(1295)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 1297.0 \pm 2.8$ MeV
Full width $\Gamma = 53 \pm 6$ MeV

$\eta(1295)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\eta\pi^+\pi^-$	seen	488
$a_0(980)\pi$	seen	245
$\eta\pi^0\pi^0$	seen	–
$\eta(\pi\pi)_{S\text{-wave}}$	seen	–

$\pi(1300)$

$I^G(J^{PC}) = 1^-(0^{-+})$

Mass $m = 1300 \pm 100$ MeV [m]
Full width $\Gamma = 200$ to 600 MeV

$\pi(1300)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\rho\pi$	seen	406
$\pi(\pi\pi)_{S\text{-wave}}$	seen	–

$a_2(1320)$

$I^G(J^{PC}) = 1^-(2^{++})$

Mass $m = 1318.1 \pm 0.6$ MeV (S = 1.1)
Full width $\Gamma = 107 \pm 5$ MeV [m] ($K^\pm K^0_S$ and $\eta\pi$ modes)

$a_2(1320)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\rho\pi$	(70.1±2.7) %	S=1.2	419
$\eta\pi$	(14.5±1.2) %		535
$\omega\pi\pi$	(10.6±3.2) %	S=1.3	362
$K\overline{K}$	(4.9±0.8) %		437
$\eta'(958)\pi$	(5.3±0.9) $\times 10^{-3}$		287
$\pi^\pm\gamma$	(2.8±0.6) $\times 10^{-3}$		652
$\gamma\gamma$	(9.4±0.7) $\times 10^{-6}$		659
$\pi^+\pi^-\pi^-$	$<$ 8 %	CL=90%	621
e^+e^-	$<$ 2.3 $\times 10^{-7}$	CL=90%	659

$f_0(1370)$ [k]

$I^G(J^{PC}) = 0^+(0^{++})$

Mass m = 1200 to 1500 MeV
Full width Γ = 200 to 500 MeV

$f_0(1370)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	seen	–
4π	seen	–
$4\pi^0$	seen	–
$2\pi^+2\pi^-$	seen	–
$\pi^+\pi^-2\pi^0$	seen	–
$2(\pi\pi)_{S\text{-wave}}$	seen	–
$\eta\eta$	seen	–
$K\overline{K}$	seen	–
$\gamma\gamma$	seen	–
e^+e^-	not seen	–

$f_1(1420)$ [n]

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 1426.2 \pm 1.2$ MeV (S = 1.3)
Full width $\Gamma = 55.0 \pm 3.0$ MeV

$f_1(1420)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}\pi$	dominant	439
$K\overline{K}^*(892)+$ c.c.	dominant	155
$\eta\pi\pi$	possibly seen	571

$\omega(1420)$ [o]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 1419 \pm 31$ MeV
Full width $\Gamma = 174 \pm 60$ MeV

$\omega(1420)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\rho\pi$	dominant	488

$\eta(1440)$ [p]

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 1400$ - 1470 MeV [m]
Full width $\Gamma = 50$ - 80 MeV [m]

$\eta(1440)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}\pi$	seen	–
$K\overline{K}^*(892)+$ c.c.	seen	–
$\eta\pi\pi$	seen	–
$a_0(980)\pi$	seen	–
$\eta(\pi\pi)_{S\text{-wave}}$	seen	–
4π	seen	–

$a_0(1450)$

$I^G(J^{PC}) = 1^-(0^{++})$

Mass $m = 1474 \pm 19$ MeV
Full width $\Gamma = 265 \pm 13$ MeV

$a_0(1450)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\eta$	seen	613
$\pi\eta'(958)$	seen	392
$K\overline{K}$	seen	530

$\rho(1450)$ [q]

$I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 1465 \pm 25$ MeV [m]
Full width $\Gamma = 310 \pm 60$ MeV [m]

$\rho(1450)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\pi\pi$	seen		719
4π	seen		665
$\omega\pi$	<2.0 %	95%	512
e^+e^-	seen		732
$\eta\rho$	<4 %		317
$\phi\pi$	<1 %		358
$K\overline{K}$	$<1.6 \times 10^{-3}$	95%	541

$f_0(1500)$ [r]

$I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 1500 \pm 10$ MeV (S = 1.3)
Full width $\Gamma = 112 \pm 10$ MeV

$f_0(1500)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\eta\eta'(958)$	seen	–
$\eta\eta$	seen	513
4π	seen	–
$4\pi^0$	seen	690
$2\pi^+2\pi^-$	seen	686
2π	seen	–
$\pi^+\pi^-$	seen	737
$2\pi^0$	seen	738
$K\overline{K}$	seen	563

$f'_2(1525)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 1525 \pm 5$ MeV [m]
Full width $\Gamma = 76 \pm 10$ MeV [m]

$f'_2(1525)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}$	(88.8 ± 3.1) %	581
$\eta\eta$	(10.3 ± 3.1) %	531
$\pi\pi$	$(8.2 \pm 1.5) \times 10^{-3}$	750
$\gamma\gamma$	$(1.32 \pm 0.21) \times 10^{-6}$	763

$\omega(1600)$ [s]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 1649 \pm 24$ MeV (S = 2.3)
Full width $\Gamma = 220 \pm 35$ MeV (S = 1.6)

$\omega(1600)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\rho\pi$	seen	637
$\omega\pi\pi$	seen	601
e^+e^-	seen	824

$\omega_3(1670)$

$I^G(J^{PC}) = 0^-(3^{--})$

Mass $m = 1667 \pm 4$ MeV
Full width $\Gamma = 168 \pm 10$ MeV [m]

$\omega_3(1670)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\rho\pi$	seen	647
$\omega\pi\pi$	seen	614
$b_1(1235)\pi$	possibly seen	359

$\pi_2(1670)$

$I^G(J^{PC}) = 1^-(2^{-+})$

Mass $m = 1670 \pm 20$ MeV [m]
Full width $\Gamma = 258 \pm 18$ MeV [m] (S = 1.7)

$\pi_2(1670)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
3π	(95.8 ± 1.4) %	806
$f_2(1270)\pi$	(56.2 ± 3.2) %	325
$\rho\pi$	(31 ± 4) %	649
$f_0(1370)\pi$	(8.7 ± 3.4) %	–
$K\overline{K}^*(892)+$ c.c.	(4.2 ± 1.4) %	453

$\phi(1680)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 1680 \pm 20$ MeV [m]
Full width $\Gamma = 150 \pm 50$ MeV [m]

$\phi(1680)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}^*(892)+$ c.c.	dominant	463
$K^0_S K\pi$	seen	620
$K\overline{K}$	seen	681
e^+e^-	seen	840
$\omega\pi\pi$	not seen	622

$\rho_3(1690)$

$I^G(J^{PC}) = 1^+(3^{--})$

J^P from the 2π and $K\overline{K}$ modes.

Mass $m = 1691 \pm 5$ MeV [m]

Full width $\Gamma = 160 \pm 10$ MeV [m] (S = 1.5)

ρ_3(1690) DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
4π	(71.1 ± 1.9) %		788
$\pi^{\pm}\pi^+\pi^-\pi^0$	(67 ±22) %		788
$\omega\pi$	(16 ± 6) %		656
$\pi\pi$	(23.6 ± 1.3) %		834
$K\overline{K}\pi$	(3.8 ± 1.2) %		628
$K\overline{K}$	(1.58± 0.26) %	1.2	686
$\eta\pi^+\pi^-$	seen		728

$\rho(1700)$ [q]

$I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 1700 \pm 20$ MeV [m] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)

Full width $\Gamma = 240 \pm 60$ MeV [m] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)

ρ(1700) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\rho\pi\pi$	dominant	640
$2(\pi^+\pi^-)$	large	792
$\rho^0\pi^+\pi^-$	large	640
$\rho^{\pm}\pi^{\mp}\pi^0$	large	642
$\pi^+\pi^-$	seen	838
$\pi^-\pi^0$	seen	839
$K\overline{K}^*(892)+$ c.c.	seen	479
$\eta\rho$	seen	533
$K\overline{K}$	seen	692
e^+e^-	seen	850
$\pi^0\omega$	seen	662

$f_J(1710)$ [t]

$I^G(J^{PC}) = 0^+(\text{even}^{++})$

Mass $m = 1712 \pm 5$ MeV (S = 1.1)
Full width $\Gamma = 133 \pm 14$ MeV (S = 1.2)

$f_J(1710)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}$	seen	690
$\eta\eta$	seen	648
$\pi\pi$	seen	837

$\pi(1800)$

$I^G(J^{PC}) = 1^-(0^{-+})$

Mass $m = 1801 \pm 13$ MeV (S = 1.9)
Full width $\Gamma = 210 \pm 15$ MeV

$\pi(1800)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi^+\pi^-\pi^-$	seen	–
$f_0(980)\pi^-$	seen	623
$f_0(1370)\pi^-$	seen	–
$\rho\pi^-$	not seen	728
$\eta\eta\pi^-$	seen	–
$a_0(980)\eta$	seen	459
$f_0(1500)\pi^-$	seen	240
$\eta\eta'(958)\pi^-$	seen	–
$K_0^*(1430)K^-$	seen	–
$K^*(892)K^-$	not seen	560

$\phi_3(1850)$

$I^G(J^{PC}) = 0^-(3^{--})$

Mass $m = 1854 \pm 7$ MeV
Full width $\Gamma = 87^{+28}_{-23}$ MeV (S = 1.2)

$\phi_3(1850)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}$	seen	785
$K\overline{K}^*(892)+$ c.c.	seen	602

$f_2(2010)$

$I^G(J^{PC}) = 0^+(2^{++})$

Seen by one group only.

Mass $m = 2011^{+60}_{-80}$ MeV
Full width $\Gamma = 202 \pm 60$ MeV

$f_2(2010)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\phi\phi$	seen	–

$a_4(2040)$

$I^G(J^{PC}) = 1^-(4^{++})$

Mass $m = 2020 \pm 16$ MeV
Full width $\Gamma = 387 \pm 70$ MeV

$a_4(2040)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}$	seen	892
$\pi^+\pi^-\pi^0$	seen	–
$\eta\pi^0$	seen	941

$f_4(2050)$

$I^G(J^{PC}) = 0^+(4^{++})$

Mass $m = 2044 \pm 11$ MeV (S = 1.4)
Full width $\Gamma = 208 \pm 13$ MeV (S = 1.2)

$f_4(2050)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\omega\omega$	(26 ± 6) %	658
$\pi\pi$	(17.0 ± 1.5) %	1012
$K\overline{K}$	$(6.8^{+3.4}_{-1.8}) \times 10^{-3}$	895
$\eta\eta$	$(2.1 \pm 0.8) \times 10^{-3}$	863
$4\pi^0$	< 1.2 %	977

$f_2(2300)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 2297 \pm 28$ MeV
Full width $\Gamma = 149 \pm 40$ MeV

$f_2(2300)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\phi\phi$	seen	529

$f_2(2340)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 2339 \pm 60$ MeV
Full width $\Gamma = 319^{+80}_{-70}$ MeV

f_2(2340) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\phi\phi$	seen	573

STRANGE MESONS
($S = \pm1$, $C = B = 0$)

$K^+ = u\overline{s}$, $K^0 = d\overline{s}$, $\overline{K}^0 = \overline{d}s$, $K^- = \overline{u}s$, similarly for K^*'s

$K^\pm$

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 493.677 \pm 0.016$ MeV [u] (S = 2.8)
Mean life $\tau = (1.2386 \pm 0.0024) \times 10^{-8}$ s (S = 2.0)
$c\tau = 3.713$ m

Slope parameter g [v]

(See Particle Listings for quadratic coefficients)

$K^+ \to \pi^+\pi^+\pi^- = -0.2154 \pm 0.0035$ (S = 1.4)
$K^- \to \pi^-\pi^-\pi^+ = -0.217 \pm 0.007$ (S = 2.5)
$K^\pm \to \pi^\pm\pi^0\pi^0 = 0.594 \pm 0.019$ (S = 1.3)

$K^\pm$ decay form factors [a,w]

K^+_{e3} $\lambda_+ = 0.0286 \pm 0.0022$
$K^+_{\mu3}$ $\lambda_+ = 0.032 \pm 0.008$ (S = 1.6)
$K^+_{\mu3}$ $\lambda_0 = 0.006 \pm 0.007$ (S = 1.6)
K^+_{e3} $|f_S/f_+| = 0.084 \pm 0.023$ (S = 1.2)
K^+_{e3} $|f_T/f_+| = 0.38 \pm 0.11$ (S = 1.1)
$K^+_{\mu3}$ $|f_T/f_+| = 0.02 \pm 0.12$
$K^+ \to e^+\nu_e\gamma$ $|F_A + F_V| = 0.148 \pm 0.010$
$K^+ \to \mu^+\nu_\mu\gamma$ $|F_A + F_V| < 0.23$, CL = 90%
$K^+ \to e^+\nu_e\gamma$ $|F_A - F_V| < 0.49$
$K^+ \to \mu^+\nu_\mu\gamma$ $|F_A - F_V| = -2.2$ to 0.3

K^- modes are charge conjugates of the modes below.

K^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\mu^+\nu_\mu$	(63.51 ± 0.18) %	S=1.3	236
$e^+\nu_e$	$(1.55\pm0.07) \times 10^{-5}$		247
$\pi^+\pi^0$	(21.16 ± 0.14) %	S=1.1	205
$\pi^+\pi^+\pi^-$	(5.59 ± 0.05) %	S=1.8	125
$\pi^+\pi^0\pi^0$	(1.73 ± 0.04) %	S=1.2	133
$\pi^0\mu^+\nu_\mu$	(3.18 ± 0.08) %	S=1.5	215
Called $K^+_{\mu3}$.			

$\pi^0 e^+ \nu_e$			(4.82±0.06) %	S=1.3	228
Called K^+_{e3}.					
$\pi^0 \pi^0 e^+ \nu_e$			(2.1 ±0.4) $\times 10^{-5}$		206
$\pi^+ \pi^- e^+ \nu_e$			(3.91±0.17) $\times 10^{-5}$		203
$\pi^+ \pi^- \mu^+ \nu_\mu$			(1.4 ±0.9) $\times 10^{-5}$		151
$\pi^0 \pi^0 \pi^0 e^+ \nu_e$			< 3.5 $\times 10^{-6}$	CL=90%	135
$\pi^+ \gamma\gamma$		[x]	(1.10±0.32) $\times 10^{-6}$		227
$\pi^+ 3\gamma$		[x]	< 1.0 $\times 10^{-4}$	CL=90%	227
$\mu^+ \nu_\mu \nu \overline{\nu}$			< 6.0 $\times 10^{-6}$	CL=90%	236
$e^+ \nu_e \nu \overline{\nu}$			< 6 $\times 10^{-5}$	CL=90%	247
$\mu^+ \nu_\mu e^+ e^-$			(1.3 ±0.4) $\times 10^{-7}$		236
$e^+ \nu_e e^+ e^-$			(3.0 $^{+3.0}_{-1.5}$) $\times 10^{-8}$		247
$\mu^+ \nu_\mu \mu^+ \mu^-$			< 4.1 $\times 10^{-7}$	CL=90%	185
$\mu^+ \nu_\mu \gamma$		[x,y]	(5.50±0.28) $\times 10^{-3}$		236
$\pi^+ \pi^0 \gamma$		[x,y]	(2.75±0.15) $\times 10^{-4}$		205
$\pi^+ \pi^0 \gamma$ (DE)		[x,z]	(1.8 ±0.4) $\times 10^{-5}$		205
$\pi^+ \pi^+ \pi^- \gamma$		[x,y]	(1.04±0.31) $\times 10^{-4}$		125
$\pi^+ \pi^0 \pi^0 \gamma$		[x,y]	(7.5 $^{+5.5}_{-3.0}$) $\times 10^{-6}$		133
$\pi^0 \mu^+ \nu_\mu \gamma$		[x,y]	< 6.1 $\times 10^{-5}$	CL=90%	215
$\pi^0 e^+ \nu_e \gamma$		[x,y]	(2.62±0.20) $\times 10^{-4}$		228
$\pi^0 e^+ \nu_e \gamma$ (SD)		[aa]	< 5.3 $\times 10^{-5}$	CL=90%	228
$\pi^0 \pi^0 e^+ \nu_e \gamma$			< 5 $\times 10^{-6}$	CL=90%	206

Lepton Family number (*LF*), Lepton number (*L*), $\Delta S = \Delta Q$ (*SQ*) violating modes, or $\Delta S = 1$ weak neutral current (*S1*) modes

$\pi^+ \pi^+ e^- \overline{\nu}_e$	*SQ*		< 1.2 $\times 10^{-8}$	CL=90%	203
$\pi^+ \pi^+ \mu^- \overline{\nu}_\mu$	*SQ*		< 3.0 $\times 10^{-6}$	CL=95%	151
$\pi^+ e^+ e^-$	*S1*		(2.74±0.23) $\times 10^{-7}$		227
$\pi^+ \mu^+ \mu^-$	*S1*		(5.0 ±1.0) $\times 10^{-8}$		172
$\pi^+ \nu \overline{\nu}$	*S1*		(4.2 $^{+9.7}_{-3.5}$) $\times 10^{-10}$		227
$\mu^- \nu e^+ e^+$	*LF*		< 2.0 $\times 10^{-8}$	CL=90%	236
$\mu^+ \nu_e$	*LF*	[d]	< 4 $\times 10^{-3}$	CL=90%	236
$\pi^+ \mu^+ e^-$	*LF*		< 2.1 $\times 10^{-10}$	CL=90%	214
$\pi^+ \mu^- e^+$	*LF*		< 7 $\times 10^{-9}$	CL=90%	214
$\pi^- \mu^+ e^+$	*L*		< 7 $\times 10^{-9}$	CL=90%	214
$\pi^- e^+ e^+$	*L*		< 1.0 $\times 10^{-8}$	CL=90%	227
$\pi^- \mu^+ \mu^+$	*L*	[d]	< 1.5 $\times 10^{-4}$	CL=90%	172
$\mu^+ \overline{\nu}_e$	*L*	[d]	< 3.3 $\times 10^{-3}$	CL=90%	236
$\pi^0 e^+ \overline{\nu}_e$	*L*		< 3 $\times 10^{-3}$	CL=90%	228

K^0

$I(J^P) = \frac{1}{2}(0^-)$

50% K_S, 50% K_L

Mass $m = 497.672 \pm 0.031$ MeV

$m_{K^0} - m_{K^\pm} = 3.995 \pm 0.034$ MeV (S = 1.1)

$\left|m_{K^0} - m_{\overline{K}^0}\right| / m_{\text{average}} < 10^{-18}$ [bb]

K^0_S

$I(J^P) = \frac{1}{2}(0^-)$

Mean life $\tau = (0.8934 \pm 0.0008) \times 10^{-10}$ s

$c\tau = 2.6762$ cm

CP-violation parameters [cc]

$\text{Im}(\eta_{+-0}) = -0.002 \pm 0.009$

$\text{Im}(\eta_{000})^2 < 0.1$, CL = 90%

K^0_S DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi^+\pi^-$		(68.61 ± 0.28) %	S=1.2	206
$\pi^0\pi^0$		(31.39 ± 0.28) %	S=1.2	209
$\pi^+\pi^-\gamma$	[y,dd]	$(1.78\pm0.05) \times 10^{-3}$		206
$\gamma\gamma$		$(2.4\pm0.9) \times 10^{-6}$		249
$\pi^+\pi^-\pi^0$		$(3.2^{+1.2}_{-1.0}) \times 10^{-7}$		133
$3\pi^0$		$< 3.7 \times 10^{-5}$	CL=90%	139
$\pi^\pm e^\mp \nu$	[ee]	$(6.70\pm0.07) \times 10^{-4}$	S=1.1	229
$\pi^\pm \mu^\mp \nu$	[ee]	$(4.69\pm0.06) \times 10^{-4}$	S=1.1	216
$\Delta S = 1$ weak neutral current (*S1*) modes				
$\mu^+\mu^-$	*S1*	$< 3.2 \times 10^{-7}$	CL=90%	225
e^+e^-	*S1*	$< 1.4 \times 10^{-7}$	CL=90%	249
$\pi^0 e^+ e^-$	*S1*	$< 1.1 \times 10^{-6}$	CL=90%	231

K^0_L

$I(J^P) = \frac{1}{2}(0^-)$

$m_{K_L} - m_{K_S} = (0.5301 \pm 0.0014) \times 10^{10}\ \hbar\ s^{-1}$
$= (3.489 \pm 0.009) \times 10^{-12}$ MeV

Mean life $\tau = (5.17 \pm 0.04) \times 10^{-8}$ s (S = 1.1)

$c\tau = 15.51$ m

Slope parameter g [v]

(See Particle Listings for quadratic coefficients)

$K^0_L \to \pi^+\pi^-\pi^0 = 0.670 \pm 0.014$ (S = 1.6)

K_L decay form factors [w]

K^0_{e3} $\lambda_+ = 0.0300 \pm 0.0016$ (S = 1.2)

$K^0_{\mu 3}$ $\lambda_+ = 0.034 \pm 0.005$ (S = 2.3)

$K^0_{\mu 3}$ $\lambda_0 = 0.025 \pm 0.006$ (S = 2.3)

K^0_{e3} $|f_S/f_+| < 0.04$, CL = 68%

K^0_{e3} $|f_T/f_+| < 0.23$, CL = 68%

$K^0_{\mu 3}$ $|f_T/f_+| = 0.12 \pm 0.12$

$K_L \to e^+e^-\gamma$: $\alpha_{K^*} = -0.28 \pm 0.08$

CP-violation parameters [cc]

$\delta = (0.327 \pm 0.012)\%$

$|\eta_{00}| = (2.275 \pm 0.019) \times 10^{-3}$ (S = 1.1)

$|\eta_{+-}| = (2.285 \pm 0.019) \times 10^{-3}$

$|\eta_{00}/\eta_{+-}| = 0.9956 \pm 0.0023$ [ff] (S = 1.8)

$\epsilon'/\epsilon = (1.5 \pm 0.8) \times 10^{-3}$ [ff] (S = 1.8)

$\phi_{+-} = (43.5 \pm 0.6)^\circ$

$\phi_{00} = (43.4 \pm 1.0)^\circ$

$\phi_{00} - \phi_{+-} = (-0.1 \pm 0.8)^\circ$

j for $K^0_L \to \pi^+\pi^-\pi^0 = 0.0011 \pm 0.0008$

$|\eta_{+-\gamma}| = (2.35 \pm 0.07) \times 10^{-3}$

$\phi_{+-\gamma} = (44 \pm 4)^\circ$

$|\epsilon'_{+-\gamma}|/\epsilon < 0.3$, CL = 90%

$\Delta S = -\Delta Q$ in $K^0_{\ell 3}$ decay

Re $x = 0.006 \pm 0.018$ (S = 1.3)
Im $x = -0.003 \pm 0.026$ (S = 1.2)

CPT-violation parameters

Re $\Delta = 0.018 \pm 0.020$
Im $\Delta = 0.02 \pm 0.04$

K^0_L DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$3\pi^0$		(21.12 ± 0.27) %	S=1.1	139
$\pi^+\pi^-\pi^0$		(12.56 ± 0.20) %	S=1.7	133
$\pi^\pm\mu^\mp\nu$	[gg]	(27.17 ± 0.25) %	S=1.1	216
Called $K^0_{\mu 3}$.				
$\pi^\pm e^\mp\nu_e$	[gg]	(38.78 ± 0.27) %	S=1.1	229
Called K^0_{e3}.				
2γ		$(5.92 \pm 0.15) \times 10^{-4}$		249
3γ		$< 2.4 \times 10^{-7}$	CL=90%	249
$\pi^0 2\gamma$	[hh]	$(1.70 \pm 0.28) \times 10^{-6}$		231
$\pi^0\pi^\pm e^\mp\nu$	[gg]	$(5.18 \pm 0.29) \times 10^{-5}$		207
$(\pi\mu\,\text{atom})\nu$		$(1.06 \pm 0.11) \times 10^{-7}$		–
$\pi^\pm e^\mp\nu_e\gamma$	[y,gg,hh]	$(3.62^{+0.26}_{-0.21}) \times 10^{-3}$		229
$\pi^+\pi^-\gamma$	[y,hh]	$(4.61 \pm 0.14) \times 10^{-5}$		206
$\pi^0\pi^0\gamma$		$< 5.6 \times 10^{-6}$		209

Charge conjugation × Parity (*CP, CPV*) or Lepton Family number (*LF*) violating modes, or $\Delta S = 1$ weak neutral current (*S1*) modes

Mode			Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi^+\pi^-$	*CPV*		$(2.067 \pm 0.035) \times 10^{-3}$	S=1.1	206
$\pi^0\pi^0$	*CPV*		$(9.36 \pm 0.20) \times 10^{-4}$		209
$\mu^+\mu^-$	*S1*		$(7.2 \pm 0.5) \times 10^{-9}$	S=1.4	225
$\mu^+\mu^-\gamma$	*S1*		$(3.25 \pm 0.28) \times 10^{-7}$		225
e^+e^-	*S1*		$< 4.1 \times 10^{-11}$	CL=90%	249
$e^+e^-\gamma$	*S1*		$(9.1 \pm 0.5) \times 10^{-6}$		249
$e^+e^-\gamma\gamma$	*S1*	[hh]	$(6.5 \pm 1.2) \times 10^{-7}$		249
$\pi^+\pi^-e^+e^-$	*S1*	[hh]	$< 4.6 \times 10^{-7}$	CL=90%	206
$\mu^+\mu^-e^+e^-$	*S1*		$(2.9^{+6.7}_{-2.4}) \times 10^{-9}$		225
$e^+e^-e^+e^-$	*S1*		$(4.1 \pm 0.8) \times 10^{-8}$	S=1.2	249
$\pi^0\mu^+\mu^-$	*CP,S1*	[ii]	$< 5.1 \times 10^{-9}$	CL=90%	177
$\pi^0 e^+e^-$	*CP,S1*	[ii]	$< 4.3 \times 10^{-9}$	CL=90%	231
$\pi^0\nu\overline{\nu}$	*CP,S1*	[jj]	$< 5.8 \times 10^{-5}$	CL=90%	231
$e^\pm\mu^\mp$	*LF*	[gg]	$< 3.3 \times 10^{-11}$	CL=90%	238
$e^\pm e^\pm\mu^\mp\mu^\mp$	*LF*	[gg]	$< 6.1 \times 10^{-9}$	CL=90%	–

$K^*(892)$

$I(J^P) = \frac{1}{2}(1^-)$

$K^*(892)^\pm$ mass $m = 891.66 \pm 0.26$ MeV
$K^*(892)^0$ mass $m = 896.10 \pm 0.28$ MeV (S = 1.4)
$K^*(892)^\pm$ full width $\Gamma = 50.8 \pm 0.9$ MeV
$K^*(892)^0$ full width $\Gamma = 50.5 \pm 0.6$ MeV (S = 1.1)

$K^*(892)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\pi$	$\sim$ 100 %		291
$K^0\gamma$	(2.30±0.20) × 10^{-3}		310
$K^\pm\gamma$	(9.9 ±0.9) × 10^{-4}		309
$K\pi\pi$	< 7 × 10^{-4}	95%	224

$K_1(1270)$

$I(J^P) = \frac{1}{2}(1^+)$

Mass $m = 1273 \pm 7$ MeV [m]
Full width $\Gamma = 90 \pm 20$ MeV [m]

$K_1(1270)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\rho$	(42 ±6) %	76
$K_0^*(1430)\pi$	(28 ±4) %	–
$K^*(892)\pi$	(16 ±5) %	301
$K\omega$	(11.0±2.0) %	–
$K f_0(1370)$	(3.0±2.0) %	–

$K_1(1400)$

$I(J^P) = \frac{1}{2}(1^+)$

Mass $m = 1402 \pm 7$ MeV
Full width $\Gamma = 174 \pm 13$ MeV (S = 1.6)

$K_1(1400)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K^*(892)\pi$	(94 ±6) %	401
$K\rho$	(3.0±3.0) %	298
$K f_0(1370)$	(2.0±2.0) %	–
$K\omega$	(1.0±1.0) %	285
$K_0^*(1430)\pi$	not seen	–

$K^*(1410)$

$I(J^P) = \frac{1}{2}(1^-)$

Mass $m = 1414 \pm 15$ MeV (S = 1.3)
Full width $\Gamma = 232 \pm 21$ MeV (S = 1.1)

$K^*(1410)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K^*(892)\pi$	> 40 %	95%	408
$K\pi$	(6.6 ± 1.3) %		611
$K\rho$	< 7 %	95%	309

$K_0^*(1430)$ [kk]

$I(J^P) = \frac{1}{2}(0^+)$

Mass $m = 1429 \pm 6$ MeV
Full width $\Gamma = 287 \pm 23$ MeV

$K_0^*(1430)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(93 ± 10) %	621

$K_2^*(1430)$

$I(J^P) = \frac{1}{2}(2^+)$

$K_2^*(1430)^\pm$ mass $m = 1425.6 \pm 1.5$ MeV (S = 1.1)
$K_2^*(1430)^0$ mass $m = 1432.4 \pm 1.3$ MeV
$K_2^*(1430)^\pm$ full width $\Gamma = 98.5 \pm 2.7$ MeV (S = 1.1)
$K_2^*(1430)^0$ full width $\Gamma = 109 \pm 5$ MeV (S = 1.9)

$K_2^*(1430)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$K\pi$	(49.9 ± 1.2) %		622
$K^*(892)\pi$	(24.7 ± 1.5) %		423
$K^*(892)\pi\pi$	(13.4 ± 2.2) %		375
$K\rho$	(8.7 ± 0.8) %	S=1.2	331
$K\omega$	(2.9 ± 0.8) %		319
$K^+\gamma$	(2.4 ± 0.5) $\times 10^{-3}$	S=1.1	627
$K\eta$	($1.5^{+3.4}_{-1.0}$) $\times 10^{-3}$	S=1.3	492
$K\omega\pi$	< 7.2 $\times 10^{-4}$	CL=95%	110
$K^0\gamma$	< 9 $\times 10^{-4}$	CL=90%	631

$K^*(1680)$

$I(J^P) = \frac{1}{2}(1^-)$

Mass $m = 1717 \pm 27$ MeV (S = 1.4)
Full width $\Gamma = 322 \pm 110$ MeV (S = 4.2)

$K^*(1680)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(38.7 ± 2.5) %	779
$K\rho$	$(31.4^{+4.7}_{-2.1})$ %	571
$K^*(892)\pi$	$(29.9^{+2.2}_{-4.7})$ %	615

$K_2(1770)$ [ll]

$I(J^P) = \frac{1}{2}(2^-)$

Mass $m = 1773 \pm 8$ MeV
Full width $\Gamma = 186 \pm 14$ MeV

$K_2(1770)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi\pi$		–
$K_2^*(1430)\pi$	dominant	287
$K^*(892)\pi$	seen	653
$K f_2(1270)$	seen	–
$K\phi$	seen	441
$K\omega$	seen	608

$K_3^*(1780)$

$I(J^P) = \frac{1}{2}(3^-)$

Mass $m = 1776 \pm 7$ MeV (S = 1.1)
Full width $\Gamma = 159 \pm 21$ MeV (S = 1.3)

$K_3^*(1780)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\rho$	(31 ± 9) %		612
$K^*(892)\pi$	(20 ± 5) %		651
$K\pi$	(18.8 ± 1.0) %		810
$K\eta$	(30 ± 13) %		715
$K_2^*(1430)\pi$	< 16 %	95%	284

$K_2(1820)$ [mm]

$I(J^P) = \frac{1}{2}(2^-)$

Mass $m = 1816 \pm 13$ MeV
Full width $\Gamma = 276 \pm 35$ MeV

$K_2(1820)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K_2^*(1430)\pi$	seen	325
$K^*(892)\pi$	seen	680
$K f_2(1270)$	seen	186
$K\omega$	seen	638

$K_4^*(2045)$

$I(J^P) = \frac{1}{2}(4^+)$

Mass $m = 2045 \pm 9$ MeV (S = 1.1)
Full width $\Gamma = 198 \pm 30$ MeV

$K_4^*(2045)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(9.9 ± 1.2) %	958
$K^*(892)\pi\pi$	$(9\ \pm5\ )$ %	800
$K^*(892)\pi\pi\pi$	$(7\ \pm5\ )$ %	764
$\rho K\pi$	(5.7 ± 3.2) %	742
$\omega K\pi$	(5.0 ± 3.0) %	736
$\phi K\pi$	(2.8 ± 1.4) %	591
$\phi K^*(892)$	(1.4 ± 0.7) %	363

CHARMED MESONS
($C = \pm1$)

$D^+ = c\overline{d}$, $D^0 = c\overline{u}$, $\overline{D}^0 = \overline{c}\,u$, $D^- = \overline{c}\,d$, similarly for D^*'s

$D^\pm$

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 1869.3 \pm 0.5$ MeV (S = 1.1)
Mean life $\tau = (1.057 \pm 0.015) \times 10^{-12}$ s
$c\tau = 317\ \mu$m

CP-violation decay-rate asymmetries

$A_{CP}(K^+K^-\pi^\pm) = -0.017 \pm 0.027$
$A_{CP}(K^\pm K^{*0}) = -0.02 \pm 0.05$
$A_{CP}(\phi\pi^\pm) = -0.014 \pm 0.033$
$A_{CP}(\pi^+\pi^-\pi^\pm) = -0.02 \pm 0.04$

$D^+ \to \overline{K}^*(892)^0 \ell^+ \nu_\ell$ form factors

$r_2 = 0.72 \pm 0.09$
$r_v = 1.85 \pm 0.12$
$\Gamma_L/\Gamma_T = 1.23 \pm 0.13$
$\Gamma_+/\Gamma_- = 0.16 \pm 0.04$

D^- modes are charge conjugates of the modes below.

D^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Inclusive modes			
e^+ anything	(17.2 ± 1.9) %		–
K^- anything	(24.2 ± 2.8) %	S=1.4	–
$\overline{K}^0$ anything + K^0 anything	(59 ± 7) %		–
K^+ anything	(5.8 ± 1.4) %		–
η anything	[nn] < 13 %	CL=90%	–

Leptonic and semileptonic modes

$\mu^+\nu_\mu$		$<$ 7.2	$\times 10^{-4}$	CL=90%	932
$\overline{K}^0\ell^+\nu_\ell$	[oo]	(6.8 $\pm$0.8) %			868
$\quad\overline{K}^0 e^+\nu_e$		(6.7 $\pm$0.9) %			868
$\quad\overline{K}^0\mu^+\nu_\mu$		(7.0 $^{+3.0}_{-2.0}$) %			865
$K^-\pi^+e^+\nu_e$		(4.1 $^{+0.9}_{-0.7}$) %			863
$\quad\overline{K}^*(892)^0 e^+\nu_e$ $\times$ B($\overline{K}^{*0}\to K^-\pi^+$)		(3.2 $\pm$0.33) %			720
$\quad K^-\pi^+e^+\nu_e$ nonresonant		$<$ 7	$\times 10^{-3}$	CL=90%	863
$K^-\pi^+\mu^+\nu_\mu$		(3.2 $\pm$0.4) %		S=1.1	851
$\quad\overline{K}^*(892)^0\mu^+\nu_\mu$ $\times$ B($\overline{K}^{*0}\to K^-\pi^+$)		(2.9 $\pm$0.4) %			715
$\quad K^-\pi^+\mu^+\nu_\mu$ nonresonant		(2.7 $\pm$1.1)	$\times 10^{-3}$		851
$(\overline{K}^*(892)\pi)^0 e^+\nu_e$		$<$ 1.2	%	CL=90%	714
$(\overline{K}\pi\pi)^0 e^+\nu_e$ non-$\overline{K}^*(892)$		$<$ 9	$\times 10^{-3}$	CL=90%	846
$K^-\pi^+\pi^0\mu^+\nu_\mu$		$<$ 1.4	$\times 10^{-3}$	CL=90%	825
$\pi^0\ell^+\nu_\ell$	[pp]	(3.1 $\pm$1.5)	$\times 10^{-3}$		930

Fractions of some of the following modes with resonances have already appeared above as submodes of particular charged-particle modes.

$\overline{K}^*(892)^0\ell^+\nu_\ell$	[oo]	(4.7 $\pm$0.4) %			720
$\quad\overline{K}^*(892)^0 e^+\nu_e$		(4.8 $\pm$0.5) %			720
$\quad\overline{K}^*(892)^0\mu^+\nu_\mu$		(4.4 $\pm$0.6) %		S=1.1	715
$\rho^0 e^+\nu_e$		(2.2 $\pm$0.8)	$\times 10^{-3}$		776
$\rho^0\mu^+\nu_\mu$		(2.7 $\pm$0.7)	$\times 10^{-3}$		772
$\phi e^+\nu_e$		$<$ 2.09	%	CL=90%	657
$\phi\mu^+\nu_\mu$		$<$ 3.72	%	CL=90%	651
$\eta\ell^+\nu_\ell$		$<$ 5	$\times 10^{-3}$	CL=90%	–
$\eta'(958)\mu^+\nu_\mu$		$<$ 9	$\times 10^{-3}$	CL=90%	684

Hadronic modes with a $\overline{K}$ or $\overline{K}K\overline{K}$

$\overline{K}^0\pi^+$		(2.89±0.26) %	S=1.1	862
$K^-\pi^+\pi^+$	[qq]	(9.0 ±0.6) %		845
$\overline{K}^*(892)^0\pi^+$ $\times$ B($\overline{K}^{*0}\to K^-\pi^+$)		(1.27±0.13) %		712
$\overline{K}^*_0(1430)^0\pi^+$ $\times$ B($\overline{K}^*_0(1430)^0\to K^-\pi^+$)		(2.3 ±0.3) %		368
$\overline{K}^*(1680)^0\pi^+$ $\times$ B($\overline{K}^*(1680)^0\to K^-\pi^+$)		(3.7 ±0.8) $\times 10^{-3}$		65
$K^-\pi^+\pi^+$ nonresonant		(8.5 ±0.8) %		845
$\overline{K}^0\pi^+\pi^0$	[qq]	(9.7 ±3.0) %	S=1.1	845
$\overline{K}^0\rho^+$		(6.6 ±2.5) %		680
$\overline{K}^*(892)^0\pi^+$ $\times$ B($\overline{K}^{*0}\to \overline{K}^0\pi^0$)		(6.3 ±0.4) $\times 10^{-3}$		712
$\overline{K}^0\pi^+\pi^0$ nonresonant		(1.3 ±1.1) %		845
$K^-\pi^+\pi^+\pi^0$	[qq]	(6.4 ±1.1) %		816
$\overline{K}^*(892)^0\rho^+$ total $\times$ B($\overline{K}^{*0}\to K^-\pi^+$)		(1.4 ±0.9) %		423
$\overline{K}_1(1400)^0\pi^+$ $\times$ B($\overline{K}_1(1400)^0\to K^-\pi^+\pi^0$)		(2.2 ±0.6) %		390
$K^-\rho^+\pi^+$ total		(3.1 ±1.1) %		616
$K^-\rho^+\pi^+$ 3-body		(1.1 ±0.4) %		616
$\overline{K}^*(892)^0\pi^+\pi^0$ total $\times$ B($\overline{K}^{*0}\to K^-\pi^+$)		(4.5 ±0.9) %		687
$\overline{K}^*(892)^0\pi^+\pi^0$ 3-body $\times$ B($\overline{K}^{*0}\to K^-\pi^+$)		(2.8 ±0.9) %		687
$K^*(892)^-\pi^+\pi^+$ 3-body $\times$ B($K^{*-}\to K^-\pi^0$)		(7 ±3) $\times 10^{-3}$		688
$K^-\pi^+\pi^+\pi^0$ nonresonant	[rr]	(1.2 ±0.6) %		816
$\overline{K}^0\pi^+\pi^+\pi^-$	[qq]	(7.0 ±0.9) %		814
$\overline{K}^0 a_1(1260)^+$ $\times$ B($a_1(1260)^+\to \pi^+\pi^+\pi^-$)		(4.0 ±0.9) %		328
$\overline{K}_1(1400)^0\pi^+$ $\times$ B($\overline{K}_1(1400)^0\to \overline{K}^0\pi^+\pi^-$)		(2.2 ±0.6) %		390
$K^*(892)^-\pi^+\pi^+$ 3-body $\times$ B($K^{*-}\to \overline{K}^0\pi^-$)		(1.4 ±0.6) %		688
$\overline{K}^0\rho^0\pi^+$ total		(4.2 ±0.9) %		614
$\overline{K}^0\rho^0\pi^+$ 3-body		(5 ±5) $\times 10^{-3}$		614
$\overline{K}^0\pi^+\pi^+\pi^-$ nonresonant		(8 ±4) $\times 10^{-3}$		814

$K^- \pi^+ \pi^+ \pi^+ \pi^-$	[qq]	$(7.2 \pm 1.0) \times 10^{-3}$		772
$\overline{K}^*(892)^0 \pi^+ \pi^+ \pi^-$ $\times$ B($\overline{K}^{*0} \to K^- \pi^+$)		$(5.4 \pm 2.3) \times 10^{-3}$		642
$\overline{K}^*(892)^0 \rho^0 \pi^+$ $\times$ B($\overline{K}^{*0} \to K^- \pi^+$)		$(1.9 {}^{+1.1}_{-1.0}) \times 10^{-3}$		242
$\overline{K}^*(892)^0 \pi^+ \pi^+ \pi^-$ no-ρ $\times$ B($\overline{K}^{*0} \to K^- \pi^+$)		$(2.9 \pm 1.1) \times 10^{-3}$		642
$K^- \rho^0 \pi^+ \pi^+$		$(3.1 \pm 0.9) \times 10^{-3}$		529
$K^- \pi^+ \pi^+ \pi^+ \pi^-$ nonresonant		$< 2.3 \times 10^{-3}$	CL=90%	772
$K^- \pi^+ \pi^+ \pi^0 \pi^0$		$(2.2 {}^{+5.0}_{-0.9}) \%$		775
$\overline{K}^0 \pi^+ \pi^+ \pi^- \pi^0$		$(5.4 {}^{+3.0}_{-1.4}) \%$		773
$\overline{K}^0 \pi^+ \pi^+ \pi^+ \pi^- \pi^-$		$(8 \pm 7) \times 10^{-4}$		714
$K^- \pi^+ \pi^+ \pi^+ \pi^- \pi^0$		$(2.0 \pm 1.8) \times 10^{-3}$		718
$\overline{K}^0 \overline{K}^0 K^+$		$(1.8 \pm 0.8) \%$		545

Fractions of some of the following modes with resonances have already appeared above as submodes of particular charged-particle modes.

$\overline{K}^0 \rho^+$		$(6.6 \pm 2.5) \%$		680
$\overline{K}^0 a_1(1260)^+$		$(8.0 \pm 1.7) \%$		328
$\overline{K}^0 a_2(1320)^+$		$< 3 \times 10^{-3}$	CL=90%	199
$\overline{K}^*(892)^0 \pi^+$		$(1.90 \pm 0.19) \%$		712
$\overline{K}^*(892)^0 \rho^+$ total	[rr]	$(2.1 \pm 1.3) \%$		423
$\overline{K}^*(892)^0 \rho^+$ *S*-wave	[rr]	$(1.6 \pm 1.6) \%$		423
$\overline{K}^*(892)^0 \rho^+$ *P*-wave		$< 1 \times 10^{-3}$	CL=90%	423
$\overline{K}^*(892)^0 \rho^+$ *D*-wave		$(10 \pm 7) \times 10^{-3}$		423
$\overline{K}^*(892)^0 \rho^+$ *D*-wave longitudinal		$< 7 \times 10^{-3}$	CL=90%	423
$\overline{K}_1(1270)^0 \pi^+$		$< 7 \times 10^{-3}$	CL=90%	487
$\overline{K}_1(1400)^0 \pi^+$		$(4.9 \pm 1.2) \%$		390
$\overline{K}^*(1410)^0 \pi^+$		$< 7 \times 10^{-3}$	CL=90%	382
$\overline{K}_0^*(1430)^0 \pi^+$		$(3.7 \pm 0.4) \%$		368
$\overline{K}^*(1680)^0 \pi^+$		$(1.43 \pm 0.30) \%$		65
$\overline{K}^*(892)^0 \pi^+ \pi^0$ total		$(6.7 \pm 1.4) \%$		687
$\overline{K}^*(892)^0 \pi^+ \pi^0$ 3-body	[rr]	$(4.2 \pm 1.4) \%$		687
$K^*(892)^- \pi^+ \pi^+$ 3-body		$(2.0 \pm 0.9) \%$		688
$K^- \rho^+ \pi^+$ total		$(3.1 \pm 1.1) \%$		616
$K^- \rho^+ \pi^+$ 3-body		$(1.1 \pm 0.4) \%$		616
$\overline{K}^0 \rho^0 \pi^+$ total		$(4.2 \pm 0.9) \%$	CL=90%	614
$\overline{K}^0 \rho^0 \pi^+$ 3-body		$(5 \pm 5) \times 10^{-3}$		614

$\overline{K}^0 f_0(980)\pi^+$	< 5	$\times 10^{-3}$	CL=90%	461
$\overline{K}^*(892)^0\pi^+\pi^+\pi^-$	$(8.1 \pm 3.4) \times 10^{-3}$		S=1.7	642
$\overline{K}^*(892)^0\rho^0\pi^+$	$(2.9\ ^{+1.7}_{-1.5}) \times 10^{-3}$		S=1.8	242
$\overline{K}^*(892)^0\pi^+\pi^+\pi^-$ no-ρ	$(4.3 \pm 1.7) \times 10^{-3}$			642
$K^-\rho^0\pi^+\pi^+$	$(3.1 \pm 0.9) \times 10^{-3}$			529

Pionic modes

$\pi^+\pi^0$	$(2.5 \pm 0.7) \times 10^{-3}$			925
$\pi^+\pi^+\pi^-$	$(3.6 \pm 0.4) \times 10^{-3}$			908
$\rho^0\pi^+$	$(1.05 \pm 0.31) \times 10^{-3}$			769
$\pi^+\pi^+\pi^-$ nonresonant	$(2.2 \pm 0.4) \times 10^{-3}$			908
$\pi^+\pi^+\pi^-\pi^0$	$(1.9\ ^{+1.5}_{-1.2})$ %			882
$\eta\pi^+ \times$ B($\eta \to \pi^+\pi^-\pi^0$)	$(1.7 \pm 0.6) \times 10^{-3}$			848
$\omega\pi^+ \times$ B($\omega \to \pi^+\pi^-\pi^0$)	< 6	$\times 10^{-3}$	CL=90%	764
$\pi^+\pi^+\pi^+\pi^-\pi^-$	$(2.1 \pm 0.4) \times 10^{-3}$			845
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^0$	$(2.9\ ^{+2.9}_{-2.0}) \times 10^{-3}$			799

Fractions of some of the following modes with resonances have already appeared above as submodes of particular charged-particle modes.

$\eta\pi^+$	$(7.5 \pm 2.5) \times 10^{-3}$			848
$\rho^0\pi^+$	$(1.05 \pm 0.31) \times 10^{-3}$			769
$\omega\pi^+$	< 7	$\times 10^{-3}$	CL=90%	764
$\eta\rho^+$	< 1.2	%	CL=90%	658
$\eta'(958)\pi^+$	< 9	$\times 10^{-3}$	CL=90%	680
$\eta'(958)\rho^+$	< 1.5	%	CL=90%	355

Hadronic modes with a $K\overline{K}$ pair

$K^+\overline{K}^0$		$(\ 7.4\ \pm1.0\ )\times10^{-3}$			792
$K^+K^-\pi^+$	[qq]	$(\ 8.8\ \pm0.8\ )\times10^{-3}$			744
$\phi\pi^+\ \times$ B$(\phi\rightarrow\ K^+K^-)$		$(\ 3.0\ \pm0.3\ )\times10^{-3}$			647
$K^+\overline{K}^*(892)^0$ $\times$ B$(\overline{K}^{*0}\rightarrow\ K^-\pi^+)$		$(\ 2.8\ \pm0.4\ )\times10^{-3}$			610
$K^+K^-\pi^+$ nonresonant		$(\ 4.5\ \pm0.9\ )\times10^{-3}$			744
$K^0\overline{K}^0\pi^+$		—			741
$K^*(892)^+\overline{K}^0$ $\times$ B$(K^{*+}\rightarrow\ K^0\pi^+)$		$(\ 2.1\ \pm1.0\ )$ %			611
$K^+K^-\pi^+\pi^0$		—			682
$\phi\pi^+\pi^0\ \times$ B$(\phi\rightarrow\ K^+K^-)$		$(\ 1.1\ \pm0.5\ )$ %			619
$\phi\rho^+\ \times$ B$(\phi\rightarrow\ K^+K^-)$		$<\ 7$	$\times10^{-3}$	CL=90%	268
$K^+K^-\pi^+\pi^0$ non-ϕ		$(\ 1.5\ ^{+0.7}_{-0.6}\ )$ %			682
$K^+\overline{K}^0\pi^+\pi^-$		$<\ 2$	%	CL=90%	678
$K^0K^-\pi^+\pi^+$		$(\ 1.0\ \pm0.6\ )$ %			678
$K^*(892)^+\overline{K}^*(892)^0$ $\times$ B$^2(K^{*+}\rightarrow\ K^0\pi^+)$		$(\ 1.2\ \pm0.5\ )$ %			273
$K^0K^-\pi^+\pi^+$ non-$K^{*+}\overline{K}^{*0}$		$<\ 7.9$	$\times10^{-3}$	CL=90%	678
$K^+K^-\pi^+\pi^+\pi^-$		—			600
$\phi\pi^+\pi^+\pi^-$ $\times$ B$(\phi\rightarrow\ K^+K^-)$		$<\ 1$	$\times10^{-3}$	CL=90%	565
$K^+K^-\pi^+\pi^+\pi^-$ nonresonant		$<\ 3$	%	CL=90%	600

Fractions of the following modes with resonances have already appeared above as submodes of particular charged-particle modes.

$\phi\pi^+$	$(\ 6.1\ \pm0.6\ )\times10^{-3}$			647
$\phi\pi^+\pi^0$	$(\ 2.3\ \pm1.0\ )$ %			619
$\phi\rho^+$	$<\ 1.4$	%	CL=90%	268
$\phi\pi^+\pi^+\pi^-$	$<\ 2$	$\times10^{-3}$	CL=90%	565
$K^+\overline{K}^*(892)^0$	$(\ 4.2\ \pm0.5\ )\times10^{-3}$			610
$K^*(892)^+\overline{K}^0$	$(\ 3.2\ \pm1.5\ )$ %			611
$K^*(892)^+\overline{K}^*(892)^0$	$(\ 2.6\ \pm1.1\ )$ %			273

Doubly Cabibbo suppressed (*DC*) modes, $\Delta C = 1$ weak neutral current (*C1*) modes, or Lepton Family number (*LF*) or Lepton number (*L*) violating modes

$K^+ \pi^+ \pi^-$	*DC*		$(6.8 \pm 1.5) \times 10^{-4}$		845
$K^+ \rho^0$	*DC*		$(2.5 \pm 1.2) \times 10^{-4}$		681
$K^*(892)^0 \pi^+$	*DC*		$(3.6 \pm 1.6) \times 10^{-4}$		712
$K^+ \pi^+ \pi^-$ nonresonant	*DC*		$(2.4 \pm 1.2) \times 10^{-4}$		845
$K^+ K^+ K^-$	*DC*		$< 1.4 \times 10^{-4}$	CL=90%	550
ϕK^+	*DC*		$< 1.3 \times 10^{-4}$	CL=90%	527
$\pi^+ e^+ e^-$	*C1*		$< 6.6 \times 10^{-5}$	CL=90%	929
$\pi^+ \mu^+ \mu^-$	*C1*		$< 1.8 \times 10^{-5}$	CL=90%	917
$\rho^+ \mu^+ \mu^-$	*C1*		$< 5.6 \times 10^{-4}$	CL=90%	759
$K^+ e^+ e^-$		[*ss*]	$< 2.0 \times 10^{-4}$	CL=90%	869
$K^+ \mu^+ \mu^-$		[*ss*]	$< 9.7 \times 10^{-5}$	CL=90%	856
$\pi^+ e^+ \mu^-$	*LF*		$< 1.1 \times 10^{-4}$	CL=90%	926
$\pi^+ e^- \mu^+$	*LF*		$< 1.3 \times 10^{-4}$	CL=90%	926
$K^+ e^+ \mu^-$	*LF*		$< 1.3 \times 10^{-4}$	CL=90%	866
$K^+ e^- \mu^+$	*LF*		$< 1.2 \times 10^{-4}$	CL=90%	866
$\pi^- e^+ e^+$	*L*		$< 1.1 \times 10^{-4}$	CL=90%	929
$\pi^- \mu^+ \mu^+$	*L*		$< 8.7 \times 10^{-5}$	CL=90%	917
$\pi^- e^+ \mu^+$	*L*		$< 1.1 \times 10^{-4}$	CL=90%	926
$\rho^- \mu^+ \mu^+$	*L*		$< 5.6 \times 10^{-4}$	CL=90%	759
$K^- e^+ e^+$	*L*		$< 1.2 \times 10^{-4}$	CL=90%	869
$K^- \mu^+ \mu^+$	*L*		$< 1.2 \times 10^{-4}$	CL=90%	856
$K^- e^+ \mu^+$	*L*		$< 1.3 \times 10^{-4}$	CL=90%	866
$K^*(892)^- \mu^+ \mu^+$	*L*		$< 8.5 \times 10^{-4}$	CL=90%	703

D^0

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 1864.6 \pm 0.5$ MeV (S = 1.1)
$m_{D^\pm} - m_{D^0} = 4.76 \pm 0.10$ MeV (S = 1.1)
Mean life $\tau = (0.415 \pm 0.004) \times 10^{-12}$ s
$c\tau = 124.4\ \mu$m
$\left|m_{D^0_1} - m_{D^0_2}\right| < 24 \times 10^{10}\ \hbar\ \mathrm{s}^{-1}$, CL = 90% [tt]
$\left|\Gamma_{D^0_1} - \Gamma_{D^0_2}\right| / \Gamma_{D^0} < 0.20$, CL = 90% [tt]
$\Gamma(K^+ \ell^- \overline{\nu}_\ell\ (\text{via } \overline{D}^0)) / \Gamma(K^- \ell^+ \nu_\ell) < 0.005$, CL = 90%
$\frac{\Gamma(K^+\pi^- \text{ or } K^+\pi^-\pi^+\pi^- (\text{via} \overline{D}^0))}{\Gamma(K^-\pi^+ \text{ or } K^-\pi^+\pi^+\pi^-)} < 0.0085$ (or < 0.0037), CL = 90% [uu]

CP-violation decay-rate asymmetries

$A_{CP}(K^+K^-) = 0.026 \pm 0.035$
$A_{CP}(\pi^+\pi^-) = -0.05 \pm 0.08$
$A_{CP}(K^0_S \phi) = -0.03 \pm 0.09$
$A_{CP}(K^0_S \pi^0) = -0.018 \pm 0.030$

$\overline{D}^0$ modes are charge conjugates of the modes below.

D^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Inclusive modes				
e^+ anything		(6.75 ± 0.29) %		–
μ^+ anything		(6.6 ± 0.8) %		–
K^- anything		(53 ± 4) %	S=1.3	–
$\overline{K}^0$ anything + K^0 anything		(42 ± 5) %		–
K^+ anything		$(3.4 ^{+0.6}_{-0.4})$ %		–
η anything	[nn]	< 13 %	CL=90%	–
Semileptonic modes				
$K^- \ell^+ \nu_\ell$	[oo]	(3.50 ± 0.17) %	S=1.3	867
$K^- e^+ \nu_e$		(3.66 ± 0.18) %		867
$K^- \mu^+ \nu_\mu$		(3.23 ± 0.17) %		863
$K^- \pi^0 e^+ \nu_e$		$(1.6 ^{+1.3}_{-0.5})$ %		861
$\overline{K}^0 \pi^- e^+ \nu_e$		$(2.8 ^{+1.7}_{-0.9})$ %		860
$\overline{K}^*(892)^- e^+ \nu_e$ $\times$ B($K^{*-} \to \overline{K}^0 \pi^-$)		(1.35 ± 0.22) %		719
$K^*(892)^- \ell^+ \nu_\ell$		—		–

$\overline{K}^*(892)^0 \pi^- e^+ \nu_e$		—			708
$K^- \pi^+ \pi^- \mu^+ \nu_\mu$		$< 1.2 \times 10^{-3}$		CL=90%	821
$(\overline{K}^*(892)\pi)^- \mu^+ \nu_\mu$		$< 1.4 \times 10^{-3}$		CL=90%	693
$\pi^- e^+ \nu_e$		$(3.7 \pm 0.6) \times 10^{-3}$			927

A fraction of the following resonance mode has already appeared above as a submode of a charged-particle mode.

$K^*(892)^- e^+ \nu_e$		(2.02 ± 0.33) %			719

Hadronic modes with a $\overline{K}$ or $\overline{K}K\overline{K}$

$K^- \pi^+$		(3.85 ± 0.09) %			861
$\overline{K}^0 \pi^0$		(2.12 ± 0.21) %		S=1.1	860
$\overline{K}^0 \pi^+ \pi^-$	[qq]	(5.4 ± 0.4) %		S=1.2	842
$\overline{K}^0 \rho^0$		(1.21 ± 0.17) %			676
$\overline{K}^0 f_0(980) \times B(f_0 \to \pi^+\pi^-)$		$(3.0 \pm 0.8) \times 10^{-3}$			549
$\overline{K}^0 f_2(1270) \times B(f_2 \to \pi^+\pi^-)$		$(2.4 \pm 0.9) \times 10^{-3}$			263
$\overline{K}^0 f_0(1370) \times B(f_0 \to \pi^+\pi^-)$		$(4.3 \pm 1.3) \times 10^{-3}$			–
$K^*(892)^- \pi^+ \times B(K^{*-} \to \overline{K}^0 \pi^-)$		(3.4 ± 0.3) %			711
$K_0^*(1430)^- \pi^+ \times B(K_0^*(1430)^- \to \overline{K}^0 \pi^-)$		$(6.4 \pm 1.6) \times 10^{-3}$			364
$\overline{K}^0 \pi^+ \pi^-$ nonresonant		(1.47 ± 0.24) %			842
$K^- \pi^+ \pi^0$	[qq]	(13.9 ± 0.9) %		S=1.3	844
$K^- \rho^+$		(10.8 ± 1.0) %			678
$K^*(892)^- \pi^+ \times B(K^{*-} \to K^- \pi^0)$		(1.7 ± 0.2) %			711
$\overline{K}^*(892)^0 \pi^0 \times B(\overline{K}^{*0} \to K^- \pi^+)$		(2.1 ± 0.3) %			709
$K^- \pi^+ \pi^0$ nonresonant		$(6.9 \pm 2.5) \times 10^{-3}$			844
$\overline{K}^0 \pi^0 \pi^0$		—			843
$\overline{K}^*(892)^0 \pi^0 \times B(\overline{K}^{*0} \to \overline{K}^0 \pi^0)$		(1.1 ± 0.2) %			709
$\overline{K}^0 \pi^0 \pi^0$ nonresonant		$(7.9 \pm 2.1) \times 10^{-3}$			843

$K^-\pi^+\pi^+\pi^-$	[qq]	(7.6 ± 0.4) %	S=1.1	812
$K^-\pi^+\rho^0$ total		(6.3 ± 0.4) %		612
$K^-\pi^+\rho^0$ 3-body		$(4.8 \pm 2.1) \times 10^{-3}$		612
$\overline{K}^*(892)^0\rho^0$ $\times$ B($\overline{K}^{*0} \to K^-\pi^+$)		$(9.8 \pm 2.2) \times 10^{-3}$		418
$K^-a_1(1260)^+$ $\times$ B($a_1(1260)^+ \to \pi^+\pi^+\pi^-$)		(3.6 ± 0.6) %		327
$\overline{K}^*(892)^0\pi^+\pi^-$ total $\times$ B($\overline{K}^{*0} \to K^-\pi^+$)		(1.5 ± 0.4) %		683
$\overline{K}^*(892)^0\pi^+\pi^-$ 3-body $\times$ B($\overline{K}^{*0} \to K^-\pi^+$)		$(9.5 \pm 2.1) \times 10^{-3}$		683
$K_1(1270)^-\pi^+$ $\times$ B($K_1(1270)^- \to K^-\pi^+\pi^-$)	[rr]	$(3.6 \pm 1.0) \times 10^{-3}$		483
$K^-\pi^+\pi^+\pi^-$ nonresonant		(1.76 ± 0.25) %		812
$\overline{K}^0\pi^+\pi^-\pi^0$	[qq]	(10.0 ± 1.2) %		812
$\overline{K}^0\eta$ $\times$ B($\eta \to \pi^+\pi^-\pi^0$)		$(1.6 \pm 0.3) \times 10^{-3}$		772
$\overline{K}^0\omega$ $\times$ B($\omega \to \pi^+\pi^-\pi^0$)		(1.9 ± 0.4) %		670
$K^*(892)^-\rho^+$ $\times$ B($K^{*-} \to \overline{K}^0\pi^-$)		(4.1 ± 1.6) %		422
$\overline{K}^*(892)^0\rho^0$ $\times$ B($\overline{K}^{*0} \to \overline{K}^0\pi^0$)		$(4.9 \pm 1.1) \times 10^{-3}$		418
$K_1(1270)^-\pi^+$ $\times$ B($K_1(1270)^- \to \overline{K}^0\pi^-\pi^0$)	[rr]	$(5.1 \pm 1.4) \times 10^{-3}$		483
$\overline{K}^*(892)^0\pi^+\pi^-$ 3-body $\times$ B($\overline{K}^{*0} \to \overline{K}^0\pi^0$)		$(4.8 \pm 1.1) \times 10^{-3}$		683
$\overline{K}^0\pi^+\pi^-\pi^0$ nonresonant		(2.1 ± 2.1) %		812
$K^-\pi^+\pi^0\pi^0$		(15 ± 5) %		815
$K^-\pi^+\pi^+\pi^-\pi^0$		(4.1 ± 0.4) %		771
$\overline{K}^*(892)^0\pi^+\pi^-\pi^0$ $\times$ B($\overline{K}^{*0} \to K^-\pi^+$)		(1.2 ± 0.6) %		641
$\overline{K}^*(892)^0\eta$ $\times$ B($\overline{K}^{*0} \to K^-\pi^+$) $\times$ B($\eta \to \pi^+\pi^-\pi^0$)		$(2.9 \pm 0.8) \times 10^{-3}$		580
$K^-\pi^+\omega$ $\times$ B($\omega \to \pi^+\pi^-\pi^0$)		(2.7 ± 0.5) %		605
$\overline{K}^*(892)^0\omega$ $\times$ B($\overline{K}^{*0} \to K^-\pi^+$) $\times$ B($\omega \to \pi^+\pi^-\pi^0$)		$(7 \pm 3) \times 10^{-3}$		406
$\overline{K}^0\pi^+\pi^+\pi^-\pi^-$		$(5.8 \pm 1.6) \times 10^{-3}$		768
$\overline{K}^0\pi^+\pi^-\pi^0\pi^0(\pi^0)$		$(10.6 {}^{+7.3}_{-3.0})$ %		771
$\overline{K}^0K^+K^-$		$(9.4 \pm 1.0) \times 10^{-3}$		544
$\overline{K}^0\phi$ $\times$ B($\phi \to K^+K^-$)		$(4.3 \pm 0.5) \times 10^{-3}$		520
$\overline{K}^0K^+K^-$ non-ϕ		$(5.1 \pm 0.8) \times 10^{-3}$		544

$K^0_S K^0_S K^0_S$		$(8.4 \pm 1.5) \times 10^{-4}$		538
$K^+ K^- K^- \pi^+$		$(2.1 \pm 0.5) \times 10^{-4}$		434
$K^+ K^- \overline{K}^0 \pi^0$		$(7.2 {}^{+4.8}_{-3.5}) \times 10^{-3}$		435

Fractions of many of the following modes with resonances have already appeared above as submodes of particular charged-particle modes. (Modes for which there are only upper limits and $\overline{K}^*(892)\rho$ submodes only appear below.)

$\overline{K}^0 \eta$		$(7.1 \pm 1.0) \times 10^{-3}$		772
$\overline{K}^0 \rho^0$		(1.21 ± 0.17) %		676
$K^- \rho^+$		(10.8 ± 1.0) %	S=1.2	678
$\overline{K}^0 \omega$		(2.1 ± 0.4) %		670
$\overline{K}^0 \eta'(958)$		(1.72 ± 0.26) %		565
$\overline{K}^0 f_0(980)$		$(5.7 \pm 1.6) \times 10^{-3}$		549
$\overline{K}^0 \phi$		$(8.6 \pm 1.0) \times 10^{-3}$		520
$K^- a_1(1260)^+$		(7.3 ± 1.1) %		327
$\overline{K}^0 a_1(1260)^0$		< 1.9 %	CL=90%	322
$\overline{K}^0 f_2(1270)$		$(4.2 \pm 1.5) \times 10^{-3}$		263
$K^- a_2(1320)^+$		$< 2 \times 10^{-3}$	CL=90%	197
$\overline{K}^0 f_0(1370)$		$(7.0 \pm 2.1) \times 10^{-3}$		–
$K^*(892)^- \pi^+$		(5.1 ± 0.4) %	S=1.2	711
$\overline{K}^*(892)^0 \pi^0$		(3.2 ± 0.4) %		709
$\overline{K}^*(892)^0 \pi^+ \pi^-$ total		(2.3 ± 0.5) %		683
$\overline{K}^*(892)^0 \pi^+ \pi^-$ 3-body		(1.43 ± 0.32) %		683
$K^- \pi^+ \rho^0$ total		(6.3 ± 0.4) %		612
$K^- \pi^+ \rho^0$ 3-body		$(4.8 \pm 2.1) \times 10^{-3}$		612
$\overline{K}^*(892)^0 \rho^0$		(1.47 ± 0.33) %		418
$\overline{K}^*(892)^0 \rho^0$ transverse		(1.5 ± 0.5) %		418
$\overline{K}^*(892)^0 \rho^0$ S-wave		(2.8 ± 0.6) %		418
$\overline{K}^*(892)^0 \rho^0$ S-wave long.		$< 3 \times 10^{-3}$	CL=90%	418
$\overline{K}^*(892)^0 \rho^0$ P-wave		$< 3 \times 10^{-3}$	CL=90%	418
$\overline{K}^*(892)^0 \rho^0$ D-wave		(1.9 ± 0.6) %		418
$K^*(892)^- \rho^+$		(6.1 ± 2.4) %		422
$K^*(892)^- \rho^+$ longitudinal		(2.9 ± 1.2) %		422
$K^*(892)^- \rho^+$ transverse		(3.2 ± 1.8) %		422
$K^*(892)^- \rho^+$ P-wave		< 1.5 %	CL=90%	422
$K^- \pi^+ f_0(980)$		< 1.1 %	CL=90%	459
$\overline{K}^*(892)^0 f_0(980)$		$< 7 \times 10^{-3}$	CL=90%	–
$K_1(1270)^- \pi^+$	[rr]	(1.06 ± 0.29) %		483
$K_1(1400)^- \pi^+$		< 1.2 %	CL=90%	386
$\overline{K}_1(1400)^0 \pi^0$		< 3.7 %	CL=90%	387

$K^*(1410)^-\pi^+$	$<$ 1.2	%	CL=90%	378
$K_0^*(1430)^-\pi^+$	(1.04±0.26)	%		364
$K_2^*(1430)^-\pi^+$	$<$ 8	$\times 10^{-3}$	CL=90%	367
$\overline{K}_2^*(1430)^0\pi^0$	$<$ 4	$\times 10^{-3}$	CL=90%	363
$\overline{K}^*(892)^0\pi^+\pi^-\pi^0$	(1.8 ±0.9)	%		641
$\overline{K}^*(892)^0\eta$	(1.9 ±0.5)	%		580
$K^-\pi^+\omega$	(3.0 ±0.6)	%		605
$\overline{K}^*(892)^0\omega$	(1.1 ±0.5)	%		406
$K^-\pi^+\eta'(958)$	(7.0 ±1.8)	$\times 10^{-3}$		479
$\overline{K}^*(892)^0\eta'(958)$	$<$ 1.1	$\times 10^{-3}$	CL=90%	99

Pionic modes

$\pi^+\pi^-$	(1.53±0.09)	$\times 10^{-3}$		922
$\pi^0\pi^0$	(8.5 ±2.2)	$\times 10^{-4}$		922
$\pi^+\pi^-\pi^0$	(1.6 ±1.1)	%	S=2.7	907
$\pi^+\pi^+\pi^-\pi^-$	(7.4 ±0.6)	$\times 10^{-3}$		879
$\pi^+\pi^+\pi^-\pi^-\pi^0$	(1.9 ±0.4)	%		844
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$	(4.0 ±3.0)	$\times 10^{-4}$		795

Hadronic modes with a $K\overline{K}$ pair

K^+K^-		$(4.27\pm0.16)\times10^{-3}$		791
$K^0\overline{K}^0$		$(6.5\pm1.8)\times10^{-4}$	S=1.2	788
$K^0K^-\pi^+$		$(6.4\pm1.0)\times10^{-3}$	S=1.1	739
$\overline{K}^*(892)^0K^0$		$<1.1\times10^{-3}$	CL=90%	605
$\times$ B($\overline{K}^{*0}\to K^-\pi^+$)				
$K^*(892)^+K^-$		$(2.3\pm0.5)\times10^{-3}$		610
$\times$ B($K^{*+}\to K^0\pi^+$)				
$K^0K^-\pi^+$ nonresonant		$(2.3\pm2.3)\times10^{-3}$		739
$\overline{K}^0K^+\pi^-$		$(5.0\pm1.0)\times10^{-3}$		739
$K^*(892)^0\overline{K}^0$		$<5\times10^{-4}$	CL=90%	605
$\times$ B($K^{*0}\to K^+\pi^-$)				
$K^*(892)^-K^+$		$(1.2\pm0.7)\times10^{-3}$		610
$\times$ B($K^{*-}\to\overline{K}^0\pi^-$)				
$\overline{K}^0K^+\pi^-$ nonresonant		$(3.9\ ^{+2.3}_{-1.9})\times10^{-3}$		739
$K^+K^-\pi^0$		$(1.3\pm0.4)\times10^{-3}$		742
$K^0_SK^0_S\pi^0$		$<5.9\times10^{-4}$		739
$K^+K^-\pi^+\pi^-$	[*vv*]	$(2.52\pm0.24)\times10^{-3}$		676
$\phi\pi^+\pi^-\times$ B($\phi\to K^+K^-$)		$(5.3\pm1.4)\times10^{-4}$		614
$\phi\rho^0\times$ B($\phi\to K^+K^-$)		$(3.0\pm1.6)\times10^{-4}$		260
$K^+K^-\rho^0$ 3-body		$(9.1\pm2.3)\times10^{-4}$		309
$K^*(892)^0K^-\pi^+$+c.c.	[*ww*]	$<5\times10^{-4}$		528
$\times$ B($K^{*0}\to K^+\pi^-$)				
$K^*(892)^0\overline{K}^*(892)^0$		$(6\pm2)\times10^{-4}$		257
$\times$ B^2($K^{*0}\to K^+\pi^-$)				
$K^+K^-\pi^+\pi^-$ non-ϕ		—		676
$K^+K^-\pi^+\pi^-$ nonresonant		$<8\times10^{-4}$	CL=90%	676
$K^0\overline{K}^0\pi^+\pi^-$		$(6.9\pm2.7)\times10^{-3}$		673
$K^+K^-\pi^+\pi^-\pi^0$		$(3.1\pm2.0)\times10^{-3}$		600

Fractions of most of the following modes with resonances have already appeared above as submodes of particular charged-particle modes.

$\overline{K}^*(892)^0K^0$		$<1.6\times10^{-3}$	CL=90%	605
$K^*(892)^+K^-$		$(3.5\pm0.8)\times10^{-3}$		610
$K^*(892)^0\overline{K}^0$		$<8\times10^{-4}$	CL=90%	605
$K^*(892)^-K^+$		$(1.8\pm1.0)\times10^{-3}$		610
$\phi\pi^0$		$<1.4\times10^{-3}$	CL=90%	644
$\phi\eta$		$<2.8\times10^{-3}$	CL=90%	489
$\phi\omega$		$<2.1\times10^{-3}$	CL=90%	239
$\phi\pi^+\pi^-$		$(1.08\pm0.29)\times10^{-3}$		614
$\phi\rho^0$		$(6\pm3)\times10^{-4}$		260
$\phi\pi^+\pi^-$ 3-body		$(7\pm5)\times10^{-4}$		614
$K^*(892)^0K^-\pi^+$ + c.c.	[*ww*]	$<8\times10^{-4}$	CL=90%	–
$K^*(892)^0\overline{K}^*(892)^0$		$(1.4\pm0.5)\times10^{-3}$		257

Doubly Cabibbo suppressed (*DC*) modes, $\Delta C = 2$ forbidden via mixing (*C2M*) modes, $\Delta C = 1$ weak neutral current (*C1*) modes, or Lepton Family number (*LF*) violating modes

$K^+ \ell^- \overline{\nu}_\ell$ (via $\overline{D}^0$)	*C2M*		$<$ 1.7		$\times 10^{-4}$	CL=90%	–
$K^+ \pi^-$ or $K^+ \pi^- \pi^+ \pi^-$ (via $\overline{D}^0$)	*C2M*		$<$ 1.0		$\times 10^{-3}$	CL=90%	–
$K^+ \pi^-$	*DC*		(2.8	$\pm$0.9)	$\times 10^{-4}$		861
$K^+ \pi^-$ (via $\overline{D}^0$)			$<$ 1.9		$\times 10^{-4}$	CL=90%	861
$K^+ \pi^- \pi^+ \pi^-$	*DC*		(1.9	$\pm$2.7)	$\times 10^{-4}$		812
$K^+ \pi^- \pi^+ \pi^-$ (via $\overline{D}^0$)			$<$ 4		$\times 10^{-4}$	CL=90%	812
μ^- anything (via $\overline{D}^0$)			$<$ 4		$\times 10^{-4}$	CL=90%	–
$e^+ e^-$	*C1*		$<$ 1.3		$\times 10^{-5}$	CL=90%	932
$\mu^+ \mu^-$	*C1*		$<$ 4.1		$\times 10^{-6}$	CL=90%	926
$\pi^0 e^+ e^-$	*C1*		$<$ 4.5		$\times 10^{-5}$	CL=90%	927
$\pi^0 \mu^+ \mu^-$	*C1*		$<$ 1.8		$\times 10^{-4}$	CL=90%	915
$\eta e^+ e^-$	*C1*		$<$ 1.1		$\times 10^{-4}$	CL=90%	852
$\eta \mu^+ \mu^-$	*C1*		$<$ 5.3		$\times 10^{-4}$	CL=90%	838
$\rho^0 e^+ e^-$	*C1*		$<$ 1.0		$\times 10^{-4}$	CL=90%	773
$\rho^0 \mu^+ \mu^-$	*C1*		$<$ 2.3		$\times 10^{-4}$	CL=90%	756
$\omega e^+ e^-$	*C1*		$<$ 1.8		$\times 10^{-4}$	CL=90%	768
$\omega \mu^+ \mu^-$	*C1*		$<$ 8.3		$\times 10^{-4}$	CL=90%	751
$\phi e^+ e^-$	*C1*		$<$ 5.2		$\times 10^{-5}$	CL=90%	654
$\phi \mu^+ \mu^-$	*C1*		$<$ 4.1		$\times 10^{-4}$	CL=90%	631
$\overline{K}^0 e^+ e^-$		[*ss*]	$<$ 1.1		$\times 10^{-4}$	CL=90%	866
$\overline{K}^0 \mu^+ \mu^-$		[*ss*]	$<$ 2.6		$\times 10^{-4}$	CL=90%	852
$\overline{K}^*(892)^0 e^+ e^-$		[*ss*]	$<$ 1.4		$\times 10^{-4}$	CL=90%	717
$\overline{K}^*(892)^0 \mu^+ \mu^-$		[*ss*]	$<$ 1.18		$\times 10^{-3}$	CL=90%	698
$\pi^+ \pi^- \pi^0 \mu^+ \mu^-$	*C1*		$<$ 8.1		$\times 10^{-4}$	CL=90%	863
$\mu^\pm e^\mp$	*LF*	[*gg*]	$<$ 1.9		$\times 10^{-5}$	CL=90%	929
$\pi^0 e^\pm \mu^\mp$	*LF*	[*gg*]	$<$ 8.6		$\times 10^{-5}$	CL=90%	924
$\eta e^\pm \mu^\mp$	*LF*	[*gg*]	$<$ 1.0		$\times 10^{-4}$	CL=90%	848
$\rho^0 e^\pm \mu^\mp$	*LF*	[*gg*]	$<$ 4.9		$\times 10^{-5}$	CL=90%	769
$\omega e^\pm \mu^\mp$	*LF*	[*gg*]	$<$ 1.2		$\times 10^{-4}$	CL=90%	764
$\phi e^\pm \mu^\mp$	*LF*	[*gg*]	$<$ 3.4		$\times 10^{-5}$	CL=90%	648
$\overline{K}^0 e^\pm \mu^\mp$	*LF*	[*gg*]	$<$ 1.0		$\times 10^{-4}$	CL=90%	862
$\overline{K}^*(892)^0 e^\pm \mu^\mp$	*LF*	[*gg*]	$<$ 1.0		$\times 10^{-4}$	CL=90%	712

$D^*(2007)^0$

$I(J^P) = \frac{1}{2}(1^-)$
I, J, P need confirmation.

Mass $m = 2006.7 \pm 0.5$ MeV (S = 1.1)
$m_{D^{*0}} - m_{D^0} = 142.12 \pm 0.07$ MeV
Full width $\Gamma < 2.1$ MeV, CL = 90%

$\overline{D}^*(2007)^0$ modes are charge conjugates of modes below.

$D^*(2007)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^0\pi^0$	(61.9 ± 2.9) %	43
$D^0\gamma$	(38.1 ± 2.9) %	137

$D^*(2010)^\pm$

$I(J^P) = \frac{1}{2}(1^-)$
I, J, P need confirmation.

Mass $m = 2010.0 \pm 0.5$ MeV (S = 1.1)
$m_{D^*(2010)^+} - m_{D^+} = 140.64 \pm 0.10$ MeV (S = 1.1)
$m_{D^*(2010)^+} - m_{D^0} = 145.397 \pm 0.030$ MeV
Full width $\Gamma < 0.131$ MeV, CL = 90%

$D^*(2010)^-$ modes are charge conjugates of the modes below.

$D^*(2010)^\pm$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^0\pi^+$	(68.3 ± 1.4) %	39
$D^+\pi^0$	(30.6 ± 2.5) %	38
$D^+\gamma$	$(1.1^{+2.1}_{-0.7})$ %	136

$D_1(2420)^0$

$I(J^P) = \frac{1}{2}(1^+)$
I, J, P need confirmation.

Mass $m = 2422.2 \pm 1.8$ MeV (S = 1.2)
Full width $\Gamma = 18.9^{+4.6}_{-3.5}$ MeV

$\overline{D}_1(2420)^0$ modes are charge conjugates of modes below.

$D_1(2420)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^*(2010)^+\pi^-$	seen	355
$D^+\pi^-$	not seen	474

$D_2^*(2460)^0$

$I(J^P) = \frac{1}{2}(2^+)$

$J^P = 2^+$ assignment strongly favored (ALBRECHT 89B).

Mass $m = 2458.9 \pm 2.0$ MeV (S = 1.2)

Full width $\Gamma = 23 \pm 5$ MeV

$\overline{D}_2^*(2460)^0$ modes are charge conjugates of modes below.

$D_2^*(2460)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^+\pi^-$	seen	503
$D^*(2010)^+\pi^-$	seen	387

$D_2^*(2460)^\pm$

$I(J^P) = \frac{1}{2}(2^+)$

$J^P = 2^+$ assignment strongly favored (ALBRECHT 89B).

Mass $m = 2459 \pm 4$ MeV (S = 1.7)

$m_{D_2^*(2460)^\pm} - m_{D_2^*(2460)^0} = 0.9 \pm 3.3$ MeV (S = 1.1)

Full width $\Gamma = 25^{+8}_{-7}$ MeV

$D_2^*(2460)^-$ modes are charge conjugates of modes below.

$D_2^*(2460)^\pm$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^0\pi^+$	seen	508
$D^{*0}\pi^+$	seen	390

CHARMED, STRANGE MESONS ($C = S = \pm1$)

$D_s^+ = c\overline{s}$, $D_s^- = \overline{c}s$, similarly for D_s^*'s

$D_s^\pm$ was $F^\pm$

$I(J^P) = 0(0^-)$

Mass $m = 1968.5 \pm 0.6$ MeV (S = 1.1)
$m_{D_s^\pm} - m_{D^\pm} = 99.2 \pm 0.5$ MeV (S = 1.1)
Mean life $\tau = (0.467 \pm 0.017) \times 10^{-12}$ s
$c\tau = 140$ μm

D_s^+ form factors

$r_2 = 1.6 \pm 0.4$
$r_v = 1.5 \pm 0.5$
$\Gamma_L/\Gamma_T = 0.72 \pm 0.18$

Branching fractions for modes with a resonance in the final state include all the decay modes of the resonance. D_s^- modes are charge conjugates of the modes below.

D_s^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Inclusive modes				
K^- anything		$(13 {}^{+14}_{-12})$ %		–
$\overline{K}^0$ anything + K^0 anything		(39 ± 28) %		–
K^+ anything		$(20 {}^{+18}_{-14})$ %		–
non-$K\overline{K}$ anything		(64 ± 17) %		–
e^+ anything		$(8 {}^{+6}_{-5})$ %		–
ϕ anything		$(18 {}^{+15}_{-10})$ %		–
Leptonic and semileptonic modes				
$\mu^+\nu_\mu$		$(4.0 {}^{+2.2}_{-2.0}) \times 10^{-3}$	S=1.4	981
$\tau^+\nu_\tau$		(7 ± 4) %		182
$\phi\ell^+\nu_\ell$	[xx]	(2.0 ± 0.5) %		–
$\eta\ell^+\nu_\ell$ + $\eta'(958)\ell^+\nu_\ell$	[xx]	(3.4 ± 1.0) %		–
$\eta\ell^+\nu_\ell$		(2.5 ± 0.7) %		–
$\eta'(958)\ell^+\nu_\ell$		$(8.8 \pm 3.4) \times 10^{-3}$		–

Hadronic modes with a $K\overline{K}$ pair (including from a ϕ)

$K^+\overline{K}^0$		(3.6 ± 1.1) %		850
$K^+K^-\pi^+$	[qq]	(4.4 ± 1.2) %	S=1.1	805
$\phi\pi^+$	[yy]	(3.6 ± 0.9) %		712
$K^+\overline{K}^*(892)^0$	[yy]	(3.3 ± 0.9) %		682
$f_0(980)\pi^+$	[yy]	(1.8 ± 0.8) %	S=1.3	732
$K^+\overline{K}^*_0(1430)^0$	[yy]	$(7 \pm 4) \times 10^{-3}$		186
$f_J(1710)\pi^+ \to K^+K^-\pi^+$	[zz]	$(1.5 \pm 1.9) \times 10^{-3}$		204
$K^+K^-\pi^+$ nonresonant		$(9 \pm 4) \times 10^{-3}$		805
$K^0\overline{K}^0\pi^+$		—		802
$K^*(892)^+\overline{K}^0$	[yy]	(4.3 ± 1.4) %		683
$K^+K^-\pi^+\pi^0$		—		748
$\phi\pi^+\pi^0$	[yy]	(9 ± 5) %		687
$\phi\rho^+$	[yy]	(6.7 ± 2.3) %		407
$\phi\pi^+\pi^0$ 3-body	[yy]	< 2.6 %	CL=90%	687
$K^+K^-\pi^+\pi^0$ non-ϕ		< 9 %	CL=90%	748
$K^+\overline{K}^0\pi^+\pi^-$		< 2.8 %	CL=90%	744
$K^0K^-\pi^+\pi^+$		(4.3 ± 1.5) %		744
$K^*(892)^+\overline{K}^*(892)^0$	[yy]	(5.8 ± 2.5) %		412
$K^0K^-\pi^+\pi^+$ non-$K^{*+}\overline{K}^{*0}$		< 2.9 %	CL=90%	744
$K^+K^-\pi^+\pi^+\pi^-$		$(8.3 \pm 3.3) \times 10^{-3}$		673
$\phi\pi^+\pi^+\pi^-$	[yy]	(1.18 ± 0.35) %		640
$K^+K^-\pi^+\pi^+\pi^-$ non-ϕ		$(3.0 {}^{+3.0}_{-2.0}) \times 10^{-3}$		673

Hadronic modes without K's

$\pi^+\pi^+\pi^-$		(1.0 ± 0.4) %	S=1.2	959
$\rho^0\pi^+$		$< 8 \times 10^{-4}$	CL=90%	827
$f_0(980)\pi^+$	[yy]	(1.8 ± 0.8) %	S=1.7	732
$f_2(1270)\pi^+$	[yy]	$(2.3 \pm 1.3) \times 10^{-3}$		559
$f_0(1500)\pi^+ \to \pi^+\pi^-\pi^+$	[aaa]	$(2.8 \pm 1.6) \times 10^{-3}$		391
$\pi^+\pi^+\pi^-$ nonresonant		$< 2.8 \times 10^{-3}$	CL=90%	959
$\pi^+\pi^+\pi^-\pi^0$		< 12 %	CL=90%	935
$\eta\pi^+$	[yy]	(2.0 ± 0.6) %		902
$\omega\pi^+$	[yy]	$(3.1 \pm 1.4) \times 10^{-3}$		822
$\pi^+\pi^+\pi^+\pi^-\pi^-$		$(6.9 \pm 3.0) \times 10^{-3}$		899
$\pi^+\pi^+\pi^-\pi^0\pi^0$		—		902
$\eta\rho^+$	[yy]	(10.3 ± 3.2) %		727
$\eta\pi^+\pi^0$ 3-body	[yy]	< 3.0 %	CL=90%	886
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^0$		(4.9 ± 3.2) %		856
$\eta'(958)\pi^+$	[yy]	(4.9 ± 1.8) %		743
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^0\pi^0$		—		803
$\eta'(958)\rho^+$	[yy]	(12 ± 4) %		470
$\eta'(958)\pi^+\pi^0$ 3-body	[yy]	< 3.1 %	CL=90%	720

Modes with one or three K's

$K^0\pi^+$			$<$ 8	$\times 10^{-3}$	CL=90%	916
$K^+\pi^+\pi^-$			(1.0 $\pm$ 0.4) %			900
$K^+\rho^0$			$<$ 2.9	$\times 10^{-3}$	CL=90%	747
$K^*(892)^0\pi^+$		[yy]	(6.5 $\pm$ 2.8)	$\times 10^{-3}$		773
$K^+K^+K^-$			$<$ 6	$\times 10^{-4}$	CL=90%	628
ϕK^+		[yy]	$<$ 5	$\times 10^{-4}$	CL=90%	607

$\Delta C = 1$ weak neutral current ($C1$) modes, or Lepton number (L) violating modes

$\pi^+\mu^+\mu^-$		[ss]	$<$ 4.3	$\times 10^{-4}$	CL=90%	968
$K^+\mu^+\mu^-$	*C1*		$<$ 5.9	$\times 10^{-4}$	CL=90%	909
$K^*(892)^+\mu^+\mu^-$	*C1*		$<$ 1.4	$\times 10^{-3}$	CL=90%	765
$\pi^-\mu^+\mu^+$	*L*		$<$ 4.3	$\times 10^{-4}$	CL=90%	968
$K^-\mu^+\mu^+$	*L*		$<$ 5.9	$\times 10^{-4}$	CL=90%	909
$K^*(892)^-\mu^+\mu^+$	*L*		$<$ 1.4	$\times 10^{-3}$	CL=90%	765

$D_s^{*\pm}$

$I(J^P) = 0(?^?)$

J^P is natural, width and decay modes consistent with 1^-.

Mass $m = 2112.4 \pm 0.7$ MeV (S = 1.1)

$m_{D_s^{*\pm}} - m_{D_s^{\pm}} = 143.8 \pm 0.4$ MeV

Full width $\Gamma < 1.9$ MeV, CL = 90%

D_s^{*-} modes are charge conjugates of the modes below.

D_s^{*+} DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D_s^+\gamma$	(94.2$\pm$2.5) %	139
$D_s^+\pi^0$	(5.8$\pm$2.5) %	48

$D_{s1}(2536)^{\pm}$

$I(J^P) = 0(1^+)$
J, P need confirmation.

Mass $m = 2535.35 \pm 0.34 \pm 0.5$ MeV
Full width $\Gamma < 2.3$ MeV, CL = 90%

$D_{s1}(2536)^-$ modes are charge conjugates of the modes below.

$D_{s1}(2536)^+$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^*(2010)^+ K^0$	seen	150
$D^*(2007)^0 K^+$	seen	169
$D^+ K^0$	not seen	382
$D^0 K^+$	not seen	392
$D_s^{*+} \gamma$	possibly seen	389

$D_{sJ}(2573)^{\pm}$

$I(J^P) = 0(?^?)$

J^P is natural, width and decay modes consistent with 2^+.

Mass $m = 2573.5 \pm 1.7$ MeV
Full width $\Gamma = 15^{+5}_{-4}$ MeV

$D_{sJ}(2573)^-$ modes are charge conjugates of the modes below.

$D_{sJ}(2573)^+$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^0 K^+$	seen	436
$D^*(2007)^0 K^+$	not seen	245

BOTTOM MESONS
($B = \pm 1$)

$B^+ = u\overline{b}$, $B^0 = d\overline{b}$, $\overline{B}^0 = \overline{d}\,b$, $B^- = \overline{u}\,b$, similarly for B^*'s

B-particle organization

Many measurements of B decays involve admixtures of B hadrons. Previously we arbitrarily included such admixtures in the $B^{\pm}$ section, but because of their importance we have created two new sections: "$B^{\pm}/B^0$ Admixture" for $\Upsilon(4S)$ results and "$B^{\pm}/B^0/B^0_s/b$-baryon Admixture" for results at higher energies. Most inclusive decay branching fractions are found in the Admixture sections. B^0-$\overline{B}^0$ mixing data are found in the B^0 section, while B^0_s-$\overline{B}^0_s$ mixing data and B-$\overline{B}$ mixing data for a B^0/B^0_s admixture are found in the B^0_s section. CP-violation data are found in the B^0 section. b-baryons are found near the end of the Baryon section.

The organization of the B sections is now as follows, where bullets indicate particle sections and brackets indicate reviews.

[Production and Decay of b-flavored Hadrons]

- $B^{\pm}$
  - mass, mean life
  - branching fractions
- B^0
  - mass, mean life
  - branching fractions
  - polarization in B^0 decay
  - B^0-$\overline{B}^0$ mixing
  - [CP Violation in B Decay]
  - CP violation
- $B^{\pm}$ B^0 Admixtures
  - branching fractions
- $B^{\pm}/B^0/B^0_s/b$-baryon Admixtures
  - mean life
  - production fractions
  - branching fractions
- B^*
  - mass
- B^0_s
  - mass, mean life
  - branching fractions
  - polarization in B^0_s decay
  - B^0_s-$\overline{B}^0_s$ mixing
  - B-$\overline{B}$ mixing (admixture of B^0, B^0_s)

At end of Baryon Listings:

- Λ_b
  - mass, mean life
  - branching fractions
- b-baryon Admixture
  - mean life
  - branching fractions

$B^{\pm}$

$I(J^P) = \frac{1}{2}(0^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B^{\pm}} = 5278.9 \pm 1.8$ MeV
Mean life $\tau_{B^{\pm}} = (1.65 \pm 0.04) \times 10^{-12}$ s
$c\tau = 495$ μm

B^- modes are charge conjugates of the modes below. Modes which do not identify the charge state of the B are listed in the $B^{\pm}/B^0$ ADMIXTURE section.

The branching fractions listed below assume 50% $B^0\overline{B}^0$ and 50% B^+B^- production at the $\Upsilon(4S)$. We have attempted to bring older measurements up to date by rescaling their assumed $\Upsilon(4S)$ production ratio to 50:50 and their assumed D, D_s, D^*, and ψ branching ratios to current values whenever this would affect our averages and best limits significantly.

Indentation is used to indicate a subchannel of a previous reaction. All resonant subchannels have been corrected for resonance branching fractions to the final state so the sum of the subchannel branching fractions can exceed that of the final state.

B^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Semileptonic and leptonic modes				
$\ell^+\nu_\ell$ anything	[pp]	(10.3 ± 0.9) %		–
$\overline{D}^0\ell^+\nu_\ell$	[pp]	(1.86 ± 0.33) %		–
$\overline{D}^*(2007)^0\ell^+\nu_\ell$	[pp]	(5.3 ± 0.8) %		–
$\pi^0 e^+\nu_e$		$< 2.2 \times 10^{-3}$	CL=90%	2638
$\omega\ell^+\nu_\ell$	[pp]	$< 2.1 \times 10^{-4}$	CL=90%	–
$\rho^0\ell^+\nu_\ell$	[pp]	$< 2.1 \times 10^{-4}$	CL=90%	–
$e^+\nu_e$		$< 1.5 \times 10^{-5}$	CL=90%	2639
$\mu^+\nu_\mu$		$< 2.1 \times 10^{-5}$	CL=90%	2638
$\tau^+\nu_\tau$		$< 5.7 \times 10^{-4}$	CL=90%	2340
$e^+\nu_e\gamma$		$< 2.0 \times 10^{-4}$	CL=90%	–
$\mu^+\nu_\mu\gamma$		$< 5.2 \times 10^{-5}$	CL=90%	–

D, D^*, or D_s modes

$\overline{D}^0\pi^+$	$(5.3 \pm 0.5) \times 10^{-3}$			2308
$\overline{D}^0\rho^+$	(1.34 ± 0.18) %			2238
$\overline{D}^0\pi^+\pi^+\pi^-$	(1.1 ± 0.4) %			2289
$\overline{D}^0\pi^+\pi^+\pi^-$ nonresonant	$(5 \pm 4) \times 10^{-3}$			2289
$\overline{D}^0\pi^+\rho^0$	$(4.2 \pm 3.0) \times 10^{-3}$			2209
$\overline{D}^0 a_1(1260)^+$	$(5 \pm 4) \times 10^{-3}$			2123
$D^*(2010)^-\pi^+\pi^+$	$(2.1 \pm 0.6) \times 10^{-3}$			2247
$D^-\pi^+\pi^+$	$< 1.4 \times 10^{-3}$	CL=90%		2299
$\overline{D}^*(2007)^0\pi^+$	$(4.6 \pm 0.4) \times 10^{-3}$			2256
$D^*(2010)^+\pi^0$	$< 1.7 \times 10^{-4}$	CL=90%		2254
$\overline{D}^*(2007)^0\rho^+$	(1.55 ± 0.31) %			2183
$\overline{D}^*(2007)^0\pi^+\pi^+\pi^-$	$(9.4 \pm 2.6) \times 10^{-3}$			2236
$\overline{D}^*(2007)^0 a_1(1260)^+$	(1.9 ± 0.5) %			2062
$D^*(2010)^-\pi^+\pi^+\pi^0$	(1.5 ± 0.7) %			2235
$D^*(2010)^-\pi^+\pi^+\pi^+\pi^-$	< 1 %	CL=90%		2217
$\overline{D}_1^*(2420)^0\pi^+$	$(1.5 \pm 0.6) \times 10^{-3}$	S=1.3		2081
$\overline{D}_1^*(2420)^0\rho^+$	$< 1.4 \times 10^{-3}$	CL=90%		1997
$\overline{D}_2^*(2460)^0\pi^+$	$< 1.3 \times 10^{-3}$	CL=90%		2064
$\overline{D}_2^*(2460)^0\rho^+$	$< 4.7 \times 10^{-3}$	CL=90%		1979
$\overline{D}^0 D_s^+$	(1.3 ± 0.4) %			1815
$\overline{D}^0 D_s^{*+}$	$(9 \pm 4) \times 10^{-3}$			1734
$\overline{D}^*(2007)^0 D_s^+$	(1.2 ± 0.5) %			1737
$\overline{D}^*(2007)^0 D_s^{*+}$	(2.7 ± 1.0) %			1650
$D_s^+\pi^0$	$< 2.0 \times 10^{-4}$	CL=90%		2270
$D_s^{*+}\pi^0$	$< 3.3 \times 10^{-4}$	CL=90%		2214
$D_s^+\eta$	$< 5 \times 10^{-4}$	CL=90%		2235
$D_s^{*+}\eta$	$< 8 \times 10^{-4}$	CL=90%		2177
$D_s^+\rho^0$	$< 4 \times 10^{-4}$	CL=90%		2198
$D_s^{*+}\rho^0$	$< 5 \times 10^{-4}$	CL=90%		2139
$D_s^+\omega$	$< 5 \times 10^{-4}$	CL=90%		2195
$D_s^{*+}\omega$	$< 7 \times 10^{-4}$	CL=90%		2136
$D_s^+ a_1(1260)^0$	$< 2.2 \times 10^{-3}$	CL=90%		2079
$D_s^{*+} a_1(1260)^0$	$< 1.6 \times 10^{-3}$	CL=90%		2014
$D_s^+\phi$	$< 3.2 \times 10^{-4}$	CL=90%		2141
$D_s^{*+}\phi$	$< 4 \times 10^{-4}$	CL=90%		2079
$D_s^+\overline{K}^0$	$< 1.1 \times 10^{-3}$	CL=90%		2241
$D_s^{*+}\overline{K}^0$	$< 1.1 \times 10^{-3}$	CL=90%		2184
$D_s^+\overline{K}^*(892)^0$	$< 5 \times 10^{-4}$	CL=90%		2171

$D_s^{*+} \overline{K}^*(892)^0$	$<$ 4	$\times 10^{-4}$	CL=90%	2110
$D_s^- \pi^+ K^+$	$<$ 8	$\times 10^{-4}$	CL=90%	2222
$D_s^{*-} \pi^+ K^+$	$<$ 1.2	$\times 10^{-3}$	CL=90%	2164
$D_s^- \pi^+ K^*(892)^+$	$<$ 6	$\times 10^{-3}$	CL=90%	2137
$D_s^{*-} \pi^+ K^*(892)^+$	$<$ 8	$\times 10^{-3}$	CL=90%	2075

Charmonium modes

$J/\psi(1S) K^+$	(9.9 $\pm$1.0)	$\times 10^{-4}$		1683
$J/\psi(1S) K^+ \pi^+ \pi^-$	(1.4 $\pm$0.6)	$\times 10^{-3}$		1612
$J/\psi(1S) K^*(892)^+$	(1.47$\pm$0.27)	$\times 10^{-3}$		1571
$J/\psi(1S) \pi^+$	(5.0 $\pm$1.5)	$\times 10^{-5}$		1727
$J/\psi(1S) \rho^+$	$<$ 7.7	$\times 10^{-4}$	CL=90%	1613
$J/\psi(1S) a_1(1260)^+$	$<$ 1.2	$\times 10^{-3}$	CL=90%	1414
$\psi(2S) K^+$	(6.9 $\pm$3.1)	$\times 10^{-4}$	S=1.3	1284
$\psi(2S) K^*(892)^+$	$<$ 3.0	$\times 10^{-3}$	CL=90%	1115
$\psi(2S) K^+ \pi^+ \pi^-$	(1.9 $\pm$1.2)	$\times 10^{-3}$		909
$\chi_{c1}(1P) K^+$	(1.0 $\pm$0.4)	$\times 10^{-3}$		1411
$\chi_{c1}(1P) K^*(892)^+$	$<$ 2.1	$\times 10^{-3}$	CL=90%	1265

***K* or *K** modes**

$K^0 \pi^+$	(2.3 $\pm$1.1)	$\times 10^{-5}$		2614
$K^+ \pi^0$	$<$ 1.6	$\times 10^{-5}$	CL=90%	2615
$\eta' K^+$	(6.5 $\pm$1.7)	$\times 10^{-5}$		2528
$\eta' K^*(892)^+$	$<$ 1.3	$\times 10^{-4}$	CL=90%	2472
ηK^+	$<$ 1.4	$\times 10^{-5}$	CL=90%	2587
$\eta K^*(892)^+$	$<$ 3.0	$\times 10^{-5}$	CL=90%	2534
$K^*(892)^0 \pi^+$	$<$ 4.1	$\times 10^{-5}$	CL=90%	2561
$K^*(892)^+ \pi^0$	$<$ 9.9	$\times 10^{-5}$	CL=90%	2562
$K^+ \pi^- \pi^+$ nonresonant	$<$ 2.8	$\times 10^{-5}$	CL=90%	2609
$K^- \pi^+ \pi^+$ nonresonant	$<$ 5.6	$\times 10^{-5}$	CL=90%	–
$K_1(1400)^0 \pi^+$	$<$ 2.6	$\times 10^{-3}$	CL=90%	2451
$K_2^*(1430)^0 \pi^+$	$<$ 6.8	$\times 10^{-4}$	CL=90%	2443
$K^+ \rho^0$	$<$ 1.9	$\times 10^{-5}$	CL=90%	2559
$K^0 \rho^+$	$<$ 4.8	$\times 10^{-5}$	CL=90%	2559
$K^*(892)^+ \pi^+ \pi^-$	$<$ 1.1	$\times 10^{-3}$	CL=90%	2556
$K^*(892)^+ \rho^0$	$<$ 9.0	$\times 10^{-4}$	CL=90%	2505
$K_1(1400)^+ \rho^0$	$<$ 7.8	$\times 10^{-4}$	CL=90%	2389
$K_2^*(1430)^+ \rho^0$	$<$ 1.5	$\times 10^{-3}$	CL=90%	2382

$K^+ \overline{K}^0$	$<$ 2.1	$\times 10^{-5}$	CL=90%	2592
$K^+ K^- \pi^+$ nonresonant	$<$ 7.5	$\times 10^{-5}$	CL=90%	–
$K^+ K^- K^+$	$<$ 2.0	$\times 10^{-4}$	CL=90%	2522
$K^+ \phi$	$<$ 1.2	$\times 10^{-5}$	CL=90%	2516
$K^+ K^- K^+$ nonresonant	$<$ 3.8	$\times 10^{-5}$	CL=90%	2516
$K^*(892)^+ K^+ K^-$	$<$ 1.6	$\times 10^{-3}$	CL=90%	2466
$K^*(892)^+ \phi$	$<$ 7.0	$\times 10^{-5}$	CL=90%	2460
$K_1(1400)^+ \phi$	$<$ 1.1	$\times 10^{-3}$	CL=90%	2339
$K_2^*(1430)^+ \phi$	$<$ 3.4	$\times 10^{-3}$	CL=90%	2332
$K^+ f_0(980)$	$<$ 8	$\times 10^{-5}$	CL=90%	2524
$K^*(892)^+ \gamma$	(5.7 $\pm$3.3)	$\times 10^{-5}$		2564
$K_1(1270)^+ \gamma$	$<$ 7.3	$\times 10^{-3}$	CL=90%	2486
$K_1(1400)^+ \gamma$	$<$ 2.2	$\times 10^{-3}$	CL=90%	2453
$K_2^*(1430)^+ \gamma$	$<$ 1.4	$\times 10^{-3}$	CL=90%	2447
$K^*(1680)^+ \gamma$	$<$ 1.9	$\times 10^{-3}$	CL=90%	2361
$K_3^*(1780)^+ \gamma$	$<$ 5.5	$\times 10^{-3}$	CL=90%	2343
$K_4^*(2045)^+ \gamma$	$<$ 9.9	$\times 10^{-3}$	CL=90%	2243

Light unflavored meson modes

$\pi^+ \pi^0$	$<$ 2.0	$\times 10^{-5}$	CL=90%	2636
$\pi^+ \pi^+ \pi^-$	$<$ 1.3	$\times 10^{-4}$	CL=90%	2630
$\rho^0 \pi^+$	$<$ 4.3	$\times 10^{-5}$	CL=90%	2582
$\pi^+ f_0(980)$	$<$ 1.4	$\times 10^{-4}$	CL=90%	2547
$\pi^+ f_2(1270)$	$<$ 2.4	$\times 10^{-4}$	CL=90%	2483
$\pi^+ \pi^- \pi^+$ nonresonant	$<$ 4.1	$\times 10^{-5}$	CL=90%	–
$\pi^+ \pi^0 \pi^0$	$<$ 8.9	$\times 10^{-4}$	CL=90%	2631
$\rho^+ \pi^0$	$<$ 7.7	$\times 10^{-5}$	CL=90%	2582
$\pi^+ \pi^- \pi^+ \pi^0$	$<$ 4.0	$\times 10^{-3}$	CL=90%	2621
$\rho^+ \rho^0$	$<$ 1.0	$\times 10^{-3}$	CL=90%	2525
$a_1(1260)^+ \pi^0$	$<$ 1.7	$\times 10^{-3}$	CL=90%	2494
$a_1(1260)^0 \pi^+$	$<$ 9.0	$\times 10^{-4}$	CL=90%	2494
$\omega \pi^+$	$<$ 4.0	$\times 10^{-4}$	CL=90%	2580
$\eta \pi^+$	$<$ 1.5	$\times 10^{-5}$	CL=90%	2609
$\eta' \pi^+$	$<$ 3.1	$\times 10^{-5}$	CL=90%	2550
$\eta' \rho^+$	$<$ 4.7	$\times 10^{-5}$	CL=90%	2493
$\eta \rho^+$	$<$ 3.2	$\times 10^{-5}$	CL=90%	2554
$\pi^+ \pi^+ \pi^+ \pi^- \pi^-$	$<$ 8.6	$\times 10^{-4}$	CL=90%	2608
$\rho^0 a_1(1260)^+$	$<$ 6.2	$\times 10^{-4}$	CL=90%	2434
$\rho^0 a_2(1320)^+$	$<$ 7.2	$\times 10^{-4}$	CL=90%	2411
$\pi^+ \pi^+ \pi^+ \pi^- \pi^- \pi^0$	$<$ 6.3	$\times 10^{-3}$	CL=90%	2592
$a_1(1260)^+ a_1(1260)^0$	$<$ 1.3	%	CL=90%	2335

Baryon modes

$p\overline{p}\pi^+$		$<$ 1.6	$\times 10^{-4}$	CL=90%	2439
$p\overline{p}\pi^+$ nonresonant		$<$ 5.3	$\times 10^{-5}$	CL=90%	–
$p\overline{p}\pi^+\pi^+\pi^-$		$<$ 5.2	$\times 10^{-4}$	CL=90%	2369
$p\overline{p}K^+$ nonresonant		$<$ 8.9	$\times 10^{-5}$	CL=90%	–
$p\overline{\Lambda}$		$<$ 6	$\times 10^{-5}$	CL=90%	2430
$p\overline{\Lambda}\pi^+\pi^-$		$<$ 2.0	$\times 10^{-4}$	CL=90%	2367
$\overline{\Delta}^0 p$		$<$ 3.8	$\times 10^{-4}$	CL=90%	2402
$\Delta^{++}\overline{p}$		$<$ 1.5	$\times 10^{-4}$	CL=90%	2402
$\Lambda_c^- p\pi^+$		(6.2 $\pm$2.7)	$\times 10^{-4}$		–
$\Lambda_c^- p\pi^+\pi^0$		$<$ 3.12	$\times 10^{-3}$	CL=90%	–
$\Lambda_c^- p\pi^+\pi^+\pi^-$		$<$ 1.46	$\times 10^{-3}$	CL=90%	–
$\Lambda_c^- p\pi^+\pi^+\pi^-\pi^0$		$<$ 1.34	%	CL=90%	–

Lepton Family number (*LF*) or Lepton number (*L*) violating modes, or $\Delta B = 1$ weak neutral current (*B1*) modes

$\pi^+ e^+ e^-$	*B1*	$<$ 3.9	$\times 10^{-3}$	CL=90%	2638
$\pi^+ \mu^+ \mu^-$	*B1*	$<$ 9.1	$\times 10^{-3}$	CL=90%	2633
$K^+ e^+ e^-$	*B1*	$<$ 6	$\times 10^{-5}$	CL=90%	2616
$K^+ \mu^+ \mu^-$	*B1*	$<$ 1.0	$\times 10^{-5}$	CL=90%	2612
$K^*(892)^+ e^+ e^-$	*B1*	$<$ 6.9	$\times 10^{-4}$	CL=90%	2564
$K^*(892)^+ \mu^+ \mu^-$	*B1*	$<$ 1.2	$\times 10^{-3}$	CL=90%	2560
$\pi^+ e^+ \mu^-$	*LF*	$<$ 6.4	$\times 10^{-3}$	CL=90%	2637
$\pi^+ e^- \mu^+$	*LF*	$<$ 6.4	$\times 10^{-3}$	CL=90%	2637
$K^+ e^+ \mu^-$	*LF*	$<$ 6.4	$\times 10^{-3}$	CL=90%	2615
$K^+ e^- \mu^+$	*LF*	$<$ 6.4	$\times 10^{-3}$	CL=90%	2615
$\pi^- e^+ e^+$	*L*	$<$ 3.9	$\times 10^{-3}$	CL=90%	2638
$\pi^- \mu^+ \mu^+$	*L*	$<$ 9.1	$\times 10^{-3}$	CL=90%	2633
$\pi^- e^+ \mu^+$	*LF*	$<$ 6.4	$\times 10^{-3}$	CL=90%	2637
$K^- e^+ e^+$	*L*	$<$ 3.9	$\times 10^{-3}$	CL=90%	2616
$K^- \mu^+ \mu^+$	*L*	$<$ 9.1	$\times 10^{-3}$	CL=90%	2612
$K^- e^+ \mu^+$	*LF*	$<$ 6.4	$\times 10^{-3}$	CL=90%	2615

B^0

$I(J^P) = \frac{1}{2}(0^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B^0} = 5279.2 \pm 1.8$ MeV

$m_{B^0} - m_{B^\pm} = 0.35 \pm 0.29$ MeV (S = 1.1)

Mean life $\tau_{B^0} = (1.56 \pm 0.04) \times 10^{-12}$ s

$c\tau = 468$ μm

$\tau_{B^+}/\tau_{B^0} = 1.02 \pm 0.04$ (average of direct and inferred)

$\tau_{B^+}/\tau_{B^0} = 1.04 \pm 0.04$ (direct measurements)

$\tau_{B^+}/\tau_{B^0} = 0.95^{+0.15}_{-0.12}$ (inferred from branching fractions)

B^0-$\overline{B}^0$ mixing parameters

$\chi_d = 0.172 \pm 0.010$

$\Delta m_{B^0} = m_{B^0_H} - m_{B^0_L} = (0.464 \pm 0.018) \times 10^{12}$ $\hbar$ s^{-1}

$x_d = \Delta m_{B^0}/\Gamma_{B^0} = 0.723 \pm 0.032$

CP violation parameters

$\left|\mathrm{Re}(\epsilon_{B^0})\right| = 0.002 \pm 0.008$

$\overline{B}^0$ modes are charge conjugates of the modes below. Reactions indicate the weak decay vertex and do not include mixing. Modes which do not identify the charge state of the B are listed in the $B^\pm/B^0$ ADMIXTURE section.

The branching fractions listed below assume 50% $B^0\overline{B}^0$ and 50% B^+B^- production at the $\Upsilon(4S)$. We have attempted to bring older measurements up to date by rescaling their assumed $\Upsilon(4S)$ production ratio to 50:50 and their assumed D, D_s, D^*, and ψ branching ratios to current values whenever this would affect our averages and best limits significantly.

Indentation is used to indicate a subchannel of a previous reaction. All resonant subchannels have been corrected for resonance branching fractions to the final state so the sum of the subchannel branching fractions can exceed that of the final state.

B^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\ell^+\nu_\ell$ anything	[pp]	(10.5 ± 0.8) %		–
$D^-\ell^+\nu_\ell$	[pp]	(2.00 ± 0.25) %		–
$D^*(2010)^-\ell^+\nu_\ell$	[pp]	(4.60 ± 0.27) %		–
$\rho^-\ell^+\nu_\ell$	[pp]	$(2.5^{+0.8}_{-1.0}) \times 10^{-4}$		–
$\pi^-\ell^+\nu_\ell$		$(1.8 \pm 0.6) \times 10^{-4}$		–
Inclusive modes				
K^+ anything		(78 ± 80) %		–

D, D^*, or D_s modes

$D^- \pi^+$	$(3.0 \pm 0.4) \times 10^{-3}$		2306
$D^- \rho^+$	$(7.9 \pm 1.4) \times 10^{-3}$		2236
$\overline{D}^0 \pi^+ \pi^-$	$< 1.6 \times 10^{-3}$	CL=90%	2301
$D^*(2010)^- \pi^+$	$(2.76 \pm 0.21) \times 10^{-3}$		2254
$D^- \pi^+ \pi^+ \pi^-$	$(8.0 \pm 2.5) \times 10^{-3}$		2287
$(D^- \pi^+ \pi^+ \pi^-)$ nonresonant	$(3.9 \pm 1.9) \times 10^{-3}$		2287
$D^- \pi^+ \rho^0$	$(1.1 \pm 1.0) \times 10^{-3}$		2207
$D^- a_1(1260)^+$	$(6.0 \pm 3.3) \times 10^{-3}$		2121
$D^*(2010)^- \pi^+ \pi^0$	(1.5 ± 0.5) %		2247
$D^*(2010)^- \rho^+$	$(6.7 \pm 3.3) \times 10^{-3}$		2181
$D^*(2010)^- \pi^+ \pi^+ \pi^-$	$(7.6 \pm 1.7) \times 10^{-3}$	S=1.3	2235
$(D^*(2010)^- \pi^+ \pi^+ \pi^-)$ non-resonant	$(0.0 \pm 2.5) \times 10^{-3}$		2235
$D^*(2010)^- \pi^+ \rho^0$	$(5.7 \pm 3.1) \times 10^{-3}$		2151
$D^*(2010)^- a_1(1260)^+$	(1.30 ± 0.27) %		2061
$D^*(2010)^- \pi^+ \pi^+ \pi^- \pi^0$	(3.4 ± 1.8) %		2218
$\overline{D}_2^*(2460)^- \pi^+$	$< 2.2 \times 10^{-3}$	CL=90%	2064
$\overline{D}_2^*(2460)^- \rho^+$	$< 4.9 \times 10^{-3}$	CL=90%	1979
$D^- D_s^+$	$(8.0 \pm 3.0) \times 10^{-3}$		1812
$D^*(2010)^- D_s^+$	$(9.6 \pm 3.4) \times 10^{-3}$		1735
$D^- D_s^{*+}$	(1.0 ± 0.5) %		1731
$D^*(2010)^- D_s^{*+}$	(2.0 ± 0.7) %		1649
$D_s^+ \pi^-$	$< 2.8 \times 10^{-4}$	CL=90%	2270
$D_s^{*+} \pi^-$	$< 5 \times 10^{-4}$	CL=90%	2214
$D_s^+ \rho^-$	$< 7 \times 10^{-4}$	CL=90%	2198
$D_s^{*+} \rho^-$	$< 8 \times 10^{-4}$	CL=90%	2139
$D_s^+ a_1(1260)^-$	$< 2.6 \times 10^{-3}$	CL=90%	2079
$D_s^{*+} a_1(1260)^-$	$< 2.2 \times 10^{-3}$	CL=90%	2014
$D_s^- K^+$	$< 2.4 \times 10^{-4}$	CL=90%	2242
$D_s^{*-} K^+$	$< 1.7 \times 10^{-4}$	CL=90%	2185
$D_s^- K^*(892)^+$	$< 9.9 \times 10^{-4}$	CL=90%	2172
$D_s^{*-} K^*(892)^+$	$< 1.1 \times 10^{-3}$	CL=90%	2112
$D_s^- \pi^+ K^0$	$< 5 \times 10^{-3}$	CL=90%	2221
$D_s^{*-} \pi^+ K^0$	$< 3.1 \times 10^{-3}$	CL=90%	2164
$D_s^- \pi^+ K^*(892)^0$	$< 4 \times 10^{-3}$	CL=90%	2136
$D_s^{*-} \pi^+ K^*(892)^0$	$< 2.0 \times 10^{-3}$	CL=90%	2074
$\overline{D}^0 \pi^0$	$< 1.2 \times 10^{-4}$	CL=90%	2308
$\overline{D}^0 \rho^0$	$< 3.9 \times 10^{-4}$	CL=90%	2238
$\overline{D}^0 \eta$	$< 1.3 \times 10^{-4}$	CL=90%	2274

$\overline{D}^0 \eta'$	$<$ 9.4	$\times 10^{-4}$	CL=90%	2198
$\overline{D}^0 \omega$	$<$ 5.1	$\times 10^{-4}$	CL=90%	2235
$\overline{D}^*(2007)^0 \pi^0$	$<$ 4.4	$\times 10^{-4}$	CL=90%	2256
$\overline{D}^*(2007)^0 \rho^0$	$<$ 5.6	$\times 10^{-4}$	CL=90%	2183
$\overline{D}^*(2007)^0 \eta$	$<$ 2.6	$\times 10^{-4}$	CL=90%	2220
$\overline{D}^*(2007)^0 \eta'$	$<$ 1.4	$\times 10^{-3}$	CL=90%	2141
$\overline{D}^*(2007)^0 \omega$	$<$ 7.4	$\times 10^{-4}$	CL=90%	2180
$D^*(2010)^+ D^*(2010)^-$	$<$ 2.2	$\times 10^{-3}$	CL=90%	1711
$D^*(2010)^+ D^-$	$<$ 1.8	$\times 10^{-3}$	CL=90%	1790
$D^+ D^*(2010)^-$	$<$ 1.2	$\times 10^{-3}$	CL=90%	1790

Charmonium modes

$J/\psi(1S) K^0$	(8.9 $\pm$ 1.2)	$\times 10^{-4}$		1683
$J/\psi(1S) K^+ \pi^-$	(1.1 $\pm$ 0.6)	$\times 10^{-3}$		1652
$J/\psi(1S) K^*(892)^0$	(1.35 $\pm$ 0.18)	$\times 10^{-3}$		1570
$J/\psi(1S) \pi^0$	$<$ 5.8	$\times 10^{-5}$	CL=90%	1728
$J/\psi(1S) \eta$	$<$ 1.2	$\times 10^{-3}$	CL=90%	1672
$J/\psi(1S) \rho^0$	$<$ 2.5	$\times 10^{-4}$	CL=90%	1614
$J/\psi(1S) \omega$	$<$ 2.7	$\times 10^{-4}$	CL=90%	1609
$\psi(2S) K^0$	$<$ 8	$\times 10^{-4}$	CL=90%	1283
$\psi(2S) K^+ \pi^-$	$<$ 1	$\times 10^{-3}$	CL=90%	1238
$\psi(2S) K^*(892)^0$	(1.4 $\pm$ 0.9)	$\times 10^{-3}$		1113
$\chi_{c1}(1P) K^0$	$<$ 2.7	$\times 10^{-3}$	CL=90%	1411
$\chi_{c1}(1P) K^*(892)^0$	$<$ 2.1	$\times 10^{-3}$	CL=90%	1263

***K* or *K** modes**

$K^+ \pi^-$	(1.5 $^{+0.5}_{-0.4}$)	$\times 10^{-5}$		2615
$K^0 \pi^0$	$<$ 4.1	$\times 10^{-5}$	CL=90%	2614
$\eta' K^0$	(4.7 $^{+2.8}_{-2.2}$)	$\times 10^{-5}$		2528
$\eta' K^*(892)^0$	$<$ 3.9	$\times 10^{-5}$	CL=90%	2472
$\eta K^*(892)^0$	$<$ 3.0	$\times 10^{-5}$	CL=90%	2534
ηK^0	$<$ 3.3	$\times 10^{-5}$	CL=90%	2593
$K^+ K^-$	$<$ 4.3	$\times 10^{-6}$	CL=90%	2593
$K^0 \overline{K}^0$	$<$ 1.7	$\times 10^{-5}$	CL=90%	2592
$K^+ \rho^-$	$<$ 3.5	$\times 10^{-5}$	CL=90%	2559
$K^0 \rho^0$	$<$ 3.9	$\times 10^{-5}$	CL=90%	2559
$K^0 f_0(980)$	$<$ 3.6	$\times 10^{-4}$	CL=90%	2523
$K^*(892)^+ \pi^-$	$<$ 7.2	$\times 10^{-5}$	CL=90%	2562
$K^*(892)^0 \pi^0$	$<$ 2.8	$\times 10^{-5}$	CL=90%	2562
$K_2^*(1430)^+ \pi^-$	$<$ 2.6	$\times 10^{-3}$	CL=90%	2445

$K^0 K^+ K^-$		$<$ 1.3	$\times 10^{-3}$	CL=90%	2522
$K^0 \phi$		$<$ 8.8	$\times 10^{-5}$	CL=90%	2516
$K^- \pi^+ \pi^+ \pi^-$	[*bbb*]	$<$ 2.3	$\times 10^{-4}$	CL=90%	2600
$K^*(892)^0 \pi^+ \pi^-$		$<$ 1.4	$\times 10^{-3}$	CL=90%	2556
$K^*(892)^0 \rho^0$		$<$ 4.6	$\times 10^{-4}$	CL=90%	2504
$K^*(892)^0 f_0(980)$		$<$ 1.7	$\times 10^{-4}$	CL=90%	2467
$K_1(1400)^+ \pi^-$		$<$ 1.1	$\times 10^{-3}$	CL=90%	2451
$K^- a_1(1260)^+$	[*bbb*]	$<$ 2.3	$\times 10^{-4}$	CL=90%	2471
$K^*(892)^0 K^+ K^-$		$<$ 6.1	$\times 10^{-4}$	CL=90%	2466
$K^*(892)^0 \phi$		$<$ 4.3	$\times 10^{-5}$	CL=90%	2459
$K_1(1400)^0 \rho^0$		$<$ 3.0	$\times 10^{-3}$	CL=90%	2389
$K_1(1400)^0 \phi$		$<$ 5.0	$\times 10^{-3}$	CL=90%	2339
$K_2^*(1430)^0 \rho^0$		$<$ 1.1	$\times 10^{-3}$	CL=90%	2380
$K_2^*(1430)^0 \phi$		$<$ 1.4	$\times 10^{-3}$	CL=90%	2330
$K^*(892)^0 \gamma$		(4.0 $\pm$ 1.9)	$\times 10^{-5}$		2564
$K_1(1270)^0 \gamma$		$<$ 7.0	$\times 10^{-3}$	CL=90%	2486
$K_1(1400)^0 \gamma$		$<$ 4.3	$\times 10^{-3}$	CL=90%	2453
$K_2^*(1430)^0 \gamma$		$<$ 4.0	$\times 10^{-4}$	CL=90%	2445
$K^*(1680)^0 \gamma$		$<$ 2.0	$\times 10^{-3}$	CL=90%	2361
$K_3^*(1780)^0 \gamma$		$<$ 1.0	%	CL=90%	2343
$K_4^*(2045)^0 \gamma$		$<$ 4.3	$\times 10^{-3}$	CL=90%	2244
$\phi \phi$		$<$ 3.9	$\times 10^{-5}$	CL=90%	2435

Light unflavored meson modes

$\pi^+ \pi^-$		$<$ 1.5	$\times 10^{-5}$	CL=90%	2636
$\pi^0 \pi^0$		$<$ 9.3	$\times 10^{-6}$	CL=90%	2636
$\eta \pi^0$		$<$ 8	$\times 10^{-6}$	CL=90%	2609
$\eta \eta$		$<$ 1.8	$\times 10^{-5}$	CL=90%	2582
$\eta' \pi^0$		$<$ 1.1	$\times 10^{-5}$	CL=90%	2551
$\eta' \eta'$		$<$ 4.7	$\times 10^{-5}$	CL=90%	2460
$\eta' \eta$		$<$ 2.7	$\times 10^{-5}$	CL=90%	2522
$\eta' \rho^0$		$<$ 2.3	$\times 10^{-5}$	CL=90%	2493
$\eta \rho^0$		$<$ 1.3	$\times 10^{-5}$	CL=90%	2554
$\pi^+ \pi^- \pi^0$		$<$ 7.2	$\times 10^{-4}$	CL=90%	2631
$\rho^0 \pi^0$		$<$ 2.4	$\times 10^{-5}$	CL=90%	2582
$\rho^\mp \pi^\pm$	[*gg*]	$<$ 8.8	$\times 10^{-5}$	CL=90%	2582
$\pi^+ \pi^- \pi^+ \pi^-$		$<$ 2.3	$\times 10^{-4}$	CL=90%	2621
$\rho^0 \rho^0$		$<$ 2.8	$\times 10^{-4}$	CL=90%	2525
$a_1(1260)^\mp \pi^\pm$	[*gg*]	$<$ 4.9	$\times 10^{-4}$	CL=90%	2494
$a_2(1320)^\mp \pi^\pm$	[*gg*]	$<$ 3.0	$\times 10^{-4}$	CL=90%	2473

$\pi^+\pi^-\pi^0\pi^0$			< 3.1	$\times 10^{-3}$	CL=90%	2622
$\rho^+\rho^-$			< 2.2	$\times 10^{-3}$	CL=90%	2525
$a_1(1260)^0\pi^0$			< 1.1	$\times 10^{-3}$	CL=90%	2494
$\omega\pi^0$			< 4.6	$\times 10^{-4}$	CL=90%	2580
$\pi^+\pi^+\pi^-\pi^-\pi^0$			< 9.0	$\times 10^{-3}$	CL=90%	2609
$a_1(1260)^+\rho^-$			< 3.4	$\times 10^{-3}$	CL=90%	2434
$a_1(1260)^0\rho^0$			< 2.4	$\times 10^{-3}$	CL=90%	2434
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$			< 3.0	$\times 10^{-3}$	CL=90%	2592
$a_1(1260)^+a_1(1260)^-$			< 2.8	$\times 10^{-3}$	CL=90%	2336
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^0$			< 1.1	%	CL=90%	2572
Baryon modes						
$p\overline{p}$			< 1.8	$\times 10^{-5}$	CL=90%	2467
$p\overline{p}\pi^+\pi^-$			< 2.5	$\times 10^{-4}$	CL=90%	2406
$p\overline{\Lambda}\pi^-$			< 1.8	$\times 10^{-4}$	CL=90%	2401
$\Delta^0\overline{\Delta}^0$			< 1.5	$\times 10^{-3}$	CL=90%	2334
$\Delta^{++}\Delta^{--}$			< 1.1	$\times 10^{-4}$	CL=90%	2334
$\overline{\Sigma}_c^{--}\Delta^{++}$			< 1.0	$\times 10^{-3}$	CL=90%	1839
$\Lambda_c^-p\pi^+\pi^-$			(1.3 ± 0.6)	$\times 10^{-3}$		–
Λ_c^-p			< 2.1	$\times 10^{-4}$	CL=90%	2021
$\Lambda_c^-p\pi^0$			< 5.9	$\times 10^{-4}$	CL=90%	–
$\Lambda_c^-p\pi^+\pi^-\pi^0$			< 5.07	$\times 10^{-3}$	CL=90%	–
$\Lambda_c^-p\pi^+\pi^-\pi^+\pi^-$			< 2.74	$\times 10^{-3}$	CL=90%	–
Lepton Family number (*LF*) violating modes, or $\Delta B = 1$ weak neutral current (*B1*) modes						
$\gamma\gamma$	*B1*		< 3.9	$\times 10^{-5}$	CL=90%	2640
e^+e^-	*B1*		< 5.9	$\times 10^{-6}$	CL=90%	2640
$\mu^+\mu^-$	*B1*		< 6.8	$\times 10^{-7}$	CL=90%	2637
$K^0e^+e^-$	*B1*		< 3.0	$\times 10^{-4}$	CL=90%	2616
$K^0\mu^+\mu^-$	*B1*		< 3.6	$\times 10^{-4}$	CL=90%	2612
$K^*(892)^0e^+e^-$	*B1*		< 2.9	$\times 10^{-4}$	CL=90%	2564
$K^*(892)^0\mu^+\mu^-$	*B1*		< 2.3	$\times 10^{-5}$	CL=90%	2559
$K^*(892)^0\nu\overline{\nu}$	*B1*		< 1.0	$\times 10^{-3}$	CL=90%	2244
$e^\pm\mu^\mp$	*LF*	[gg]	< 5.9	$\times 10^{-6}$	CL=90%	2639
$e^\pm\tau^\mp$	*LF*	[gg]	< 5.3	$\times 10^{-4}$	CL=90%	2341
$\mu^\pm\tau^\mp$	*LF*	[gg]	< 8.3	$\times 10^{-4}$	CL=90%	2339

$B^{\pm}/B^0$ ADMIXTURE

The branching fraction measurements are for an admixture of B mesons at the $\Upsilon(4S)$. The values quoted assume that $B(\Upsilon(4S) \to B\overline{B}) = 100\%$.

For inclusive branching fractions, *e.g.*, $B \to D^{\pm}$ anything, the treatment of multiple D's in the final state must be defined. One possiblity would be to count the number of events with one-or-more D's and divide by the total number of B's. Another possibility would be to count the total number of D's and divide by the total number of B's, which is the definition of average multiplicity. The two definitions are identical when only one of the specified particles is allowed in the final state. Even though the "one-or-more" definition seems sensible, for practical reasons inclusive branching fractions are almost always measured using the multiplicity definition. For heavy final state particles, authors call their results inclusive branching fractions while for light particles some authors call their results multiplicities. In the B sections, we list all results as inclusive branching fractions, adopting a multiplicity definition. This means that inclusive branching fractions can exceed 100% and that inclusive partial widths can exceed total widths, just as inclusive cross sections can exceed total cross sections.

$\overline{B}$ modes are charge conjugates of the modes below. Reactions indicate the weak decay vertex and do not include mixing.

B DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Semileptonic and leptonic modes				
$B \to e^+ \nu_e$ anything	[*ccc*]	(10.41±0.29) %	S=1.2	–
$B \to \overline{p} e^+ \nu_e$ anything		< 1.6 × 10^{-3}	CL=90%	–
$B \to \mu^+ \nu_\mu$ anything	[*ccc*]	(10.3 ±0.5) %		–
$B \to \ell^+ \nu_\ell$ anything	[*pp,ccc*]	(10.45±0.21) %		–
$B \to D^- \ell^+ \nu_\ell$ anything	[*pp*]	(2.7 ±0.8) %		–
$B \to \overline{D}^0 \ell^+ \nu_\ell$ anything	[*pp*]	(7.0 ±1.4) %		–
$B \to \overline{D}^{**} \ell^+ \nu_\ell$	[*pp,ddd*]	(2.7 ±0.7) %		–
$B \to \overline{D}_1(2420) \ell^+ \nu_\ell$ anything		(7.4 ±1.6) × 10^{-3}		–
$B \to D \pi \ell^+ \nu_\ell$ anything + $D^* \pi \ell^+ \nu_\ell$ anything		(2.3 ±0.4) %		–
$B \to \overline{D}^*_2(2460) \ell^+ \nu_\ell$ anything		< 6.5 × 10^{-3}	CL=95%	–
$B \to D^{*-} \pi^+ \ell^+ \nu_\ell$ anything		(1.00±0.34) %		–

$B \to D_s^- \ell^+ \nu_\ell$ anything	[pp]	< 9	$\times 10^{-3}$	CL=90%	–
$B \to D_s^- \ell^+ \nu_\ell K^+$ anything	[pp]	< 6	$\times 10^{-3}$	CL=90%	–
$B \to D_s^- \ell^+ \nu_\ell K^0$ anything	[pp]	< 9	$\times 10^{-3}$	CL=90%	–
$B \to K^+ \ell^+ \nu_\ell$ anything	[pp]	(6.0 ± 0.5)	%		–
$B \to K^- \ell^+ \nu_\ell$ anything	[pp]	(10 ± 4)	$\times 10^{-3}$		–
$B \to K^0/\overline{K}^0 \ell^+ \nu_\ell$ anything	[pp]	(4.4 ± 0.5)	%		–
D, D^*, or D_s modes					
$B \to D^\pm$ anything		(24.1 ± 1.9)	%		–
$B \to D^0/\overline{D}^0$ anything		(63.1 ± 2.9)	%	S=1.1	–
$B \to D^*(2010)^\pm$ anything		(22.7 ± 1.6)	%		–
$B \to D^*(2007)^0$ anything		(26.0 ± 2.7)	%		–
$B \to D_s^\pm$ anything	[gg]	(10.0 ± 2.5)	%		–
$b \to c\overline{c}s$		(22 ± 4)	%		–
$B \to D_s D$, $D_s^* D$, $D_s D^*$, or $D_s^* D^*$	[gg]	(4.9 ± 1.3)	%		–
$B \to D^*(2010)\gamma$		< 1.1	$\times 10^{-3}$	CL=90%	–
$B \to D_s^+ \pi^-$, $D_s^{*+} \pi^-$, $D_s^+ \rho^-$, $D_s^{*+} \rho^-$, $D_s^+ \pi^0$, $D_s^{*+} \pi^0$, $D_s^+ \eta$, $D_s^{*+} \eta$, $D_s^+ \rho^0$, $D_s^{*+} \rho^0$, $D_s^+ \omega$, $D_s^{*+} \omega$	[gg]	< 5	$\times 10^{-4}$	CL=90%	–
$B \to D_{s1}(2536)^+$ anything		< 9.5	$\times 10^{-3}$	CL=90%	–
Charmonium modes					
$B \to J/\psi(1S)$ anything		(1.13 ± 0.06)	%		–
$B \to J/\psi(1S)$(direct) anything		(8.0 ± 0.8)	$\times 10^{-3}$		–
$B \to \psi(2S)$ anything		(3.5 ± 0.5)	$\times 10^{-3}$		–
$B \to \chi_{c1}(1P)$ anything		(4.2 ± 0.7)	$\times 10^{-3}$		–
$B \to \chi_{c1}(1P)$(direct) anything		(3.7 ± 0.7)	$\times 10^{-3}$		–
$B \to \chi_{c2}(1P)$ anything		< 3.8	$\times 10^{-3}$	CL=90%	–
$B \to \eta_c(1S)$ anything		< 9	$\times 10^{-3}$	CL=90%	–
K or K^* modes					
$B \to K^\pm$ anything	[gg]	(78.9 ± 2.5)	%		–
$B \to K^+$ anything		(66 ± 5)	%		–
$B \to K^-$ anything		(13 ± 4)	%		–
$B \to K^0/\overline{K}^0$ anything	[gg]	(64 ± 4)	%		–
$B \to K^*(892)^\pm$ anything		(18 ± 6)	%		–
$B \to K^*(892)^0/\overline{K}^*(892)^0$ anything	[gg]	(14.6 ± 2.6)	%		–

$B \to K_1(1400)\gamma$		$< 4.1 \times 10^{-4}$	CL=90%	–
$B \to K_2^*(1430)\gamma$		$< 8.3 \times 10^{-4}$	CL=90%	–
$B \to K_2(1770)\gamma$		$< 1.2 \times 10^{-3}$	CL=90%	–
$B \to K_3^*(1780)\gamma$		$< 3.0 \times 10^{-3}$	CL=90%	–
$B \to K_4^*(2045)\gamma$		$< 1.0 \times 10^{-3}$	CL=90%	–
$B \to \overline{b} \to \overline{s}\gamma$		$(2.3 \pm 0.7) \times 10^{-4}$		–
$B \to \overline{b} \to \overline{s}$ gluon		< 6.8 %	CL=90%	–

Light unflavored meson modes

$B \to \pi^{\pm}$ anything	[gg,eee]	(359 ± 7) %		–
$B \to \eta$ anything		(17.6 ± 1.6) %		–
$B \to \rho^0$ anything		(21 ± 5) %		–
$B \to \omega$ anything		< 81 %	CL=90%	–
$B \to \phi$ anything		(3.5 ± 0.7) %	S=1.8	–

Baryon modes

$B \to \Lambda_c^{\pm}$ anything		(6.4 ± 1.1) %		–
$B \to \Lambda_c^- e^+$ anything		$< 3.2 \times 10^{-3}$	CL=90%	–
$B \to \Lambda_c^- p$ anything		(3.6 ± 0.7) %		–
$B \to \Lambda_c^- p e^+ \nu_e$		$< 1.5 \times 10^{-3}$	CL=90%	–
$B \to \overline{\Sigma}_c^{--}$ anything		$(4.2 \pm 2.4) \times 10^{-3}$		–
$B \to \overline{\Sigma}_c^{-}$ anything		$< 9.6 \times 10^{-3}$	CL=90%	–
$B \to \overline{\Sigma}_c^{0}$ anything		$(4.6 \pm 2.4) \times 10^{-3}$		–
$B \to \overline{\Sigma}_c^{0} N (N = p$ or $n)$		$< 1.5 \times 10^{-3}$	CL=90%	–
$B \to \Xi_c^0$ anything $\times$ B($\Xi_c^0 \to \Xi^- \pi^+$)		$(1.4 \pm 0.5) \times 10^{-4}$		–
$B \to \Xi_c^+$ anything $\times$ B($\Xi_c^+ \to \Xi^- \pi^+ \pi^+$)		$(4.5 ^{+1.3}_{-1.2}) \times 10^{-4}$		–
$B \to p/\overline{p}$ anything	[gg]	(8.0 ± 0.4) %		–
$B \to p/\overline{p}$(direct) anything	[gg]	(5.5 ± 0.5) %		–
$B \to \Lambda/\overline{\Lambda}$ anything	[gg]	(4.0 ± 0.5) %		–
$B \to \Xi^-/\overline{\Xi}^+$ anything	[gg]	$(2.7 \pm 0.6) \times 10^{-3}$		–
$B \to$ baryons anything		(6.8 ± 0.6) %		–
$B \to p\overline{p}$ anything		(2.47 ± 0.23) %		–
$B \to \Lambda\overline{p}/\overline{\Lambda}p$ anything	[gg]	(2.5 ± 0.4) %		–
$B \to \Lambda\overline{\Lambda}$ anything		$< 5 \times 10^{-3}$	CL=90%	–

Lepton Family number (*LF*) violating modes or
$\Delta B = 1$ weak neutral current (*B1*) modes

$B \to e^+ e^- s$	*B1*	$< 5.7 \times 10^{-5}$	CL=90%	–
$B \to \mu^+ \mu^- s$	*B1*	$< 5.8 \times 10^{-5}$	CL=90%	–
$B \to e^{\pm} \mu^{\mp} s$	*LF*	$< 2.2 \times 10^{-5}$	CL=90%	–

$B^{\pm}/B^0/B^0_s/b$-baryon ADMIXTURE

These measurements are for an admixture of bottom particles at high energy (LEP, Tevatron, S$p\overline{p}$S).

Mean life $\tau = (1.564 \pm 0.014) \times 10^{-12}$ s

Mean life $\tau = (1.72 \pm 0.10) \times 10^{-12}$ s Charged b-hadron admixture

Mean life $\tau = (1.58 \pm 0.14) \times 10^{-12}$ s Neutral b-hadron admixture

$\tau_{\text{charged } b-\text{hadron}}/\tau_{\text{neutral } b-\text{hadron}} = 1.09 \pm 0.13$

The branching fraction measurements are for an admixture of B mesons and baryons at energies above the $\Upsilon(4S)$. Only the highest energy results (LEP, Tevatron, S$p\overline{p}$S) are used in the branching fraction averages. The production fractions give our best current estimate of the admixture at LEP.

For inclusive branching fractions, *e.g.*, $B \to D^{\pm}$ anything, the treatment of multiple D's in the final state must be defined. One possiblity would be to count the number of events with one-or-more D's and divide by the total number of B's. Another possibility would be to count the total number of D's and divide by the total number of B's, which is the definition of average multiplicity. The two definitions are identical when only one of the specified particles is allowed in the final state. Even though the "one-or-more" definition seems sensible, for practical reasons inclusive branching fractions are almost always measured using the multiplicity definition. For heavy final state particles, authors call their results inclusive branching fractions while for light particles some authors call their results multiplicities. In the B sections, we list all results as inclusive branching fractions, adopting a multiplicity definition. This means that inclusive branching fractions can exceed 100% and that inclusive partial widths can exceed total widths, just as inclusive cross sections can exceed total cross sections.

The modes below are listed for a $\overline{b}$ initial state. b modes are their charge conjugates. Reactions indicate the weak decay vertex and do not include mixing.

$\overline{b}$ **DECAY MODES**		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)

PRODUCTION FRACTIONS

The production fractions for weakly decaying b-hadrons at the Z have been calculated from the best values of mean lives, mixing parameters, and branching fractions in this edition by the LEP B Oscillation Working Group as described in the note "Production and Decay of b-Flavored Hadrons" in the $B^{\pm}$ Particle Listings. Values assume

$$\mathrm{B}(\overline{b} \to B^+) = \mathrm{B}(\overline{b} \to B^0)$$
$$\mathrm{B}(\overline{b} \to B^+) + \mathrm{B}(\overline{b} \to B^0) + \mathrm{B}(\overline{b} \to B^0_s) + \mathrm{B}(b \to \Lambda_b) = 100\ \%.$$

The notation for production fractions varies in the literature (f_{B^0}, $f(b \to \overline{B}^0)$, $\mathrm{Br}(b \to \overline{B}^0)$). We use our own branching fraction notation here, $\mathrm{B}(\overline{b} \to B^0)$.

B^+		$(39.7 {}^{+1.8}_{-2.2})$ %		–
B^0		$(39.7 {}^{+1.8}_{-2.2})$ %		–
B^0_s		$(10.5 {}^{+1.8}_{-1.7})$ %		–
Λ_b		$(10.1 {}^{+3.9}_{-3.1})$ %		–

DECAY MODES

Semileptonic and leptonic modes

ν anything		(23.1 ± 1.5) %		–
$\ell^+ \nu_\ell$ anything	[pp,ccc]	(10.99 ± 0.23) %		–
$e^+ \nu_e$ anything	[ccc]	(10.9 ± 0.5) %		–
$\mu^+ \nu_\mu$ anything	[ccc]	(10.8 ± 0.5) %		–
$D^- \ell^+ \nu_\ell$ anything	[pp]	(2.02 ± 0.29) %		–
$\overline{D}^0 \ell^+ \nu_\ell$ anything	[pp]	(6.5 ± 0.6) %		–
$D^{*-} \ell^+ \nu_\ell$ anything	[pp]	(2.76 ± 0.29) %		–
$\overline{D}^0_j \ell^+ \nu_\ell$ anything	[pp,fff]	seen		–
$D^-_j \ell^+ \nu_\ell$ anything	[pp,fff]	seen		–
$\overline{D}^*_2(2460)^0 \ell^+ \nu_\ell$ anything		seen		–
$D^*_2(2460)^- \ell^+ \nu_\ell$ anything		seen		–
$\tau^+ \nu_\tau$ anything		(2.6 ± 0.4) %		–
$\overline{c} \to \ell^- \overline{\nu}_\ell$ anything	[pp]	(7.8 ± 0.6) %		–

Charmed meson and baryon modes				
$\overline{D}^0$ anything		(60.1 ± 3.2) %		–
D^- anything		(23.7 ± 2.3) %		–
$\overline{D}_s$ anything		(18 ± 5) %		–
Λ_c anything		(9.7 ± 2.9) %		–
$\overline{c}/c$ anything	[eee]	(117 ± 4) %		–
Charmonium modes				
$J/\psi(1S)$ anything		(1.16± 0.10) %		–
$\psi(2S)$ anything		(4.8 ± 2.4) $\times 10^{-3}$		–
$\chi_{c1}(1P)$ anything		(1.8 ± 0.5) %		–
***K* or *K** modes**				
$\overline{s}\gamma$		< 5.4 $\times 10^{-4}$	90%	–
$K^\pm$ anything		(88 ±19) %		–
K^0_S anything		(29.0 ± 2.9) %		–
Pion modes				
π^0 anything	[eee]	(278 ±60) %		–
Baryon modes				
$p/\overline{p}$ anything		(14 ± 6) %		–
Other modes				
charged anything	[eee]	(497 ± 7) %		–
hadron$^+$ hadron$^-$		($1.7^{+1.0}_{-0.7}$) $\times 10^{-5}$		–
charmless		(7 ±21) $\times 10^{-3}$		–
Baryon modes				
$\Lambda/\overline{\Lambda}$ anything		(5.9 ± 0.6) %		–
$\Delta B = 1$ weak neutral current (*B1*) modes				
$\mu^+\mu^-$ anything	*B1*	< 3.2 $\times 10^{-4}$	90%	–

B^*

$$I(J^P) = \tfrac{1}{2}(1^-)$$

I, *J*, *P* need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B^*} = 5324.9 \pm 1.8$ MeV

$m_{B^*} - m_B = 45.78 \pm 0.35$ MeV

B* **DECAY MODES**	Fraction (Γ_i/Γ)	p (MeV/c)
$B\gamma$	dominant	46

BOTTOM, STRANGE MESONS $(B = \pm 1, S = \mp 1)$

$B_s^0 = s\overline{b}$, $\overline{B}_s^0 = \overline{s}\,b$, similarly for B_s^*'s

B_s^0

$I(J^P) = 0(0^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B_s^0} = 5369.3 \pm 2.0$ MeV

Mean life $\tau = (1.54 \pm 0.07) \times 10^{-12}$ s

$c\tau = 462$ μm

B_s^0-$\overline{B}_s^0$ mixing parameters

χ_B at high energy $= f_d \chi_d + f_s \chi_s = 0.118 \pm 0.006$

$\Delta m_{B_s^0} = m_{B_{sH}^0} - m_{B_{sL}^0} > 9.1 \times 10^{12}$ $\hbar$ s^{-1}, CL = 95%

$x_s = \Delta m_{B_s^0} / \Gamma_{B_s^0} > 14.0$, CL = 95%

$\chi_s > 0.4975$, CL = 95%

These branching fractions all scale with B($\overline{b} \rightarrow B_s^0$), the LEP B_s^0 production fraction. The first four were evaluated using B($\overline{b} \rightarrow B_s^0$) = $(10.5^{+1.8}_{-1.7})$% and the rest assume B($\overline{b} \rightarrow B_s^0$) = 12%.

The branching fraction B($B_s^0 \rightarrow D_s^- \ell^+ \nu_\ell$ anything) is not a pure measurement since the measured product branching fraction B($\overline{b} \rightarrow B_s^0$) $\times$ B($B_s^0 \rightarrow D_s^- \ell^+ \nu_\ell$ anything) was used to determine B($\overline{b} \rightarrow B_s^0$), as described in the note on "Production and Decay of b-Flavored Hadrons."

B_s^0 DECAY MODES			Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
D_s^- anything			(92 ± 33) %		–
$D_s^- \ell^+ \nu_\ell$ anything		[ggg]	(8.1 ± 2.5) %		–
$D_s^- \pi^+$			< 13 %		2321
$J/\psi(1S)\phi$			$(9.3 \pm 3.3) \times 10^{-4}$		1590
$J/\psi(1S)\pi^0$			$< 1.2 \times 10^{-3}$	90%	1788
$J/\psi(1S)\eta$			$< 3.8 \times 10^{-3}$	90%	1735
$\psi(2S)\phi$			seen		1122
$\pi^+\pi^-$			$< 1.7 \times 10^{-4}$	90%	1122
$\pi^0\pi^0$			$< 2.1 \times 10^{-4}$	90%	2861
$\eta\pi^0$			$< 1.0 \times 10^{-3}$	90%	2655
$\eta\eta$			$< 1.5 \times 10^{-3}$	90%	2628
$\pi^+ K^-$			$< 2.1 \times 10^{-4}$	90%	2660
$K^+ K^-$			$< 5.9 \times 10^{-5}$	90%	2639
$p\overline{p}$			$< 5.9 \times 10^{-5}$	90%	2515
$\gamma\gamma$			$< 1.48 \times 10^{-4}$	90%	2685
$\phi\gamma$			$< 7 \times 10^{-4}$	90%	2588
Lepton Family number (*LF*) violating modes or $\Delta B = 1$ weak neutral current (*B1*) modes					
$\mu^+\mu^-$	*B1*		$< 2.0 \times 10^{-6}$	90%	2682
$e^+ e^-$	*B1*		$< 5.4 \times 10^{-5}$	90%	2864
$e^\pm \mu^\mp$	*LF*	[gg]	$< 4.1 \times 10^{-5}$	90%	2864
$\phi\nu\overline{\nu}$	*B1*		$< 5.4 \times 10^{-3}$	90%	–

$c\overline{c}$ MESONS

$\eta_c(1S)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 2979.8 \pm 2.1$ MeV (S = 2.1)
Full width $\Gamma = 13.2^{+3.8}_{-3.2}$ MeV

$\eta_c(1S)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
Decays involving hadronic resonances			
$\eta'(958)\pi\pi$	(4.1 ± 1.7) %		1319
$\rho\rho$	(2.6 ± 0.9) %		1275
$K^*(892)^0 K^-\pi^+ +$ c.c.	(2.0 ± 0.7) %		1273
$K^*(892)\overline{K}^*(892)$	$(8.5 \pm 3.1) \times 10^{-3}$		1193
$\phi\phi$	$(7.1 \pm 2.8) \times 10^{-3}$		1086
$a_0(980)\pi$	< 2 %	90%	1323
$a_2(1320)\pi$	< 2 %	90%	1193
$K^*(892)\overline{K} +$ c.c.	< 1.28 %	90%	1307
$f_2(1270)\eta$	< 1.1 %	90%	1142
$\omega\omega$	$< 3.1 \times 10^{-3}$	90%	1268
Decays into stable hadrons			
$K\overline{K}\pi$	(5.5 ± 1.7) %		1378
$\eta\pi\pi$	(4.9 ± 1.8) %		1425
$\pi^+\pi^- K^+ K^-$	$(2.0 {}^{+0.7}_{-0.6})$ %		1342
$2(K^+ K^-)$	(2.1 ± 1.2) %		1053
$2(\pi^+\pi^-)$	(1.2 ± 0.4) %		1457
$p\overline{p}$	$(1.2 \pm 0.4) \times 10^{-3}$		1157
$K\overline{K}\eta$	< 3.1 %	90%	1262
$\pi^+\pi^- p\overline{p}$	< 1.2 %	90%	1023
$\Lambda\overline{\Lambda}$	$< 2 \times 10^{-3}$	90%	987
Radiative decays			
$\gamma\gamma$	$(3.0 \pm 1.2) \times 10^{-4}$		1489

$J/\psi(1S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 3096.88 \pm 0.04$ MeV
Full width $\Gamma = 87 \pm 5$ keV
$\Gamma_{ee} = 5.26 \pm 0.37$ keV (Assuming $\Gamma_{ee} = \Gamma_{\mu\mu}$)

$J/\psi(1S)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
hadrons		(87.7 ± 0.5) %		–
virtual $\gamma \to$ hadrons		(17.0 ± 2.0) %		–
e^+e^-		(6.02 ± 0.19) %		1548
$\mu^+\mu^-$		(6.01 ± 0.19) %		1545
Decays involving hadronic resonances				
$\rho\pi$		(1.27 ± 0.09) %		1449
$\rho^0\pi^0$		$(4.2 \pm 0.5) \times 10^{-3}$		1449
$a_2(1320)\rho$		(1.09 ± 0.22) %		1125
$\omega\pi^+\pi^+\pi^-\pi^-$		$(8.5 \pm 3.4) \times 10^{-3}$		1392
$\omega\pi^+\pi^-$		$(7.2 \pm 1.0) \times 10^{-3}$		1435
$\omega f_2(1270)$		$(4.3 \pm 0.6) \times 10^{-3}$		1143
$K^*(892)^0\overline{K}{}_2^*(1430)^0$ + c.c.		$(6.7 \pm 2.6) \times 10^{-3}$		1005
$\omega K^*(892)\overline{K}$ + c.c.		$(5.3 \pm 2.0) \times 10^{-3}$		1098
$K^+\overline{K}{}^*(892)^-$ + c.c.		$(5.0 \pm 0.4) \times 10^{-3}$		1373
$K^0\overline{K}{}^*(892)^0$ + c.c.		$(4.2 \pm 0.4) \times 10^{-3}$		1371
$\omega\pi^0\pi^0$		$(3.4 \pm 0.8) \times 10^{-3}$		1436
$b_1(1235)^{\pm}\pi^{\mp}$	[gg]	$(3.0 \pm 0.5) \times 10^{-3}$		1299
$\omega K^{\pm}K_S^0\pi^{\mp}$	[gg]	$(3.0 \pm 0.7) \times 10^{-3}$		1210
$b_1(1235)^0\pi^0$		$(2.3 \pm 0.6) \times 10^{-3}$		1299
$\phi K^*(892)\overline{K}$ + c.c.		$(2.04 \pm 0.28) \times 10^{-3}$		969
$\omega K\overline{K}$		$(1.9 \pm 0.4) \times 10^{-3}$		1268
$\omega f_J(1710) \to \omega K\overline{K}$		$(4.8 \pm 1.1) \times 10^{-4}$		878
$\phi 2(\pi^+\pi^-)$		$(1.60 \pm 0.32) \times 10^{-3}$		1318
$\Delta(1232)^{++}\overline{p}\pi^-$		$(1.6 \pm 0.5) \times 10^{-3}$		1030
$\omega\eta$		$(1.58 \pm 0.16) \times 10^{-3}$		1394
$\phi K\overline{K}$		$(1.48 \pm 0.22) \times 10^{-3}$		1179
$\phi f_J(1710) \to \phi K\overline{K}$		$(3.6 \pm 0.6) \times 10^{-4}$		875
$p\overline{p}\omega$		$(1.30 \pm 0.25) \times 10^{-3}$	S=1.3	769
$\Delta(1232)^{++}\overline{\Delta}(1232)^{--}$		$(1.10 \pm 0.29) \times 10^{-3}$		938
$\Sigma(1385)^-\overline{\Sigma}(1385)^+$ (or c.c.)	[gg]	$(1.03 \pm 0.13) \times 10^{-3}$		692
$p\overline{p}\eta'(958)$		$(9 \pm 4) \times 10^{-4}$	S=1.7	596
$\phi f_2'(1525)$		$(8 \pm 4) \times 10^{-4}$	S=2.7	871
$\phi\pi^+\pi^-$		$(8.0 \pm 1.2) \times 10^{-4}$		1365

$\phi K^{\pm} K^0_S \pi^{\mp}$	[gg]	$(7.2 \pm 0.9) \times 10^{-4}$		1114
$\omega f_1(1420)$		$(6.8 \pm 2.4) \times 10^{-4}$		1062
$\phi \eta$		$(6.5 \pm 0.7) \times 10^{-4}$		1320
$\Xi(1530)^- \overline{\Xi}^+$		$(5.9 \pm 1.5) \times 10^{-4}$		597
$p K^- \overline{\Sigma}(1385)^0$		$(5.1 \pm 3.2) \times 10^{-4}$		645
$\omega \pi^0$		$(4.2 \pm 0.6) \times 10^{-4}$	S=1.4	1447
$\phi \eta'(958)$		$(3.3 \pm 0.4) \times 10^{-4}$		1192
$\phi f_0(980)$		$(3.2 \pm 0.9) \times 10^{-4}$	S=1.9	1182
$\Xi(1530)^0 \overline{\Xi}^0$		$(3.2 \pm 1.4) \times 10^{-4}$		608
$\Sigma(1385)^- \overline{\Sigma}^+$ (or c.c.)	[gg]	$(3.1 \pm 0.5) \times 10^{-4}$		857
$\phi f_1(1285)$		$(2.6 \pm 0.5) \times 10^{-4}$	S=1.1	1032
$\rho \eta$		$(1.93 \pm 0.23) \times 10^{-4}$		1398
$\omega \eta'(958)$		$(1.67 \pm 0.25) \times 10^{-4}$		1279
$\omega f_0(980)$		$(1.4 \pm 0.5) \times 10^{-4}$		1271
$\rho \eta'(958)$		$(1.05 \pm 0.18) \times 10^{-4}$		1283
$p \overline{p} \phi$		$(4.5 \pm 1.5) \times 10^{-5}$		527
$a_2(1320)^{\pm} \pi^{\mp}$	[gg]	$< 4.3 \times 10^{-3}$	CL=90%	1263
$K \overline{K}^*_2(1430)+$ c.c.		$< 4.0 \times 10^{-3}$	CL=90%	1159
$K^*_2(1430)^0 \overline{K}^*_2(1430)^0$		$< 2.9 \times 10^{-3}$	CL=90%	588
$K^*(892)^0 \overline{K}^*(892)^0$		$< 5 \times 10^{-4}$	CL=90%	1263
$\phi f_2(1270)$		$< 3.7 \times 10^{-4}$	CL=90%	1036
$p \overline{p} \rho$		$< 3.1 \times 10^{-4}$	CL=90%	779
$\phi \eta(1440) \rightarrow \phi \eta \pi \pi$		$< 2.5 \times 10^{-4}$	CL=90%	946
$\omega f'_2(1525)$		$< 2.2 \times 10^{-4}$	CL=90%	1003
$\Sigma(1385)^0 \overline{\Lambda}$		$< 2 \times 10^{-4}$	CL=90%	911
$\Delta(1232)^+ \overline{p}$		$< 1 \times 10^{-4}$	CL=90%	1100
$\Sigma^0 \overline{\Lambda}$		$< 9 \times 10^{-5}$	CL=90%	1032
$\phi \pi^0$		$< 6.8 \times 10^{-6}$	CL=90%	1377

Decays into stable hadrons

$2(\pi^+\pi^-)\pi^0$		(3.37 ± 0.26) %		1496
$3(\pi^+\pi^-)\pi^0$		(2.9 ± 0.6) %		1433
$\pi^+\pi^-\pi^0$		(1.50 ± 0.20) %		1533
$\pi^+\pi^-\pi^0 K^+ K^-$		(1.20 ± 0.30) %		1368
$4(\pi^+\pi^-)\pi^0$		$(9.0 \pm 3.0) \times 10^{-3}$		1345
$\pi^+\pi^- K^+ K^-$		$(7.2 \pm 2.3) \times 10^{-3}$		1407
$K \overline{K} \pi$		$(6.1 \pm 1.0) \times 10^{-3}$		1440
$p \overline{p} \pi^+ \pi^-$		$(6.0 \pm 0.5) \times 10^{-3}$	S=1.3	1107
$2(\pi^+\pi^-)$		$(4.0 \pm 1.0) \times 10^{-3}$		1517
$3(\pi^+\pi^-)$		$(4.0 \pm 2.0) \times 10^{-3}$		1466
$n \overline{n} \pi^+ \pi^-$		$(4 \pm 4) \times 10^{-3}$		1106
$\Sigma^0 \overline{\Sigma}^0$		$(1.27 \pm 0.17) \times 10^{-3}$		992
$2(\pi^+\pi^-) K^+ K^-$		$(3.1 \pm 1.3) \times 10^{-3}$		1320
$p \overline{p} \pi^+ \pi^- \pi^0$	[hhh]	$(2.3 \pm 0.9) \times 10^{-3}$	S=1.9	1033

$p\overline{p}$		$(2.14\pm0.10)\times10^{-3}$		1232
$p\overline{p}\eta$		$(2.09\pm0.18)\times10^{-3}$		948
$p\overline{n}\pi^-$		$(2.00\pm0.10)\times10^{-3}$		1174
$n\overline{n}$		$(1.9\pm0.5)\times10^{-3}$		1231
$\Xi\overline{\Xi}$		$(1.8\pm0.4)\times10^{-3}$	S=1.8	818
$\Lambda\overline{\Lambda}$		$(1.35\pm0.14)\times10^{-3}$	S=1.2	1074
$p\overline{p}\pi^0$		$(1.09\pm0.09)\times10^{-3}$		1176
$\Lambda\overline{\Sigma}^-\pi^+$ (or c.c.)	[gg]	$(1.06\pm0.12)\times10^{-3}$		945
$pK^-\overline{\Lambda}$		$(8.9\pm1.6)\times10^{-4}$		876
$2(K^+K^-)$		$(7.0\pm3.0)\times10^{-4}$		1131
$pK^-\overline{\Sigma}^0$		$(2.9\pm0.8)\times10^{-4}$		820
K^+K^-		$(2.37\pm0.31)\times10^{-4}$		1468
$\Lambda\overline{\Lambda}\pi^0$		$(2.2\pm0.7)\times10^{-4}$		998
$\pi^+\pi^-$		$(1.47\pm0.23)\times10^{-4}$		1542
$K^0_S K^0_L$		$(1.08\pm0.14)\times10^{-4}$		1466
$\Lambda\overline{\Sigma}$ + c.c.		$<1.5\times10^{-4}$	CL=90%	1032
$K^0_S K^0_S$		$<5.2\times10^{-6}$	CL=90%	1466

Radiative decays

$\gamma\eta_c(1S)$		(1.3 ± 0.4) %		116
$\gamma\pi^+\pi^-2\pi^0$		$(8.3\pm3.1)\times10^{-3}$		1518
$\gamma\eta\pi\pi$		$(6.1\pm1.0)\times10^{-3}$		1487
$\gamma\eta(1440)\rightarrow\gamma K\overline{K}\pi$	[p]	$(9.1\pm1.8)\times10^{-4}$		1223
$\gamma\eta(1440)\rightarrow\gamma\gamma\rho^0$		$(6.4\pm1.4)\times10^{-5}$		1223
$\gamma\eta(1440)\rightarrow\gamma\eta\pi^+\pi^-$		$(3.4\pm0.7)\times10^{-4}$		–
$\gamma\rho\rho$		$(4.5\pm0.8)\times10^{-3}$		1343
$\gamma\eta'(958)$		$(4.31\pm0.30)\times10^{-3}$		1400
$\gamma 2\pi^+2\pi^-$		$(2.8\pm0.5)\times10^{-3}$	S=1.9	1517
$\gamma f_4(2050)$		$(2.7\pm0.7)\times10^{-3}$		874
$\gamma\omega\omega$		$(1.59\pm0.33)\times10^{-3}$		1337
$\gamma\eta(1440)\rightarrow\gamma\rho^0\rho^0$		$(1.7\pm0.4)\times10^{-3}$	S=1.3	1223
$\gamma f_2(1270)$		$(1.38\pm0.14)\times10^{-3}$		1286
$\gamma f_J(1710)\rightarrow\gamma K\overline{K}$		$(8.5\ ^{+1.2}_{-0.9})\times10^{-4}$	S=1.2	1075
$\gamma\eta$		$(8.6\pm0.8)\times10^{-4}$		1500
$\gamma f_1(1420)\rightarrow\gamma K\overline{K}\pi$		$(8.3\pm1.5)\times10^{-4}$		1220
$\gamma f_1(1285)$		$(6.5\pm1.0)\times10^{-4}$		1283
$\gamma f'_2(1525)$		$(4.7\ ^{+0.7}_{-0.5})\times10^{-4}$		1173
$\gamma\phi\phi$		$(4.0\pm1.2)\times10^{-4}$	S=2.1	1166
$\gamma p\overline{p}$		$(3.8\pm1.0)\times10^{-4}$		1232
$\gamma\eta(2225)$		$(2.9\pm0.6)\times10^{-4}$		834

$\gamma\eta(1760) \to \gamma\rho^0\rho^0$	$(1.3 \pm 0.9) \times 10^{-4}$		1048
$\gamma\pi^0$	$(3.9 \pm 1.3) \times 10^{-5}$		1546
$\gamma p\overline{p}\pi^+\pi^-$	$< 7.9 \times 10^{-4}$	CL=90%	1107
$\gamma\gamma$	$< 5 \times 10^{-4}$	CL=90%	1548
$\gamma\Lambda\overline{\Lambda}$	$< 1.3 \times 10^{-4}$	CL=90%	1074
3γ	$< 5.5 \times 10^{-5}$	CL=90%	1548
$\gamma f_J(2220)$	$> 2.50 \times 10^{-3}$	CL=99.9%	–
$\gamma f_0(1500)$	$(5.7 \pm 0.8) \times 10^{-4}$		1184
$\gamma e^+ e^-$	$(8.8 \pm 1.4) \times 10^{-3}$		–

$\chi_{c0}(1P)$

$I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 3417.3 \pm 2.8$ MeV

Full width $\Gamma = 14 \pm 5$ MeV

$\chi_{c0}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
Hadronic decays			
$2(\pi^+\pi^-)$	(3.7 ± 0.7) %		1679
$\pi^+\pi^- K^+ K^-$	(3.0 ± 0.7) %		1580
$\rho^0\pi^+\pi^-$	(1.6 ± 0.5) %		1608
$3(\pi^+\pi^-)$	(1.5 ± 0.5) %		1633
$K^+\overline{K}^*(892)^0\pi^- +$ c.c.	(1.2 ± 0.4) %		1522
$\pi^+\pi^-$	$(7.5\pm2.1) \times 10^{-3}$		1702
K^+K^-	$(7.1\pm2.4) \times 10^{-3}$		1635
$\pi^+\pi^- p\overline{p}$	$(5.0\pm2.0) \times 10^{-3}$		1320
$p\overline{p}$	$< 9.0 \times 10^{-4}$	90%	1427
Radiative decays			
$\gamma J/\psi(1S)$	$(6.6\pm1.8) \times 10^{-3}$		303
$\gamma\gamma$	$< 5 \times 10^{-4}$	95%	1708

$\chi_{c1}(1P)$

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 3510.53 \pm 0.12$ MeV
Full width $\Gamma = 0.88 \pm 0.14$ MeV

$\chi_{c1}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
Hadronic decays		
$3(\pi^+\pi^-)$	(2.2±0.8) %	1683
$2(\pi^+\pi^-)$	(1.6±0.5) %	1727
$\pi^+\pi^- K^+ K^-$	(9 ±4) × 10^{-3}	1632
$\rho^0\pi^+\pi^-$	(3.9±3.5) × 10^{-3}	1659
$K^+\overline{K}^*(892)^0\pi^-$ + c.c.	(3.2±2.1) × 10^{-3}	1576
$\pi^+\pi^- p\overline{p}$	(1.4±0.9) × 10^{-3}	1381
$p\overline{p}$	(8.6±1.2) × 10^{-5}	1483
$\pi^+\pi^-$ + K^+K^-	< 2.1 × 10^{-3}	–
Radiative decays		
$\gamma J/\psi(1S)$	(27.3±1.6) %	389

$\chi_{c2}(1P)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 3556.17 \pm 0.13$ MeV
Full width $\Gamma = 2.00 \pm 0.18$ MeV

$\chi_{c2}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
Hadronic decays			
$2(\pi^+\pi^-)$	(2.2±0.5) %		1751
$\pi^+\pi^- K^+ K^-$	(1.9±0.5) %		1656
$3(\pi^+\pi^-)$	(1.2±0.8) %		1707
$\rho^0\pi^+\pi^-$	(7 ±4) × 10^{-3}		1683
$K^+\overline{K}^*(892)^0\pi^-$ + c.c.	(4.8±2.8) × 10^{-3}		1601
$\pi^+\pi^- p\overline{p}$	(3.3±1.3) × 10^{-3}		1410
$\pi^+\pi^-$	(1.9±1.0) × 10^{-3}		1773
K^+K^-	(1.5±1.1) × 10^{-3}		1708
$p\overline{p}$	(10.0±1.0) × 10^{-5}		1510
$J/\psi(1S)\pi^+\pi^-\pi^0$	< 1.5 %	90%	185
Radiative decays			
$\gamma J/\psi(1S)$	(13.5±1.1) %		430
$\gamma\gamma$	(1.6±0.5) × 10^{-4}		1778

$\psi(2S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 3686.00 \pm 0.09$ MeV
Full width $\Gamma = 277 \pm 31$ keV (S = 1.1)
$\Gamma_{ee} = 2.14 \pm 0.21$ keV (Assuming $\Gamma_{ee} = \Gamma_{\mu\mu}$)

$\psi(2S)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
hadrons	(98.10 ± 0.30) %		–
virtual $\gamma \to$ hadrons	(2.9 ± 0.4) %		–
$e^+ e^-$	$(8.5 \pm 0.7) \times 10^{-3}$		1843
$\mu^+ \mu^-$	$(7.7 \pm 1.7) \times 10^{-3}$		1840
Decays into $J/\psi(1S)$ and anything			
$J/\psi(1S)$ anything	(54.2 ± 3.0) %		–
$J/\psi(1S)$ neutrals	(22.8 ± 1.7) %		–
$J/\psi(1S)\pi^+\pi^-$	(30.2 ± 1.9) %		477
$J/\psi(1S)\pi^0\pi^0$	(17.9 ± 1.8) %		481
$J/\psi(1S)\eta$	(2.7 ± 0.4) %	S=1.7	200
$J/\psi(1S)\pi^0$	$(9.7 \pm 2.1) \times 10^{-4}$		527
$J/\psi(1S)\mu^+\mu^-$	$(10.0 \pm 3.3) \times 10^{-3}$		–
Hadronic decays			
$3(\pi^+\pi^-)\pi^0$	$(3.5 \pm 1.6) \times 10^{-3}$		1746
$2(\pi^+\pi^-)\pi^0$	$(3.0 \pm 0.8) \times 10^{-3}$		1799
$\pi^+\pi^- K^+ K^-$	$(1.6 \pm 0.4) \times 10^{-3}$		1726
$\pi^+\pi^- p\overline{p}$	$(8.0 \pm 2.0) \times 10^{-4}$		1491
$K^+\overline{K}^*(892)^0\pi^- +$ c.c.	$(6.7 \pm 2.5) \times 10^{-4}$		1673
$2(\pi^+\pi^-)$	$(4.5 \pm 1.0) \times 10^{-4}$		1817
$\rho^0\pi^+\pi^-$	$(4.2 \pm 1.5) \times 10^{-4}$		1751
$\overline{p}p$	$(1.9 \pm 0.5) \times 10^{-4}$		1586
$3(\pi^+\pi^-)$	$(1.5 \pm 1.0) \times 10^{-4}$		1774
$\overline{p}p\pi^0$	$(1.4 \pm 0.5) \times 10^{-4}$		1543
K^+K^-	$(1.0 \pm 0.7) \times 10^{-4}$		1776
$\pi^+\pi^-\pi^0$	$(9 \pm 5) \times 10^{-5}$		1830
$\rho\pi$	$< 8.3 \times 10^{-5}$	CL=90%	1760
$\pi^+\pi^-$	$(8 \pm 5) \times 10^{-5}$		1838
$\Lambda\overline{\Lambda}$	$< 4 \times 10^{-4}$	CL=90%	1467
$\Xi^-\overline{\Xi}^+$	$< 2 \times 10^{-4}$	CL=90%	1285
$K^+K^-\pi^0$	$< 2.96 \times 10^{-5}$	CL=90%	1754
$K^+\overline{K}^*(892)^- +$ c.c.	$< 5.4 \times 10^{-5}$	CL=90%	1698

Radiative decays

$\gamma \chi_{c0}(1P)$	(9.3 ±0.9) %			261
$\gamma \chi_{c1}(1P)$	(8.7 ±0.8) %			171
$\gamma \chi_{c2}(1P)$	(7.8 ±0.8) %			127
$\gamma \eta_c(1S)$	(2.8 ±0.6) $\times 10^{-3}$			639
$\gamma \eta'(958)$	< 1.1 $\times 10^{-3}$		CL=90%	1719
$\gamma \gamma$	< 1.6 $\times 10^{-4}$		CL=90%	1843
$\gamma \eta(1440) \rightarrow \gamma K \overline{K} \pi$	< 1.2 $\times 10^{-4}$		CL=90%	1569

$\psi(3770)$

$I^G(J^{PC}) = ?^?(1^{--})$

Mass $m = 3769.9 \pm 2.5$ MeV (S = 1.8)
Full width $\Gamma = 23.6 \pm 2.7$ MeV (S = 1.1)
$\Gamma_{ee} = 0.26 \pm 0.04$ keV (S = 1.2)

$\psi(3770)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
$D\overline{D}$	dominant		242
$e^+ e^-$	$(1.12\pm0.17) \times 10^{-5}$	1.2	1885

$\psi(4040)$ [iii]

$I^G(J^{PC}) = ?^?(1^{--})$

Mass $m = 4040 \pm 10$ MeV
Full width $\Gamma = 52 \pm 10$ MeV
$\Gamma_{ee} = 0.75 \pm 0.15$ keV

$\psi(4040)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$e^+ e^-$	$(1.4\pm0.4) \times 10^{-5}$	2020
$D^0 \overline{D}^0$	seen	777
$D^*(2007)^0 \overline{D}^0$ + c.c.	seen	578
$D^*(2007)^0 \overline{D}^*(2007)^0$	seen	232

$\psi(4160)$ [iii]

$I^G(J^{PC}) = ?^?(1^{--})$

Mass $m = 4159 \pm 20$ MeV
Full width $\Gamma = 78 \pm 20$ MeV
$\Gamma_{ee} = 0.77 \pm 0.23$ keV

$\psi(4160)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$e^+ e^-$	$(10\pm4) \times 10^{-6}$	2079

$\psi(4415)$ [iii]

$I^G(J^{PC}) = ?^?(1^{--})$

Mass $m = 4415 \pm 6$ MeV
Full width $\Gamma = 43 \pm 15$ MeV (S = 1.8)
$\Gamma_{ee} = 0.47 \pm 0.10$ keV

$\psi(4415)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
hadrons	dominant	–
$e^+ e^-$	$(1.1\pm0.4) \times 10^{-5}$	2207

$b\overline{b}$ MESONS

$\Upsilon(1S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 9460.37 \pm 0.21$ MeV (S = 2.7)
Full width $\Gamma = 52.5 \pm 1.8$ keV
$\Gamma_{ee} = 1.32 \pm 0.05$ keV

$\Upsilon(1S)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\tau^+\tau^-$	$(2.67^{+0.14}_{-0.16})$ %		4384
e^+e^-	(2.52 ± 0.17) %		4730
$\mu^+\mu^-$	(2.48 ± 0.07) %	S=1.1	4729
Hadronic decays			
$J/\psi(1S)$anything	$(1.1 \pm0.4) \times 10^{-3}$		4223
$\rho\pi$	$< 2 \times 10^{-4}$	CL=90%	4698
$\pi^+\pi^-$	$< 5 \times 10^{-4}$	CL=90%	4728
K^+K^-	$< 5 \times 10^{-4}$	CL=90%	4704
$p\overline{p}$	$< 5 \times 10^{-4}$	CL=90%	4636

Radiative decays

$\gamma 2h^+ 2h^-$	$(7.0 \pm 1.5) \times 10^{-4}$		4720
$\gamma 3h^+ 3h^-$	$(5.4 \pm 2.0) \times 10^{-4}$		4703
$\gamma 4h^+ 4h^-$	$(7.4 \pm 3.5) \times 10^{-4}$		4679
$\gamma \pi^+ \pi^- K^+ K^-$	$(2.9 \pm 0.9) \times 10^{-4}$		4686
$\gamma 2\pi^+ 2\pi^-$	$(2.5 \pm 0.9) \times 10^{-4}$		4720
$\gamma 3\pi^+ 3\pi^-$	$(2.5 \pm 1.2) \times 10^{-4}$		4703
$\gamma 2\pi^+ 2\pi^- K^+ K^-$	$(2.4 \pm 1.2) \times 10^{-4}$		4658
$\gamma \pi^+ \pi^- p \overline{p}$	$(1.5 \pm 0.6) \times 10^{-4}$		4604
$\gamma 2\pi^+ 2\pi^- p \overline{p}$	$(4 \pm 6) \times 10^{-5}$		4563
$\gamma 2K^+ 2K^-$	$(2.0 \pm 2.0) \times 10^{-5}$		4601
$\gamma \eta'(958)$	$< 1.3 \times 10^{-3}$	CL=90%	4682
$\gamma \eta$	$< 3.5 \times 10^{-4}$	CL=90%	4714
$\gamma f'_2(1525)$	$< 1.4 \times 10^{-4}$	CL=90%	4607
$\gamma f_2(1270)$	$< 1.3 \times 10^{-4}$	CL=90%	4644
$\gamma \eta(1440)$	$< 8.2 \times 10^{-5}$	CL=90%	4624
$\gamma f_J(1710) \rightarrow \gamma K \overline{K}$	$< 2.6 \times 10^{-4}$	CL=90%	4576
$\gamma f_0(2200) \rightarrow \gamma K^+ K^-$	$< 2 \times 10^{-4}$	CL=90%	4475
$\gamma f_J(2220) \rightarrow \gamma K^+ K^-$	$< 1.5 \times 10^{-5}$	CL=90%	4469
$\gamma \eta(2225) \rightarrow \gamma \phi \phi$	$< 3 \times 10^{-3}$	CL=90%	4469
γX	$< 3 \times 10^{-5}$	CL=90%	–
X = pseudoscalar with $m< 7.2$ GeV)			
$\gamma X \overline{X}$	$< 1 \times 10^{-3}$	CL=90%	–
$X \overline{X}$ = vectors with $m< 3.1$ GeV)			

$\chi_{b0}(1P)$ [jjj]

$I^G(J^{PC}) = 0^+(0^{++})$
J needs confirmation.

Mass $m = 9859.8 \pm 1.3$ MeV

$\chi_{b0}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\gamma \Upsilon(1S)$	<6 %	90%	391

$\chi_{b1}(1P)$ [jjj]

$I^G(J^{PC}) = 0^+(1^{++})$
J needs confirmation.

Mass $m = 9891.9 \pm 0.7$ MeV

$\chi_{b1}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\gamma \Upsilon(1S)$	(35 ± 8) %	422

$\chi_{b2}(1P)$ [jjj]

$I^G(J^{PC}) = 0^+(2^{++})$
J needs confirmation.

Mass $m = 9913.2 \pm 0.6$ MeV

$\chi_{b2}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\gamma\,\Upsilon(1S)$	(22 ± 4) %	443

$\Upsilon(2S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 10.02330 \pm 0.00031$ GeV
Full width $\Gamma = 44 \pm 7$ keV
$\Gamma_{ee} = 0.520 \pm 0.032$ keV

$\Upsilon(2S)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Upsilon(1S)\pi^+\pi^-$	$(18.5\ \pm0.8\ )$ %		475
$\Upsilon(1S)\pi^0\pi^0$	$(\ 8.8\ \pm1.1\ )$ %		480
$\tau^+\tau^-$	$(\ 1.7\ \pm1.6\ )$ %		4686
$\mu^+\mu^-$	$(\ 1.31\pm0.21)$ %		5011
e^+e^-	$(\ 1.18\pm0.20)$ %		5012
$\Upsilon(1S)\pi^0$	$< 8 \times 10^{-3}$	90%	531
$\Upsilon(1S)\eta$	$< 2 \times 10^{-3}$	90%	127
$J/\psi(1S)$anything	$< 6 \times 10^{-3}$	90%	4533
Radiative decays			
$\gamma\chi_{b1}(1P)$	$(\ 6.7\ \pm0.9\ )$ %		131
$\gamma\chi_{b2}(1P)$	$(\ 6.6\ \pm0.9\ )$ %		110
$\gamma\chi_{b0}(1P)$	$(\ 4.3\ \pm1.0\ )$ %		162
$\gamma f_J(1710)$	$< 5.9 \times 10^{-4}$	90%	4866
$\gamma f'_2(1525)$	$< 5.3 \times 10^{-4}$	90%	4896
$\gamma f_2(1270)$	$< 2.41 \times 10^{-4}$	90%	4931

$\chi_{b0}(2P)$ [jjj]

$I^G(J^{PC}) = 0^+(0^{++})$
J needs confirmation.

Mass $m = 10.2321 \pm 0.0006$ GeV

$\chi_{b0}(2P)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\gamma\,\Upsilon(2S)$	(4.6 ± 2.1) %	210
$\gamma\,\Upsilon(1S)$	$(9\ \pm6\ )\times10^{-3}$	746

$\chi_{b1}(2P)$ [jjj]

$I^G(J^{PC}) = 0^+(1^{++})$
J needs confirmation.

Mass $m = 10.2552 \pm 0.0005$ GeV
$m_{\chi_{b1}(2P)} - m_{\chi_{b0}(2P)} = 23.5 \pm 1.0$ MeV

$\chi_{b1}(2P)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
$\gamma\,\Upsilon(2S)$	(21 ± 4) %	1.5	229
$\gamma\,\Upsilon(1S)$	(8.5 ± 1.3) %	1.3	764

$\chi_{b2}(2P)$ [jjj]

$I^G(J^{PC}) = 0^+(2^{++})$
J needs confirmation.

Mass $m = 10.2685 \pm 0.0004$ GeV
$m_{\chi_{b2}(2P)} - m_{\chi_{b1}(2P)} = 13.5 \pm 0.6$ MeV

$\chi_{b2}(2P)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\gamma\,\Upsilon(2S)$	(16.2 ± 2.4) %	242
$\gamma\,\Upsilon(1S)$	(7.1 ± 1.0) %	776

$\Upsilon(3S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 10.3553 \pm 0.0005$ GeV
Full width $\Gamma = 26.3 \pm 3.5$ keV

$\Upsilon(3S)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\Upsilon(2S)$anything	(10.6 ± 0.8) %		296
$\Upsilon(2S)\pi^+\pi^-$	(2.8 ± 0.6) %	S=2.2	177
$\Upsilon(2S)\pi^0\pi^0$	(2.00 ± 0.32) %		190
$\Upsilon(2S)\gamma\gamma$	(5.0 ± 0.7) %		327
$\Upsilon(1S)\pi^+\pi^-$	(4.48 ± 0.21) %		814
$\Upsilon(1S)\pi^0\pi^0$	(2.06 ± 0.28) %		816
$\Upsilon(1S)\eta$	$< 2.2 \times 10^{-3}$	CL=90%	–
$\mu^+\mu^-$	(1.81 ± 0.17) %		5177
e^+e^-	seen		5177
Radiative decays			
$\gamma\chi_{b2}(2P)$	(11.4 ± 0.8) %	S=1.3	87
$\gamma\chi_{b1}(2P)$	(11.3 ± 0.6) %		100
$\gamma\chi_{b0}(2P)$	(5.4 ± 0.6) %	S=1.1	123

$\Upsilon(4S)$ or $\Upsilon(10580)$

$I^G(J^{PC}) = ?^?(1^{--})$

Mass $m = 10.5800 \pm 0.0035$ GeV
Full width $\Gamma = 10 \pm 4$ MeV
$\Gamma_{ee} = 0.248 \pm 0.031$ keV (S = 1.3)

$\Upsilon(4S)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$B\overline{B}$	> 96 %	95%	–
non-$B\overline{B}$	< 4 %	95%	–
e^+e^-	$(2.8\pm0.7) \times 10^{-5}$		5290
$J/\psi(3097)$anything	$(2.2\pm0.7) \times 10^{-3}$		–
D^{*+}anything + c.c.	< 7.4 %	90%	5099
ϕanything	$< 2.3 \times 10^{-3}$	90%	5240
$\Upsilon(1S)$anything	$< 4 \times 10^{-3}$	90%	1053

$\Upsilon(10860)$

$I^G(J^{PC}) = ?^?(1^{--})$

Mass $m = 10.865 \pm 0.008$ GeV (S = 1.1)
Full width $\Gamma = 110 \pm 13$ MeV
$\Gamma_{ee} = 0.31 \pm 0.07$ keV (S = 1.3)

$\Upsilon(10860)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
e^+e^-	$(2.8\pm0.7) \times 10^{-6}$	5432

$\Upsilon(11020)$

$I^G(J^{PC}) = ?^?(1^{--})$

Mass $m = 11.019 \pm 0.008$ GeV
Full width $\Gamma = 79 \pm 16$ MeV
$\Gamma_{ee} = 0.130 \pm 0.030$ keV

$\Upsilon(11020)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
e^+e^-	$(1.6\pm0.5) \times 10^{-6}$	5509

NOTES

[*a*] See the "Note on $\pi^{\pm} \rightarrow \ell^{\pm}\nu\gamma$ and $K^{\pm} \rightarrow \ell^{\pm}\nu\gamma$ Form Factors" in the $\pi^{\pm}$ Particle Listings for definitions and details.

[*b*] Measurements of $\Gamma(e^{+}\nu_{e})/\Gamma(\mu^{+}\nu_{\mu})$ always include decays with γ's, and measurements of $\Gamma(e^{+}\nu_{e}\gamma)$ and $\Gamma(\mu^{+}\nu_{\mu}\gamma)$ never include low-energy γ's. Therefore, since no clean separation is possible, we consider the modes with γ's to be subreactions of the modes without them, and let $[\Gamma(e^{+}\nu_{e}) + \Gamma(\mu^{+}\nu_{\mu})]/\Gamma_{\text{total}} = 100\%$.

[*c*] See the $\pi^{\pm}$ Particle Listings for the energy limits used in this measurement; low-energy γ's are not included.

[*d*] Derived from an analysis of neutrino-oscillation experiments.

[*e*] Astrophysical and cosmological arguments give limits of order 10^{-13}; see the π^{0} Particle Listings.

[*f*] See the "Note on the Decay Width $\Gamma(\eta \rightarrow \gamma\gamma)$" in our 1994 edition, Phys. Rev. **D50**, 1 August 1994, Part I, p. 1451.

[*g*] *C* parity forbids this to occur as a single-photon process.

[*h*] See the "Note on scalar mesons" in the $f_0(1370)$ Particle Listings . The interpretation of this entry as a particle is controversial.

[*i*] See the "Note on $\rho(770)$" in the $\rho(770)$ Particle Listings .

[*j*] The $e^{+}e^{-}$ branching fraction is from $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ experiments only. The $\omega\rho$ interference is then due to $\omega\rho$ mixing only, and is expected to be small. If $e\mu$ universality holds, $\Gamma(\rho^{0} \rightarrow \mu^{+}\mu^{-}) = \Gamma(\rho^{0} \rightarrow e^{+}e^{-}) \times 0.99785$.

[*k*] See the "Note on scalar mesons" in the $f_0(1370)$ Particle Listings .

[*l*] See the "Note on $a_1(1260)$" in the $a_1(1260)$ Particle Listings .

[*m*] This is only an educated guess; the error given is larger than the error on the average of the published values. See the Particle Listings for details.

[*n*] See the "Note on the $f_1(1420)$" in the $\eta(1440)$ Particle Listings.

[*o*] See also the $\omega(1600)$ Particle Listings.

[*p*] See the "Note on the $\eta(1440)$" in the $\eta(1440)$ Particle Listings.

[*q*] See the "Note on the $\rho(1450)$ and the $\rho(1700)$" in the $\rho(1700)$ Particle Listings.

[*r*] See the "Note on non-$q\overline{q}$ mesons" in the Particle Listings (see the index for the page number).

[*s*] See also the $\omega(1420)$ Particle Listings.

[*t*] See the "Note on $f_J(1710)$" in the $f_J(1710)$ Particle Listings .

[*u*] See the note in the $K^{\pm}$ Particle Listings.

[*v*] The definition of the slope parameter g of the $K \to 3\pi$ Dalitz plot is as follows (see also "Note on Dalitz Plot Parameters for $K \to 3\pi$ Decays" in the $K^{\pm}$ Particle Listings):

$$|M|^2 = 1 + g(s_3 - s_0)/m^2_{\pi^+} + \cdots .$$

[*w*] For more details and definitions of parameters see the Particle Listings.

[*x*] See the $K^{\pm}$ Particle Listings for the energy limits used in this measurement.

[*y*] Most of this radiative mode, the low-momentum γ part, is also included in the parent mode listed without γ's.

[*z*] Direct-emission branching fraction.

[*aa*] Structure-dependent part.

[*bb*] Derived from measured values of ϕ_{+-}, ϕ_{00}, $|\eta|$, $|m_{K^0_L} - m_{K^0_S}|$, and $\tau_{K^0_S}$, as described in the introduction to "Tests of Conservation Laws."

[*cc*] The *CP*-violation parameters are defined as follows (see also "Note on *CP* Violation in $K_S \to 3\pi$" and "Note on *CP* Violation in K^0_L Decay" in the Particle Listings):

$$\eta_{+-} = |\eta_{+-}| e^{i\phi_{+-}} = \frac{A(K^0_L \to \pi^+\pi^-)}{A(K^0_S \to \pi^+\pi^-)} = \epsilon + \epsilon'$$

$$\eta_{00} = |\eta_{00}| e^{i\phi_{00}} = \frac{A(K^0_L \to \pi^0\pi^0)}{A(K^0_S \to \pi^0\pi^0)} = \epsilon - 2\epsilon'$$

$$\delta = \frac{\Gamma(K^0_L \to \pi^-\ell^+\nu) - \Gamma(K^0_L \to \pi^+\ell^-\nu)}{\Gamma(K^0_L \to \pi^-\ell^+\nu) + \Gamma(K^0_L \to \pi^+\ell^-\nu)} ,$$

$$\mathrm{Im}(\eta_{+-0})^2 = \frac{\Gamma(K^0_S \to \pi^+\pi^-\pi^0)^{CP\text{ viol.}}}{\Gamma(K^0_L \to \pi^+\pi^-\pi^0)} ,$$

$$\mathrm{Im}(\eta_{000})^2 = \frac{\Gamma(K^0_S \to \pi^0\pi^0\pi^0)}{\Gamma(K^0_L \to \pi^0\pi^0\pi^0)} .$$

where for the last two relations *CPT* is assumed valid, *i.e.*, $\mathrm{Re}(\eta_{+-0}) \simeq 0$ and $\mathrm{Re}(\eta_{000}) \simeq 0$.

[*dd*] See the K^0_S Particle Listings for the energy limits used in this measurement.

[*ee*] Calculated from K^0_L semileptonic rates and the K^0_S lifetime assuming $\Delta S = \Delta Q$.

[*ff*] ϵ'/ϵ is derived from $|\eta_{00}/\eta_{+-}|$ measurements using theoretical input on phases.

[*gg*] The value is for the sum of the charge states of particle/antiparticle states indicated.

[*hh*] See the K^0_L Particle Listings for the energy limits used in this measurement.

[*ii*] Allowed by higher-order electroweak interactions.

[*jj*] Violates *CP* in leading order. Test of direct *CP* violation since the indirect *CP*-violating and *CP*-conserving contributions are expected to be suppressed.

[*kk*] See the "Note on $f_0(1370)$" in the $f_0(1370)$ Particle Listings and in the 1994 edition.

[*ll*] See the note in the $L(1770)$ Particle Listings in Reviews of Modern Physics **56** No. 2 Pt. II (1984), p. S200. See also the "Note on $K_2(1770)$ and the $K_2(1820)$" in the $K_2(1770)$ Particle Listings .

[*mm*] See the "Note on $K_2(1770)$ and the $K_2(1820)$" in the $K_2(1770)$ Particle Listings .

[*nn*] This is a weighted average of $D^{\pm}$ (44%) and D^0 (56%) branching fractions. See "D^+ and $D^0 \rightarrow$ (η anything) / (total D^+ and D^0)" under "D^+ Branching Ratios" in the Particle Listings.

[*oo*] This value averages the e^+ and μ^+ branching fractions, after making a small phase-space adjustment to the μ^+ fraction to be able to use it as an e^+ fraction; hence our ℓ^+ here is really an e^+.

[*pp*] An ℓ indicates an e or a μ mode, not a sum over these modes.

[*qq*] The branching fraction for this mode may differ from the sum of the submodes that contribute to it, due to interference effects. See the relevant papers in the Particle Listings.

[*rr*] The two experiments measuring this fraction are in serious disagreement. See the Particle Listings.

[*ss*] This mode is not a useful test for a ΔC=1 weak neutral current because both quarks must change flavor in this decay.

[*tt*] The D^0_1-D^0_2 limits are inferred from the D^0-$\overline{D}^0$ mixing ratio $\Gamma(K^+\ell^-\overline{\nu}_\ell(\text{via } \overline{D}^0))$ / $\Gamma(K^-\ell^+\nu_\ell)$.

[*uu*] The larger limit (from E791) allows interference between the doubly Cabibbo-suppressed and mixing amplitudes; the smaller limit (from E691) doesn't. See the papers for details.

[*vv*] The experiments on the division of this charge mode amongst its submodes disagree, and the submode branching fractions here add up to considerably more than the charged-mode fraction.

[*ww*] However, these upper limits are in serious disagreement with values obtained in another experiment.

[*xx*] For now, we average together measurements of the $X e^+ \nu_e$ and $X \mu^+ \nu_\mu$ branching fractions. This is the *average*, not the *sum*.

[*yy*] This branching fraction includes all the decay modes of the final-state resonance.

[*zz*] This value includes only $K^+ K^-$ decays of the $f_J(1710)$, because branching fractions of this resonance are not known.

[*aaa*] This value includes only $\pi^+ \pi^-$ decays of the $f_0(1500)$, because branching fractions of this resonance are not known.

[*bbb*] B^0 and B_s^0 contributions not separated. Limit is on weighted average of the two decay rates.

[*ccc*] These values are model dependent. See 'Note on Semileptonic Decays' in the B^+ Particle Listings.

[*ddd*] D^{**} stands for the sum of the $D(1\,^1P_1)$, $D(1\,^3P_0)$, $D(1\,^3P_1)$, $D(1\,^3P_2)$, $D(2\,^1S_0)$, and $D(2\,^1S_1)$ resonances.

[*eee*] Inclusive branching fractions have a multiplicity definition and can be greater than 100%.

[*fff*] D_j represents an unresolved mixture of pseudoscalar and tensor D^{**} (P-wave) states.

[*ggg*] Not a pure measurement. See note at head of B_s^0 Decay Modes.

[*hhh*] Includes $p\overline{p}\pi^+\pi^-\gamma$ and excludes $p\overline{p}\eta$, $p\overline{p}\omega$, $p\overline{p}\eta'$.

[*iii*] J^{PC} known by production in e^+e^- via single photon annihilation. I^G is not known; interpretation of this state as a single resonance is unclear because of the expectation of substantial threshold effects in this energy region.

[*jjj*] Spectroscopic labeling for these states is theoretical, pending experimental information.

N BARYONS
$(S = 0, I = 1/2)$

p, $N^+ = uud$; n, $N^0 = udd$

p

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Mass $m = 938.27231 \pm 0.00028$ MeV [a]

$= 1.007276470 \pm 0.000000012$ u

$\left|\frac{q_{\overline{p}}}{m_{\overline{p}}}\right|/(\frac{q_p}{m_p}) = 1.0000000015 \pm 0.0000000011$

$\left|q_p + q_{\overline{p}}\right|/e < 2 \times 10^{-5}$

$\left|q_p + q_e\right|/e < 1.0 \times 10^{-21}$ [b]

Magnetic moment $\mu = 2.79284739 \pm 0.00000006\ \mu_N$

Electric dipole moment $d = (-4 \pm 6) \times 10^{-23}$ e cm

Electric polarizability $\overline{\alpha} = (12.1 \pm 0.9) \times 10^{-4}$ fm^3

Magnetic polarizability $\overline{\beta} = (2.1 \pm 0.9) \times 10^{-4}$ fm^3

Mean life $\tau > 1.6 \times 10^{25}$ years (independent of mode)

$> 10^{31}$ to 5×10^{32} years [c] (mode dependent)

Below, for N decays, p and n distinguish proton and neutron partial lifetimes. See also the "Note on Nucleon Decay" in our 1994 edition (Phys. Rev. **D50**, 1673) for a short review.

The "partial mean life" limits tabulated here are the limits on τ/B_i, where τ is the total mean life and B_i is the branching fraction for the mode in question.

p DECAY MODES	Partial mean life (10^{30} years)	Confidence level	p (MeV/c)
	Antilepton + meson		
$N \rightarrow e^+\pi$	> 130 (n), > 550 (p)	90%	459
$N \rightarrow \mu^+\pi$	> 100 (n), > 270 (p)	90%	453
$N \rightarrow \nu\pi$	> 100 (n), > 25 (p)	90%	459
$p \rightarrow e^+\eta$	> 140	90%	309
$p \rightarrow \mu^+\eta$	> 69	90%	296
$n \rightarrow \nu\eta$	> 54	90%	310
$N \rightarrow e^+\rho$	> 58 (n), > 75 (p)	90%	153
$N \rightarrow \mu^+\rho$	> 23 (n), > 110 (p)	90%	119
$N \rightarrow \nu\rho$	> 19 (n), > 27 (p)	90%	153
$p \rightarrow e^+\omega$	> 45	90%	142

$p \to \mu^+ \omega$	> 57	90%	104
$n \to \nu \omega$	> 43	90%	144
$N \to e^+ K$	> 1.3 (n), > 150 (p)	90%	337
$p \to e^+ K^0_S$	> 76	90%	337
$p \to e^+ K^0_L$	> 44	90%	337
$N \to \mu^+ K$	> 1.1 (n), > 120 (p)	90%	326
$p \to \mu^+ K^0_S$	> 64	90%	326
$p \to \mu^+ K^0_L$	> 44	90%	326
$N \to \nu K$	> 86 (n), > 100 (p)	90%	339
$p \to e^+ K^*(892)^0$	> 52	90%	45
$N \to \nu K^*(892)$	> 22 (n), > 20 (p)	90%	45
Antilepton + mesons			
$p \to e^+ \pi^+ \pi^-$	> 21	90%	448
$p \to e^+ \pi^0 \pi^0$	> 38	90%	449
$n \to e^+ \pi^- \pi^0$	> 32	90%	449
$p \to \mu^+ \pi^+ \pi^-$	> 17	90%	425
$p \to \mu^+ \pi^0 \pi^0$	> 33	90%	427
$n \to \mu^+ \pi^- \pi^0$	> 33	90%	427
$n \to e^+ K^0 \pi^-$	> 18	90%	319
Lepton + meson			
$n \to e^- \pi^+$	> 65	90%	459
$n \to \mu^- \pi^+$	> 49	90%	453
$n \to e^- \rho^+$	> 62	90%	154
$n \to \mu^- \rho^+$	> 7	90%	120
$n \to e^- K^+$	> 32	90%	340
$n \to \mu^- K^+$	> 57	90%	330
Lepton + mesons			
$p \to e^- \pi^+ \pi^+$	> 30	90%	448
$n \to e^- \pi^+ \pi^0$	> 29	90%	449
$p \to \mu^- \pi^+ \pi^+$	> 17	90%	425
$n \to \mu^- \pi^+ \pi^0$	> 34	90%	427
$p \to e^- \pi^+ K^+$	> 20	90%	320
$p \to \mu^- \pi^+ K^+$	> 5	90%	279
Antilepton + photon(s)			
$p \to e^+ \gamma$	> 460	90%	469
$p \to \mu^+ \gamma$	> 380	90%	463
$n \to \nu \gamma$	> 24	90%	470
$p \to e^+ \gamma \gamma$	> 100	90%	469

Three (or more) leptons

$p \to e^+ e^+ e^-$	> 510	90%	469
$p \to e^+ \mu^+ \mu^-$	> 81	90%	457
$p \to e^+ \nu \nu$	> 11	90%	469
$n \to e^+ e^- \nu$	> 74	90%	470
$n \to \mu^+ e^- \nu$	> 47	90%	464
$n \to \mu^+ \mu^- \nu$	> 42	90%	458
$p \to \mu^+ e^+ e^-$	> 91	90%	464
$p \to \mu^+ \mu^+ \mu^-$	> 190	90%	439
$p \to \mu^+ \nu \nu$	> 21	90%	463
$p \to e^- \mu^+ \mu^+$	> 6	90%	457
$n \to 3\nu$	> 0.0005	90%	470

Inclusive modes

$N \to e^+$ anything	> 0.6 (n, p)	90%	–
$N \to \mu^+$ anything	> 12 (n, p)	90%	–
$N \to e^+ \pi^0$ anything	> 0.6 (n, p)	90%	–

$\Delta B = 2$ dinucleon modes

The following are lifetime limits per iron nucleus.

$pp \to \pi^+ \pi^+$	> 0.7	90%	–
$pn \to \pi^+ \pi^0$	> 2	90%	–
$nn \to \pi^+ \pi^-$	> 0.7	90%	–
$nn \to \pi^0 \pi^0$	> 3.4	90%	–
$pp \to e^+ e^+$	> 5.8	90%	–
$pp \to e^+ \mu^+$	> 3.6	90%	–
$pp \to \mu^+ \mu^+$	> 1.7	90%	–
$pn \to e^+ \overline{\nu}$	> 2.8	90%	–
$pn \to \mu^+ \overline{\nu}$	> 1.6	90%	–
$nn \to \nu_e \overline{\nu}_e$	> 0.000012	90%	–
$nn \to \nu_\mu \overline{\nu}_\mu$	> 0.000006	90%	–

$\overline{p}$ DECAY MODES

$\overline{p}$ DECAY MODES	Partial mean life (years)	Confidence level	p (MeV/c)
$\overline{p} \to e^- \gamma$	> 1848	95%	469
$\overline{p} \to e^- \pi^0$	> 554	95%	459
$\overline{p} \to e^- \eta$	> 171	95%	309
$\overline{p} \to e^- K^0_S$	> 29	95%	337
$\overline{p} \to e^- K^0_L$	> 9	95%	337

n

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Mass $m = 939.56563 \pm 0.00028$ MeV [a]
$= 1.008664904 \pm 0.000000014$ u
$m_n - m_p = 1.293318 \pm 0.000009$ MeV
$= 0.001388434 \pm 0.000000009$ u
Mean life $\tau = 886.7 \pm 1.9$ s (S = 1.2)
$c\tau = 2.658 \times 10^8$ km
Magnetic moment $\mu = -1.9130428 \pm 0.0000005\ \mu_N$
Electric dipole moment $d < 0.97 \times 10^{-25}\ e\,$cm, CL = 90%
Electric polarizability $\alpha = (0.98^{+0.19}_{-0.23}) \times 10^{-3}$ fm^3 (S = 1.1)
Charge $q = (-0.4 \pm 1.1) \times 10^{-21}\ e$
Mean $n\overline{n}$-oscillation time $> 1.2\times 10^8$ s, CL = 90% [d] (bound n)
$> 0.86 \times 10^8$ s, CL = 90% (free n)

Decay parameters [e]

$p e^- \overline{\nu}_e$	$g_A/g_V = -1.2670 \pm 0.0035$ (S = 1.9)
"	$A = -0.1162 \pm 0.0013$ (S = 1.8)
"	$B = 0.990 \pm 0.008$
"	$a = -0.102 \pm 0.005$
"	$\phi_{AV} = (180.07 \pm 0.18)^\circ$ [f]
"	$D = (-0.5 \pm 1.4) \times 10^{-3}$

n DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$p e^- \overline{\nu}_e$	100 %		1.19
Charge conservation (Q) violating mode			
$p \nu_e \overline{\nu}_e$	Q $< 8 \times 10^{-27}$	68%	1.29

***N*(1440) P_{11}**

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Breit-Wigner mass = 1430 to 1470 (≈ 1440) MeV
Breit-Wigner full width = 250 to 450 (≈ 350) MeV
$p_{\text{beam}} = 0.61$ GeV/c $4\pi\lambdabar^2 = 31.0$ mb
Re(pole position) = 1345 to 1385 (≈ 1365) MeV
−2Im(pole position) = 160 to 260 (≈ 210) MeV

***N*(1440) DECAY MODES**	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	60–70 %	397
$N\pi\pi$	30–40 %	342
$\Delta\pi$	20–30 %	143
$N\rho$	<8 %	†
$N(\pi\pi)^{I=0}_{S\text{-wave}}$	5–10 %	–
$p\gamma$	0.035–0.048 %	414
$p\gamma$, helicity=1/2	0.035–0.048 %	414
$n\gamma$	0.009–0.032 %	413
$n\gamma$, helicity=1/2	0.009–0.032 %	413

***N*(1520) D_{13}**

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$

Breit-Wigner mass = 1515 to 1530 (≈ 1520) MeV
Breit-Wigner full width = 110 to 135 (≈ 120) MeV
$p_{\text{beam}} = 0.74$ GeV/c $4\pi\lambdabar^2 = 23.5$ mb
Re(pole position) = 1505 to 1515 (≈ 1510) MeV
−2Im(pole position) = 110 to 120 (≈ 115) MeV

***N*(1520) DECAY MODES**	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	50–60 %	456
$N\pi\pi$	40–50 %	410
$\Delta\pi$	15–25 %	228
$N\rho$	15–25 %	†
$N(\pi\pi)^{I=0}_{S\text{-wave}}$	<8 %	–
$p\gamma$	0.46–0.56 %	470
$p\gamma$, helicity=1/2	0.001–0.034 %	470
$p\gamma$, helicity=3/2	0.44–0.53 %	470
$n\gamma$	0.30–0.53 %	470
$n\gamma$, helicity=1/2	0.04–0.10 %	470
$n\gamma$, helicity=3/2	0.25–0.45 %	470

$N(1535)\ S_{11}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$

Breit-Wigner mass = 1520 to 1555 (≈ 1535) MeV
Breit-Wigner full width = 100 to 250 (≈ 150) MeV
$p_{\text{beam}} = 0.76$ GeV/c $\quad 4\pi\lambda\!\!\!^{-2} = 22.5$ mb
Re(pole position) = 1495 to 1515 (≈ 1505) MeV
−2Im(pole position) = 90 to 250 (≈ 170) MeV

$N(1535)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	35–55 %	467
$N\eta$	30–55 %	182
$N\pi\pi$	1–10 %	422
$\Delta\pi$	<1 %	242
$N\rho$	<4 %	†
$N(\pi\pi)^{I=0}_{S\text{-wave}}$	<3 %	–
$N(1440)\pi$	<7 %	†
$p\gamma$	0.15–0.35 %	481
$p\gamma$, helicity=1/2	0.15–0.35 %	481
$n\gamma$	0.004–0.29 %	480
$n\gamma$, helicity=1/2	0.004–0.29 %	480

$N(1650)\ S_{11}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$

Breit-Wigner mass = 1640 to 1680 (≈ 1650) MeV
Breit-Wigner full width = 145 to 190 (≈ 150) MeV
$p_{\text{beam}} = 0.96$ GeV/c $4\pi\lambdabar^2 = 16.4$ mb
Re(pole position) = 1640 to 1680 (≈ 1660) MeV
−2Im(pole position) = 150 to 170 (≈ 160) MeV

N(1650) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	55–90 %	547
$N\eta$	3–10 %	346
ΛK	3–11 %	161
$N\pi\pi$	10–20 %	511
$\Delta\pi$	1–7 %	344
$N\rho$	4–12 %	†
$N(\pi\pi)^{I=0}_{S\text{-wave}}$	<4 %	–
$N(1440)\pi$	<5 %	147
$p\gamma$	0.04–0.18 %	558
$p\gamma$, helicity=1/2	0.04–0.18 %	558
$n\gamma$	0.003–0.17 %	557
$n\gamma$, helicity=1/2	0.003–0.17 %	557

$N(1675)\ D_{15}$

$I(J^P) = \frac{1}{2}(\frac{5}{2}^-)$

Breit-Wigner mass = 1670 to 1685 (≈ 1675) MeV
Breit-Wigner full width = 140 to 180 (≈ 150) MeV
p_{beam} = 1.01 GeV/c $4\pi\lambda\!\!\!^{-2}$ = 15.4 mb
Re(pole position) = 1655 to 1665 (≈ 1660) MeV
−2Im(pole position) = 125 to 155 (≈ 140) MeV

$N(1675)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	40–50 %	563
ΛK	<1 %	209
$N\pi\pi$	50–60 %	529
$\Delta\pi$	50–60 %	364
$N\rho$	< 1–3 %	†
$p\gamma$	0.004–0.023 %	575
$p\gamma$, helicity=1/2	0.0–0.015 %	575
$p\gamma$, helicity=3/2	0.0–0.011 %	575
$n\gamma$	0.02–0.12 %	574
$n\gamma$, helicity=1/2	0.006–0.046 %	574
$n\gamma$, helicity=3/2	0.01–0.08 %	574

$N(1680)\ F_{15}$

$I(J^P) = \frac{1}{2}(\frac{5}{2}^+)$

Breit-Wigner mass = 1675 to 1690 (≈ 1680) MeV
Breit-Wigner full width = 120 to 140 (≈ 130) MeV
$p_{\text{beam}} = 1.01$ GeV/c $4\pi\lambda\!\!\!^{-2} = 15.2$ mb
Re(pole position) = 1665 to 1675 (≈ 1670) MeV
−2Im(pole position) = 105 to 135 (≈ 120) MeV

N(1680) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	60–70 %	567
$N\pi\pi$	30–40 %	532
$\Delta\pi$	5–15 %	369
$N\rho$	3–15 %	†
$N(\pi\pi)^{I=0}_{S\text{-wave}}$	5–20 %	–
$p\gamma$	0.21–0.32 %	578
$p\gamma$, helicity=1/2	0.001–0.011 %	578
$p\gamma$, helicity=3/2	0.20–0.32 %	578
$n\gamma$	0.021–0.046 %	577
$n\gamma$, helicity=1/2	0.004–0.029 %	577
$n\gamma$, helicity=3/2	0.01–0.024 %	577

$N(1700)\ D_{13}$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$

Breit-Wigner mass = 1650 to 1750 (≈ 1700) MeV
Breit-Wigner full width = 50 to 150 (≈ 100) MeV
$p_{\text{beam}} = 1.05$ GeV/c $4\pi\lambda\!\!\!^{-2} = 14.5$ mb
Re(pole position) = 1630 to 1730 (≈ 1680) MeV
−2Im(pole position) = 50 to 150 (≈ 100) MeV

N(1700) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	5–15 %	580
ΛK	<3 %	250
$N\pi\pi$	85–95 %	547
$N\rho$	<35 %	†
$p\gamma$	0.01–0.05 %	591
$p\gamma$, helicity=1/2	0.0–0.024 %	591
$p\gamma$, helicity=3/2	0.002–0.026 %	591
$n\gamma$	0.01–0.13 %	590
$n\gamma$, helicity=1/2	0.0–0.09 %	590
$n\gamma$, helicity=3/2	0.01–0.05 %	590

$N(1710)\ P_{11}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Breit-Wigner mass = 1680 to 1740 (≈ 1710) MeV
Breit-Wigner full width = 50 to 250 (≈ 100) MeV
$p_{\text{beam}} = 1.07$ GeV/c $4\pi\bar{\lambda}^2 = 14.2$ mb
Re(pole position) = 1670 to 1770 (≈ 1720) MeV
−2Im(pole position) = 80 to 380 (≈ 230) MeV

N(1710) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	10–20 %	587
ΛK	5–25 %	264
$N\pi\pi$	40–90 %	554
$\Delta\pi$	15–40 %	393
$N\rho$	5–25 %	48
$N(\pi\pi)^{I=0}_{S\text{-wave}}$	10–40 %	–
$p\gamma$	0.002–0.05%	598
$p\gamma$, helicity=1/2	0.002–0.05%	598
$n\gamma$	0.0–0.02%	597
$n\gamma$, helicity=1/2	0.0–0.02%	597

$N(1720)\ P_{13}$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$

Breit-Wigner mass = 1650 to 1750 (≈ 1720) MeV
Breit-Wigner full width = 100 to 200 (≈ 150) MeV
$p_{\text{beam}} = 1.09$ GeV/c $4\pi\bar{\lambda}^2 = 13.9$ mb
Re(pole position) = 1650 to 1750 (≈ 1700) MeV
−2Im(pole position) = 110 to 390 (≈ 250) MeV

N(1720) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	10–20 %	594
ΛK	1–15 %	278
$N\pi\pi$	>70 %	561
$N\rho$	70–85 %	104
$p\gamma$	0.003–0.10 %	604
$p\gamma$, helicity=1/2	0.003–0.08 %	604
$p\gamma$, helicity=3/2	0.001–0.03 %	604
$n\gamma$	0.002–0.39 %	603
$n\gamma$, helicity=1/2	0.0–0.002 %	603
$n\gamma$, helicity=3/2	0.001–0.39 %	603

$N(2190)\ G_{17}$

$I(J^P) = \frac{1}{2}(\frac{7}{2}^-)$

Breit-Wigner mass = 2100 to 2200 (≈ 2190) MeV
Breit-Wigner full width = 350 to 550 (≈ 450) MeV
p_{beam} = 2.07 GeV/c $4\pi\lambda\!\!\!^{-2}$ = 6.21 mb
Re(pole position) = 1950 to 2150 (≈ 2050) MeV
−2Im(pole position) = 350 to 550 (≈ 450) MeV

N(2190) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	10–20 %	888

$N(2220)\ H_{19}$

$I(J^P) = \frac{1}{2}(\frac{9}{2}^+)$

Breit-Wigner mass = 2180 to 2310 (≈ 2220) MeV
Breit-Wigner full width = 320 to 550 (≈ 400) MeV
p_{beam} = 2.14 GeV/c $4\pi\lambda\!\!\!^{-2}$ = 5.97 mb
Re(pole position) = 2100 to 2240 (≈ 2170) MeV
−2Im(pole position) = 370 to 570 (≈ 470) MeV

N(2220) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	10–20 %	905

$N(2250)\ G_{19}$

$I(J^P) = \frac{1}{2}(\frac{9}{2}^-)$

Breit-Wigner mass = 2170 to 2310 (≈ 2250) MeV
Breit-Wigner full width = 290 to 470 (≈ 400) MeV
p_{beam} = 2.21 GeV/c $4\pi\lambda\!\!\!^{-2}$ = 5.74 mb
Re(pole position) = 2080 to 2200 (≈ 2140) MeV
−2Im(pole position) = 280 to 680 (≈ 480) MeV

N(2250) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	5–15 %	923

$N(2600)$ $I_{1,11}$

$I(J^P) = \frac{1}{2}(\frac{11}{2}^-)$

Breit-Wigner mass = 2550 to 2750 (≈ 2600) MeV
Breit-Wigner full width = 500 to 800 (≈ 650) MeV
$p_{\text{beam}} = 3.12$ GeV/c $\quad$ $4\pi\bar{\lambda}^2 = 3.86$ mb

$N(2600)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	5–10 %	1126

Δ BARYONS
$(S = 0, I = 3/2)$

$\Delta^{++} = uuu, \quad \Delta^{+} = uud, \quad \Delta^{0} = udd, \quad \Delta^{-} = ddd$

$\Delta(1232)$ P_{33}

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$

Breit-Wigner mass (mixed charges) = 1230 to 1234 (≈ 1232) MeV
Breit-Wigner full width (mixed charges) = 115 to 125 (≈ 120) MeV
$p_{\text{beam}} = 0.30$ GeV/c $\quad 4\pi\lambda\!\!\!^{-2} = 94.8$ mb
Re(pole position) = 1209 to 1211 (≈ 1210) MeV
−2Im(pole position) = 98 to 102 (≈ 100) MeV

$\Delta(1232)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	>99 %	227
$N\gamma$	0.52–0.60 %	259
$N\gamma$, helicity=1/2	0.11–0.13 %	259
$N\gamma$, helicity=3/2	0.41–0.47 %	259

$\Delta(1600)$ P_{33}

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$

Breit-Wigner mass = 1550 to 1700 (≈ 1600) MeV
Breit-Wigner full width = 250 to 450 (≈ 350) MeV
$p_{\text{beam}} = 0.87$ GeV/c $\quad 4\pi\lambda\!\!\!^{-2} = 18.6$ mb
Re(pole position) = 1500 to 1700 (≈ 1600) MeV
−2Im(pole position) = 200 to 400 (≈ 300) MeV

$\Delta(1600)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	10–25 %	512
$N\pi\pi$	75–90 %	473
$\Delta\pi$	40–70 %	301
$N\rho$	<25 %	†
$N(1440)\pi$	10–35 %	74
$N\gamma$	0.001–0.02 %	525
$N\gamma$, helicity=1/2	0.0–0.02 %	525
$N\gamma$, helicity=3/2	0.001–0.005 %	525

$\Delta(1620)\ S_{31}$

$I(J^P) = \frac{3}{2}(\frac{1}{2}^-)$

Breit-Wigner mass = 1615 to 1675 (≈ 1620) MeV
Breit-Wigner full width = 120 to 180 (≈ 150) MeV
$p_{\text{beam}} = 0.91$ GeV/c $4\pi\lambda\!\!\!^{-2} = 17.7$ mb
Re(pole position) = 1580 to 1620 (≈ 1600) MeV
-2Im(pole position) = 100 to 130 (≈ 115) MeV

$\Delta(1620)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	20–30 %	526
$N\pi\pi$	70–80 %	488
$\Delta\pi$	30–60 %	318
$N\rho$	7–25 %	†
$N\gamma$	0.004–0.044 %	538
$N\gamma$, helicity=1/2	0.004–0.044 %	538

$\Delta(1700)\ D_{33}$

$I(J^P) = \frac{3}{2}(\frac{3}{2}^-)$

Breit-Wigner mass = 1670 to 1770 (≈ 1700) MeV
Breit-Wigner full width = 200 to 400 (≈ 300) MeV
$p_{\text{beam}} = 1.05$ GeV/c $4\pi\lambda\!\!\!^{-2} = 14.5$ mb
Re(pole position) = 1620 to 1700 (≈ 1660) MeV
-2Im(pole position) = 150 to 250 (≈ 200) MeV

$\Delta(1700)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	10–20 %	580
$N\pi\pi$	80–90 %	547
$\Delta\pi$	30–60 %	385
$N\rho$	30–55 %	†
$N\gamma$	0.12–0.26 %	591
$N\gamma$, helicity=1/2	0.08–0.16 %	591
$N\gamma$, helicity=3/2	0.025–0.12 %	591

$\Delta(1905)\ F_{35}$

$I(J^P) = \frac{3}{2}(\frac{5}{2}^+)$

Breit-Wigner mass = 1870 to 1920 (≈ 1905) MeV
Breit-Wigner full width = 280 to 440 (≈ 350) MeV
$p_{\text{beam}} = 1.45$ GeV/c $4\pi\lambda\!\!\!^{-2} = 9.62$ mb
Re(pole position) = 1800 to 1860 (≈ 1830) MeV
−2Im(pole position) = 230 to 330 (≈ 280) MeV

Δ(1905) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	5–15 %	713
$N\pi\pi$	85–95 %	687
$\Delta\pi$	<25 %	542
$N\rho$	>60 %	421
$N\gamma$	0.01–0.03 %	721
$N\gamma$, helicity=1/2	0.0–0.1 %	721
$N\gamma$, helicity=3/2	0.004–0.03 %	721

$\Delta(1910)\ P_{31}$

$I(J^P) = \frac{3}{2}(\frac{1}{2}^+)$

Breit-Wigner mass = 1870 to 1920 (≈ 1910) MeV
Breit-Wigner full width = 190 to 270 (≈ 250) MeV
$p_{\text{beam}} = 1.46$ GeV/c $4\pi\lambda\!\!\!^{-2} = 9.54$ mb
Re(pole position) = 1830 to 1880 (≈ 1855) MeV
−2Im(pole position) = 200 to 500 (≈ 350) MeV

Δ(1910) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	15–30 %	716
$N\gamma$	0.0–0.2 %	725
$N\gamma$, helicity=1/2	0.0–0.2 %	725

$\Delta(1920)\ P_{33}$

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$

Breit-Wigner mass = 1900 to 1970 (≈ 1920) MeV
Breit-Wigner full width = 150 to 300 (≈ 200) MeV
$p_{\text{beam}} = 1.48$ GeV/c $4\pi\lambda\!\!\!^{-2} = 9.37$ mb
Re(pole position) = 1850 to 1950 (≈ 1900) MeV
−2Im(pole position) = 200 to 400 (≈ 300) MeV

Δ(1920) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	5–20 %	722

$\Delta(1930)\ D_{35}$

$I(J^P) = \frac{3}{2}(\frac{5}{2}^-)$

Breit-Wigner mass = 1920 to 1970 (≈ 1930) MeV
Breit-Wigner full width = 250 to 450 (≈ 350) MeV
$p_{beam} = 1.50$ GeV/c $4\pi\lambda\!\!\!^{-2} = 9.21$ mb
Re(pole position) = 1840 to 1940 (≈ 1890) MeV
−2Im(pole position) = 200 to 300 (≈ 250) MeV

$\Delta(1930)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	10–20 %	729
$N\gamma$	0.0–0.02 %	737
$N\gamma$, helicity=1/2	0.0–0.01 %	737
$N\gamma$, helicity=3/2	0.0–0.01 %	737

$\Delta(1950)\ F_{37}$

$I(J^P) = \frac{3}{2}(\frac{7}{2}^+)$

Breit-Wigner mass = 1940 to 1960 (≈ 1950) MeV
Breit-Wigner full width = 290 to 350 (≈ 300) MeV
$p_{beam} = 1.54$ GeV/c $4\pi\lambda\!\!\!^{-2} = 8.91$ mb
Re(pole position) = 1880 to 1890 (≈ 1885) MeV
−2Im(pole position) = 210 to 270 (≈ 240) MeV

$\Delta(1950)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	35–40 %	741
$N\pi\pi$		716
$\Delta\pi$	20–30 %	574
$N\rho$	<10 %	469
$N\gamma$	0.08–0.13 %	749
$N\gamma$, helicity=1/2	0.03–0.055 %	749
$N\gamma$, helicity=3/2	0.05–0.075 %	749

$\Delta(2420)\ H_{3,11}$

$I(J^P) = \frac{3}{2}(\frac{11}{2}^+)$

Breit-Wigner mass = 2300 to 2500 (≈ 2420) MeV
Breit-Wigner full width = 300 to 500 (≈ 400) MeV
$p_{beam} = 2.64$ GeV/c $4\pi\lambda\!\!\!^{-2} = 4.68$ mb
Re(pole position) = 2260 to 2400 (≈ 2330) MeV
−2Im(pole position) = 350 to 750 (≈ 550) MeV

$\Delta(2420)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	5–15 %	1023

Λ BARYONS
$(S = -1, I = 0)$

$\Lambda^0 = uds$

Λ

$I(J^P) = 0(\frac{1}{2}^+)$

Mass $m = 1115.683 \pm 0.006$ MeV
Mean life $\tau = (2.632 \pm 0.020) \times 10^{-10}$ s (S = 1.6)
$c\tau = 7.89$ cm
Magnetic moment $\mu = -0.613 \pm 0.004\ \mu_N$
Electric dipole moment $d < 1.5 \times 10^{-16}$ e cm, CL = 95%

Decay parameters

$p\pi^-$	$\alpha_- = 0.642 \pm 0.013$
"	$\phi_- = (-6.5 \pm 3.5)^\circ$
"	$\gamma_- = 0.76$ [g]
"	$\Delta_- = (8 \pm 4)^\circ$ [g]
$n\pi^0$	$\alpha_0 = +0.65 \pm 0.05$
$pe^-\overline{\nu}_e$	$g_A/g_V = -0.718 \pm 0.015$ [e]

Λ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$p\pi^-$	(63.9 ± 0.5) %	101
$n\pi^0$	(35.8 ± 0.5) %	104
$n\gamma$	$(1.75 \pm 0.15) \times 10^{-3}$	162
$p\pi^-\gamma$	[h] $(8.4 \pm 1.4) \times 10^{-4}$	101
$pe^-\overline{\nu}_e$	$(8.32 \pm 0.14) \times 10^{-4}$	163
$p\mu^-\overline{\nu}_\mu$	$(1.57 \pm 0.35) \times 10^{-4}$	131

$\Lambda(1405)\ S_{01}$

$I(J^P) = 0(\frac{1}{2}^-)$

Mass $m = 1407 \pm 4$ MeV
Full width $\Gamma = 50.0 \pm 2.0$ MeV
Below $\overline{K}N$ threshold

$\Lambda(1405)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Sigma\pi$	100 %	152

$\Lambda(1520)$ D_{03}

$I(J^P) = 0(\frac{3}{2}^-)$

Mass $m = 1519.5 \pm 1.0$ MeV [i]
Full width $\Gamma = 15.6 \pm 1.0$ MeV [i]
$p_{\text{beam}} = 0.39$ GeV/c $\quad 4\pi\lambdabar^2 = 82.8$ mb

$\Lambda(1520)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	$45 \pm 1\%$	244
$\Sigma\pi$	$42 \pm 1\%$	267
$\Lambda\pi\pi$	$10 \pm 1\%$	252
$\Sigma\pi\pi$	$0.9 \pm 0.1\%$	152
$\Lambda\gamma$	$0.8 \pm 0.2\%$	351

$\Lambda(1600)$ P_{01}

$I(J^P) = 0(\frac{1}{2}^+)$

Mass $m = 1560$ to 1700 (≈ 1600) MeV
Full width $\Gamma = 50$ to 250 (≈ 150) MeV
$p_{\text{beam}} = 0.58$ GeV/c $\quad 4\pi\lambdabar^2 = 41.6$ mb

$\Lambda(1600)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	15–30 %	343
$\Sigma\pi$	10–60 %	336

$\Lambda(1670)$ S_{01}

$I(J^P) = 0(\frac{1}{2}^-)$

Mass $m = 1660$ to 1680 (≈ 1670) MeV
Full width $\Gamma = 25$ to 50 (≈ 35) MeV
$p_{\text{beam}} = 0.74$ GeV/c $\quad 4\pi\lambdabar^2 = 28.5$ mb

$\Lambda(1670)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	15–25 %	414
$\Sigma\pi$	20–60 %	393
$\Lambda\eta$	15–35 %	64

$\Lambda(1690)\ D_{03}$

$I(J^P) = 0(\frac{3}{2}^-)$

Mass m = 1685 to 1695 ($\approx$ 1690) MeV
Full width Γ = 50 to 70 ($\approx$ 60) MeV
p_{beam} = 0.78 GeV/c $4\pi\lambda\!\!\!^{-2}$ = 26.1 mb

Λ(1690) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	20–30 %	433
$\Sigma\pi$	20–40 %	409
$\Lambda\pi\pi$	$\sim$ 25 %	415
$\Sigma\pi\pi$	$\sim$ 20 %	350

$\Lambda(1800)\ S_{01}$

$I(J^P) = 0(\frac{1}{2}^-)$

Mass m = 1720 to 1850 ($\approx$ 1800) MeV
Full width Γ = 200 to 400 ($\approx$ 300) MeV
p_{beam} = 1.01 GeV/c $4\pi\lambda\!\!\!^{-2}$ = 17.5 mb

Λ(1800) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	25–40 %	528
$\Sigma\pi$	seen	493
$\Sigma(1385)\pi$	seen	345
$N\overline{K}^*(892)$	seen	†

$\Lambda(1810)\ P_{01}$

$I(J^P) = 0(\frac{1}{2}^+)$

Mass m = 1750 to 1850 ($\approx$ 1810) MeV
Full width Γ = 50 to 250 ($\approx$ 150) MeV
p_{beam} = 1.04 GeV/c $4\pi\lambda\!\!\!^{-2}$ = 17.0 mb

Λ(1810) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	20–50 %	537
$\Sigma\pi$	10–40 %	501
$\Sigma(1385)\pi$	seen	356
$N\overline{K}^*(892)$	30–60 %	†

$\Lambda(1820)$ F_{05}

$I(J^P) = 0(\frac{5}{2}^+)$

Mass m = 1815 to 1825 ($\approx$ 1820) MeV
Full width Γ = 70 to 90 ($\approx$ 80) MeV
p_{beam} = 1.06 GeV/c $\quad 4\pi\bar{\lambda}^2$ = 16.5 mb

$\Lambda(1820)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	55–65 %	545
$\Sigma\pi$	8–14 %	508
$\Sigma(1385)\pi$	5–10 %	362

$\Lambda(1830)$ D_{05}

$I(J^P) = 0(\frac{5}{2}^-)$

Mass m = 1810 to 1830 ($\approx$ 1830) MeV
Full width Γ = 60 to 110 ($\approx$ 95) MeV
p_{beam} = 1.08 GeV/c $\quad 4\pi\bar{\lambda}^2$ = 16.0 mb

$\Lambda(1830)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	3–10 %	553
$\Sigma\pi$	35–75 %	515
$\Sigma(1385)\pi$	$>$15 %	371

$\Lambda(1890)$ P_{03}

$I(J^P) = 0(\frac{3}{2}^+)$

Mass m = 1850 to 1910 ($\approx$ 1890) MeV
Full width Γ = 60 to 200 ($\approx$ 100) MeV
p_{beam} = 1.21 GeV/c $\quad 4\pi\bar{\lambda}^2$ = 13.6 mb

$\Lambda(1890)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	20–35 %	599
$\Sigma\pi$	3–10 %	559
$\Sigma(1385)\pi$	seen	420
$N\overline{K}^*(892)$	seen	233

$\Lambda(2100)\ G_{07}$

$I(J^P) = 0(\frac{7}{2}^-)$

Mass m = 2090 to 2110 ($\approx$ 2100) MeV
Full width Γ = 100 to 250 ($\approx$ 200) MeV
p_{beam} = 1.68 GeV/c $4\pi\lambda\!\!\!^{-2}$ = 8.68 mb

Λ(2100) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	25–35 %	751
$\Sigma\pi$	$\sim$ 5 %	704
$\Lambda\eta$	<3 %	617
ΞK	<3 %	483
$\Lambda\omega$	<8 %	443
$N\overline{K}^*(892)$	10–20 %	514

$\Lambda(2110)\ F_{05}$

$I(J^P) = 0(\frac{5}{2}^+)$

Mass m = 2090 to 2140 ($\approx$ 2110) MeV
Full width Γ = 150 to 250 ($\approx$ 200) MeV
p_{beam} = 1.70 GeV/c $4\pi\lambda\!\!\!^{-2}$ = 8.53 mb

Λ(2110) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	5–25 %	757
$\Sigma\pi$	10–40 %	711
$\Lambda\omega$	seen	455
$\Sigma(1385)\pi$	seen	589
$N\overline{K}^*(892)$	10–60 %	524

$\Lambda(2350)\ H_{09}$

$I(J^P) = 0(\frac{9}{2}^+)$

Mass m = 2340 to 2370 ($\approx$ 2350) MeV
Full width Γ = 100 to 250 ($\approx$ 150) MeV
p_{beam} = 2.29 GeV/c $4\pi\lambda\!\!\!^{-2}$ = 5.85 mb

Λ(2350) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	$\sim$ 12 %	915
$\Sigma\pi$	$\sim$ 10 %	867

Σ BARYONS
$(S = -1, I = 1)$

$\Sigma^+ = uus$, $\Sigma^0 = uds$, $\Sigma^- = dds$

Σ^+

$I(J^P) = 1(\frac{1}{2}^+)$

Mass $m = 1189.37 \pm 0.07$ MeV (S = 2.2)
Mean life $\tau = (0.799 \pm 0.004) \times 10^{-10}$ s
$c\tau = 2.396$ cm
Magnetic moment $\mu = 2.458 \pm 0.010\ \mu_N$ (S = 2.1)
$\Gamma(\Sigma^+ \to n\ell^+\nu)/\Gamma(\Sigma^- \to n\ell^-\overline{\nu}) < 0.043$

Decay parameters

$p\pi^0$	$\alpha_0 = -0.980^{+0.017}_{-0.015}$
"	$\phi_0 = (36 \pm 34)^\circ$
"	$\gamma_0 = 0.16$ [g]
"	$\Delta_0 = (187 \pm 6)^\circ$ [g]
$n\pi^+$	$\alpha_+ = 0.068 \pm 0.013$
"	$\phi_+ = (167 \pm 20)^\circ$ (S = 1.1)
"	$\gamma_+ = -0.97$ [g]
"	$\Delta_+ = (-73^{+133}_{-\ 10})^\circ$ [g]
$p\gamma$	$\alpha_\gamma = -0.76 \pm 0.08$

Σ^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$p\pi^0$		(51.57 ± 0.30) %		189
$n\pi^+$		(48.31 ± 0.30) %		185
$p\gamma$		$(1.23\pm0.05) \times 10^{-3}$		225
$n\pi^+\gamma$	[h]	$(4.5\ \pm0.5\ ) \times 10^{-4}$		185
$\Lambda e^+\nu_e$		$(2.0\ \pm0.5\ ) \times 10^{-5}$		71
$\Delta S = \Delta Q$ (SQ) violating modes or $\Delta S = 1$ weak neutral current ($S1$) modes				
$ne^+\nu_e$	SQ	$< 5 \times 10^{-6}$	90%	224
$n\mu^+\nu_\mu$	SQ	$< 3.0 \times 10^{-5}$	90%	202
pe^+e^-	$S1$	$< 7 \times 10^{-6}$		225

Σ^0

$I(J^P) = 1(\frac{1}{2}^+)$

Mass $m = 1192.642 \pm 0.024$ MeV
$m_{\Sigma^-} - m_{\Sigma^0} = 4.807 \pm 0.035$ MeV (S = 1.1)
$m_{\Sigma^0} - m_{\Lambda} = 76.959 \pm 0.023$ MeV
Mean life $\tau = (7.4 \pm 0.7) \times 10^{-20}$ s
$c\tau = 2.22 \times 10^{-11}$ m
Transition magnetic moment $\left|\mu_{\Sigma\Lambda}\right| = 1.61 \pm 0.08\ \mu_N$

Σ^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda\gamma$		100 %		74
$\Lambda\gamma\gamma$		< 3 %	90%	74
$\Lambda e^+ e^-$	[j]	5×10^{-3}		74

Σ^-

$I(J^P) = 1(\frac{1}{2}^+)$

Mass $m = 1197.449 \pm 0.030$ MeV (S = 1.2)
$m_{\Sigma^-} - m_{\Sigma^+} = 8.08 \pm 0.08$ MeV (S = 1.9)
$m_{\Sigma^-} - m_{\Lambda} = 81.766 \pm 0.030$ MeV (S = 1.2)
Mean life $\tau = (1.479 \pm 0.011) \times 10^{-10}$ s (S = 1.3)
$c\tau = 4.434$ cm
Magnetic moment $\mu = -1.160 \pm 0.025\ \mu_N$ (S = 1.7)

Decay parameters

$n\pi^-$	$\alpha_- = -0.068 \pm 0.008$
"	$\phi_- = (10 \pm 15)^\circ$
"	$\gamma_- = 0.98$ [g]
"	$\Delta_- = (249^{+\ 12}_{-120})^\circ$ [g]
$n e^- \overline{\nu}_e$	$g_A/g_V = 0.340 \pm 0.017$ [e]
"	$f_2(0)/f_1(0) = 0.97 \pm 0.14$
"	$D = 0.11 \pm 0.10$
$\Lambda e^- \overline{\nu}_e$	$g_V/g_A = 0.01 \pm 0.10$ [e] (S = 1.5)
"	$g_{WM}/g_A = 2.4 \pm 1.7$ [e]

Σ^- DECAY MODES		Fraction (Γ_i/Γ)	p (MeV/c)
$n\pi^-$		(99.848 ± 0.005) %	193
$n\pi^-\gamma$	[h]	$(4.6 \pm 0.6) \times 10^{-4}$	193
$n e^- \overline{\nu}_e$		$(1.017 \pm 0.034) \times 10^{-3}$	230
$n \mu^- \overline{\nu}_\mu$		$(4.5 \pm 0.4) \times 10^{-4}$	210
$\Lambda e^- \overline{\nu}_e$		$(5.73 \pm 0.27) \times 10^{-5}$	79

$\Sigma(1385)\ P_{13}$

$I(J^P) = 1(\frac{3}{2}^+)$

$\Sigma(1385)^+$ mass $m = 1382.8 \pm 0.4$ MeV (S = 2.0)
$\Sigma(1385)^0$ mass $m = 1383.7 \pm 1.0$ MeV (S = 1.4)
$\Sigma(1385)^-$ mass $m = 1387.2 \pm 0.5$ MeV (S = 2.2)
$\Sigma(1385)^+$ full width $\Gamma = 35.8 \pm 0.8$ MeV
$\Sigma(1385)^0$ full width $\Gamma = 36 \pm 5$ MeV
$\Sigma(1385)^-$ full width $\Gamma = 39.4 \pm 2.1$ MeV (S = 1.7)
Below $\overline{K}N$ threshold

$\Sigma(1385)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda\pi$	88±2 %	208
$\Sigma\pi$	12±2 %	127

$\Sigma(1660)\ P_{11}$

$I(J^P) = 1(\frac{1}{2}^+)$

Mass $m = 1630$ to 1690 (≈ 1660) MeV
Full width $\Gamma = 40$ to 200 (≈ 100) MeV
$p_{\text{beam}} = 0.72$ GeV/c $4\pi\lambda\!\!\!^{-2} = 29.9$ mb

$\Sigma(1660)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	10–30 %	405
$\Lambda\pi$	seen	439
$\Sigma\pi$	seen	385

$\Sigma(1670)\ D_{13}$

$I(J^P) = 1(\frac{3}{2}^-)$

Mass $m = 1665$ to 1685 (≈ 1670) MeV
Full width $\Gamma = 40$ to 80 (≈ 60) MeV
$p_{\text{beam}} = 0.74$ GeV/c $4\pi\lambda\!\!\!^{-2} = 28.5$ mb

$\Sigma(1670)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	7–13 %	414
$\Lambda\pi$	5–15 %	447
$\Sigma\pi$	30–60 %	393

$\Sigma(1750)\ S_{11}$

$I(J^P) = 1(\frac{1}{2}^-)$

Mass m = 1730 to 1800 (≈ 1750) MeV
Full width Γ = 60 to 160 (≈ 90) MeV
p_{beam} = 0.91 GeV/c $4\pi\bar{\lambda}^2$ = 20.7 mb

Σ(1750) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	10–40 %	486
$\Lambda\pi$	seen	507
$\Sigma\pi$	<8 %	455
$\Sigma\eta$	15–55 %	81

$\Sigma(1775)\ D_{15}$

$I(J^P) = 1(\frac{5}{2}^-)$

Mass m = 1770 to 1780 (≈ 1775) MeV
Full width Γ = 105 to 135 (≈ 120) MeV
p_{beam} = 0.96 GeV/c $4\pi\bar{\lambda}^2$ = 19.0 mb

Σ(1775) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	37–43%	508
$\Lambda\pi$	14–20%	525
$\Sigma\pi$	2–5%	474
$\Sigma(1385)\pi$	8–12%	324
$\Lambda(1520)\pi$	17–23%	198

$\Sigma(1915)\ F_{15}$

$I(J^P) = 1(\frac{5}{2}^+)$

Mass m = 1900 to 1935 (≈ 1915) MeV
Full width Γ = 80 to 160 (≈ 120) MeV
p_{beam} = 1.26 GeV/c $4\pi\bar{\lambda}^2$ = 12.8 mb

Σ(1915) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	5–15 %	618
$\Lambda\pi$	seen	622
$\Sigma\pi$	seen	577
$\Sigma(1385)\pi$	<5 %	440

$\Sigma(1940)\ D_{13}$

$I(J^P) = 1(\frac{3}{2}^-)$

Mass m = 1900 to 1950 ($\approx$ 1940) MeV
Full width Γ = 150 to 300 ($\approx$ 220) MeV
$p_{\text{beam}} = 1.32$ GeV/c $\quad 4\pi\bar{\lambda}^2 = 12.1$ mb

Σ(1940) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	<20 %	637
$\Lambda\pi$	seen	639
$\Sigma\pi$	seen	594
$\Sigma(1385)\pi$	seen	460
$\Lambda(1520)\pi$	seen	354
$\Delta(1232)\overline{K}$	seen	410
$N\overline{K}^*(892)$	seen	320

$\Sigma(2030)\ F_{17}$

$I(J^P) = 1(\frac{7}{2}^+)$

Mass m = 2025 to 2040 ($\approx$ 2030) MeV
Full width Γ = 150 to 200 ($\approx$ 180) MeV
$p_{\text{beam}} = 1.52$ GeV/c $\quad 4\pi\bar{\lambda}^2 = 9.93$ mb

Σ(2030) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	17–23 %	702
$\Lambda\pi$	17–23 %	700
$\Sigma\pi$	5–10 %	657
ΞK	<2 %	412
$\Sigma(1385)\pi$	5–15 %	529
$\Lambda(1520)\pi$	10–20 %	430
$\Delta(1232)\overline{K}$	10–20 %	498
$N\overline{K}^*(892)$	<5 %	438

$\Sigma(2250)$

$I(J^P) = 1(?^?)$

Mass $m = 2210$ to 2280 (≈ 2250) MeV
Full width $\Gamma = 60$ to 150 (≈ 100) MeV
$p_{\text{beam}} = 2.04$ GeV/c $\qquad 4\pi\lambda\!\!\!^{-2} = 6.76$ mb

$\Sigma(2250)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	<10 %	851
$\Lambda\pi$	seen	842
$\Sigma\pi$	seen	803

Ξ BARYONS
$(S=-2, I=1/2)$

$\Xi^0 = uss$, $\Xi^- = dss$

Ξ^0

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

P is not yet measured; + is the quark model prediction.

Mass $m = 1314.9 \pm 0.6$ MeV
$m_{\Xi^-} - m_{\Xi^0} = 6.4 \pm 0.6$ MeV
Mean life $\tau = (2.90 \pm 0.09) \times 10^{-10}$ s
$c\tau = 8.71$ cm
Magnetic moment $\mu = -1.250 \pm 0.014\ \mu_N$

Decay parameters

$\Lambda\pi^0$	$\alpha = -0.411 \pm 0.022$ (S = 2.1)
"	$\phi = (21 \pm 12)^\circ$
"	$\gamma = 0.85$ [g]
"	$\Delta = (218^{+12}_{-19})^\circ$ [g]
$\Lambda\gamma$	$\alpha = 0.4 \pm 0.4$
$\Sigma^0\gamma$	$\alpha = 0.20 \pm 0.32$

Ξ^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda\pi^0$		(99.54 ± 0.05) %		135
$\Lambda\gamma$		$(1.06\pm0.16) \times 10^{-3}$		184
$\Sigma^0\gamma$		$(3.5\pm0.4) \times 10^{-3}$		117
$\Sigma^+ e^- \overline{\nu}_e$		$< 1.1 \times 10^{-3}$	90%	120
$\Sigma^+ \mu^- \overline{\nu}_\mu$		$< 1.1 \times 10^{-3}$	90%	64
$\Delta S = \Delta Q$ (SQ) violating modes or $\Delta S = 2$ forbidden ($S2$) modes				
$\Sigma^- e^+ \nu_e$	SQ	$< 9 \times 10^{-4}$	90%	112
$\Sigma^- \mu^+ \nu_\mu$	SQ	$< 9 \times 10^{-4}$	90%	49
$p\pi^-$	$S2$	$< 4 \times 10^{-5}$	90%	299
$p e^- \overline{\nu}_e$	$S2$	$< 1.3 \times 10^{-3}$		323
$p \mu^- \overline{\nu}_\mu$	$S2$	$< 1.3 \times 10^{-3}$		309

Ξ^-

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

P is not yet measured; + is the quark model prediction.

Mass $m = 1321.32 \pm 0.13$ MeV
Mean life $\tau = (1.639 \pm 0.015) \times 10^{-10}$ s
$c\tau = 4.91$ cm
Magnetic moment $\mu = -0.6507 \pm 0.0025\ \mu_N$

Decay parameters

$\Lambda\pi^-$	$\alpha = -0.456 \pm 0.014$ (S = 1.8)
"	$\phi = (4 \pm 4)^\circ$
"	$\gamma = 0.89$ [g]
"	$\Delta = (188 \pm 8)^\circ$ [g]
$\Lambda e^- \overline{\nu}_e$	$g_A/g_V = -0.25 \pm 0.05$ [e]

Ξ^- DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda\pi^-$		(99.887 ± 0.035) %		139
$\Sigma^-\gamma$		$(1.27 \pm 0.23) \times 10^{-4}$		118
$\Lambda e^- \overline{\nu}_e$		$(5.63 \pm 0.31) \times 10^{-4}$		190
$\Lambda \mu^- \overline{\nu}_\mu$		$(3.5^{+3.5}_{-2.2}) \times 10^{-4}$		163
$\Sigma^0 e^- \overline{\nu}_e$		$(8.7 \pm 1.7) \times 10^{-5}$		122
$\Sigma^0 \mu^- \overline{\nu}_\mu$		$< 8 \times 10^{-4}$	90%	70
$\Xi^0 e^- \overline{\nu}_e$		$< 2.3 \times 10^{-3}$	90%	6
$\Delta S = 2$ forbidden ($S2$) modes				
$n\pi^-$	$S2$	$< 1.9 \times 10^{-5}$	90%	303
$n e^- \overline{\nu}_e$	$S2$	$< 3.2 \times 10^{-3}$	90%	327
$n \mu^- \overline{\nu}_\mu$	$S2$	< 1.5 %	90%	314
$p\pi^-\pi^-$	$S2$	$< 4 \times 10^{-4}$	90%	223
$p\pi^- e^- \overline{\nu}_e$	$S2$	$< 4 \times 10^{-4}$	90%	304
$p\pi^- \mu^- \overline{\nu}_\mu$	$S2$	$< 4 \times 10^{-4}$	90%	250
$p\mu^-\mu^-$	L	$< 4 \times 10^{-4}$	90%	272

$\Xi(1530)\ P_{13}$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$

$\Xi(1530)^0$ mass $m = 1531.80 \pm 0.32$ MeV (S = 1.3)
$\Xi(1530)^-$ mass $m = 1535.0 \pm 0.6$ MeV
$\Xi(1530)^0$ full width $\Gamma = 9.1 \pm 0.5$ MeV
$\Xi(1530)^-$ full width $\Gamma = 9.9^{+1.7}_{-1.9}$ MeV

Ξ(1530) DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Xi\pi$	100 %		152
$\Xi\gamma$	<4 %	90%	200

$\Xi(1690)$

$I(J^P) = \frac{1}{2}(?^?)$

Mass $m = 1690 \pm 10$ MeV [i]
Full width $\Gamma < 50$ MeV

Ξ(1690) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda\overline{K}$	seen	240
$\Sigma\overline{K}$	seen	51
$\Xi^-\pi^+\pi^-$	possibly seen	214

$\Xi(1820)\ D_{13}$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$

Mass $m = 1823 \pm 5$ MeV [i]
Full width $\Gamma = 24^{+15}_{-10}$ MeV [i]

Ξ(1820) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda\overline{K}$	large	400
$\Sigma\overline{K}$	small	320
$\Xi\pi$	small	413
$\Xi(1530)\pi$	small	234

$\Xi(1950)$

$I(J^P) = \frac{1}{2}(?^?)$

Mass $m = 1950 \pm 15$ MeV [i]
Full width $\Gamma = 60 \pm 20$ MeV [i]

$\Xi(1950)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda \overline{K}$	seen	522
$\Sigma \overline{K}$	possibly seen	460
$\Xi \pi$	seen	518

$\Xi(2030)$

$I(J^P) = \frac{1}{2}(\geq \frac{5}{2}^?)$

Mass $m = 2025 \pm 5$ MeV [i]
Full width $\Gamma = 20^{+15}_{-\ 5}$ MeV [i]

$\Xi(2030)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda \overline{K}$	~ 20 %	589
$\Sigma \overline{K}$	~ 80 %	533
$\Xi \pi$	small	573
$\Xi(1530)\pi$	small	421
$\Lambda \overline{K} \pi$	small	501
$\Sigma \overline{K} \pi$	small	430

Ω BARYONS ($S=-3$, $I=0$)

$\Omega^- = sss$

Ω^-

$I(J^P) = 0(\frac{3}{2}^+)$

J^P is not yet measured; $\frac{3}{2}^+$ is the quark model prediction.

Mass $m = 1672.45 \pm 0.29$ MeV
Mean life $\tau = (0.822 \pm 0.012) \times 10^{-10}$ s
$c\tau = 2.46$ cm
Magnetic moment $\mu = -2.02 \pm 0.05\ \mu_N$

Decay parameters

ΛK^-	$\alpha = -0.026 \pm 0.026$
$\Xi^0 \pi^-$	$\alpha = 0.09 \pm 0.14$
$\Xi^- \pi^0$	$\alpha = 0.05 \pm 0.21$

Ω^- DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
ΛK^-		(67.8 ± 0.7) %		211
$\Xi^0 \pi^-$		(23.6 ± 0.7) %		294
$\Xi^- \pi^0$		(8.6 ± 0.4) %		290
$\Xi^- \pi^+ \pi^-$		$(4.3^{+3.4}_{-1.3}) \times 10^{-4}$		190
$\Xi(1530)^0 \pi^-$		$(6.4^{+5.1}_{-2.0}) \times 10^{-4}$		17
$\Xi^0 e^- \overline{\nu}_e$		$(5.6\pm2.8) \times 10^{-3}$		319
$\Xi^- \gamma$		$< 4.6 \times 10^{-4}$	90%	314
$\Delta S = 2$ forbidden ($S2$) modes				
$\Lambda \pi^-$	$S2$	$< 1.9 \times 10^{-4}$	90%	449

$\Omega(2250)^-$

$I(J^P) = 0(?^?)$

Mass $m = 2252 \pm 9$ MeV
Full width $\Gamma = 55 \pm 18$ MeV

$\Omega(2250)^-$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Xi^- \pi^+ K^-$	seen	531
$\Xi(1530)^0 K^-$	seen	437

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CHARMED BARYONS
($C=+1$)

$\Lambda_c^+ = u\,d\,c$, $\Sigma_c^{++} = u\,u\,c$, $\Sigma_c^+ = u\,d\,c$, $\Sigma_c^0 = d\,d\,c$,
$\Xi_c^+ = u\,s\,c$, $\Xi_c^0 = d\,s\,c$, $\Omega_c^0 = s\,s\,c$

Λ_c^+

$I(J^P) = 0(\frac{1}{2}^+)$

J not confirmed; $\frac{1}{2}$ is the quark model prediction.

Mass $m = 2284.9 \pm 0.6$ MeV
Mean life $\tau = (0.206 \pm 0.012) \times 10^{-12}$ s
$c\tau = 61.8\ \mu$m

Decay asymmetry parameters

$\Lambda\pi^+$ $\alpha = -0.98 \pm 0.19$
$\Sigma^+\pi^0$ $\alpha = -0.45 \pm 0.32$
$\Lambda\ell^+\nu_\ell$ $\alpha = -0.82^{+0.11}_{-0.07}$

Nearly all branching fractions of the Λ_c^+ are measured relative to the $pK^-\pi^+$ mode, but there are no model-independent measurements of this branching fraction. We explain how we arrive at our value of B($\Lambda_c^+ \to pK^-\pi^+$) in a Note at the beginning of the branching-ratio measurements, in the Listings. When this branching fraction is eventually well determined, all the other branching fractions will slide up or down proportionally as the true value differs from the value we use here.

Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p and one $\overline{K}$				
$p\overline{K}^0$		(2.5 ± 0.7) %		872
$pK^-\pi^+$	[k]	(5.0 ± 1.3) %		822
$p\overline{K}^*(892)^0$	[l]	(1.8 ± 0.6) %		681
$\Delta(1232)^{++}K^-$		$(8 \pm 5) \times 10^{-3}$		709
$\Lambda(1520)\pi^+$	[l]	$(4.5\ ^{+2.5}_{-2.1}) \times 10^{-3}$		626
$pK^-\pi^+$ nonresonant		(2.8 ± 0.9) %		822
$p\overline{K}^0\eta$		(1.3 ± 0.4) %		567

$p\overline{K}^0\pi^+\pi^-$		(2.4 ± 1.1) %		753
$pK^-\pi^+\pi^0$		seen		758
$pK^*(892)^-\pi^+$	[l]	(1.1 ± 0.6) %		579
$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(3.6 ± 1.2) %		758
$\Delta(1232)\overline{K}^*(892)$		seen		416
$pK^-\pi^+\pi^+\pi^-$		$(1.1 \pm 0.8) \times 10^{-3}$		670
$pK^-\pi^+\pi^0\pi^0$		$(8 \pm 4) \times 10^{-3}$		676
$pK^-\pi^+\pi^0\pi^0\pi^0$		$(5.0 \pm 3.4) \times 10^{-3}$		573

Hadronic modes with a *p* and zero or two *K*'s

$p\pi^+\pi^-$		$(3.5 \pm 2.0) \times 10^{-3}$		926
$pf_0(980)$	[l]	$(2.8 \pm 1.9) \times 10^{-3}$		621
$p\pi^+\pi^+\pi^-\pi^-$		$(1.8 \pm 1.2) \times 10^{-3}$		851
pK^+K^-		$(2.3 \pm 0.9) \times 10^{-3}$		615
$p\phi$	[l]	$(1.2 \pm 0.5) \times 10^{-3}$		589

Hadronic modes with a hyperon

$\Lambda\pi^+$		$(9.0 \pm 2.8) \times 10^{-3}$		863
$\Lambda\pi^+\pi^0$		(3.6 ± 1.3) %		843
$\Lambda\rho^+$		< 5 %	CL=95%	638
$\Lambda\pi^+\pi^+\pi^-$		(3.3 ± 1.0) %		806
$\Lambda\pi^+\eta$		(1.7 ± 0.6) %		690
$\Sigma(1385)^+\eta$	[l]	$(8.5 \pm 3.3) \times 10^{-3}$		569
$\Lambda K^+\overline{K}^0$		$(6.0 \pm 2.1) \times 10^{-3}$		441
$\Sigma^0\pi^+$		$(9.9 \pm 3.2) \times 10^{-3}$		824
$\Sigma^+\pi^0$		(1.00 ± 0.34) %		826
$\Sigma^+\eta$		$(5.5 \pm 2.3) \times 10^{-3}$		712
$\Sigma^+\pi^+\pi^-$		(3.4 ± 1.0) %		803
$\Sigma^+\rho^0$		< 1.4 %	CL=95%	578
$\Sigma^-\pi^+\pi^+$		(1.8 ± 0.8) %		798
$\Sigma^0\pi^+\pi^0$		(1.8 ± 0.8) %		802
$\Sigma^0\pi^+\pi^+\pi^-$		(1.1 ± 0.4) %		762
$\Sigma^+\pi^+\pi^-\pi^0$		—		766
$\Sigma^+\omega$	[l]	(2.7 ± 1.0) %		568
$\Sigma^+\pi^+\pi^+\pi^-\pi^-$		$(3.0\ ^{+4.1}_{-2.1}) \times 10^{-3}$		707
$\Sigma^+K^+K^-$		$(3.5 \pm 1.2) \times 10^{-3}$		346
$\Sigma^+\phi$	[l]	$(3.5 \pm 1.7) \times 10^{-3}$		292
$\Sigma^+K^+\pi^-$		$(7\ ^{+6}_{-4}) \times 10^{-3}$		668
Ξ^0K^+		$(3.9 \pm 1.4) \times 10^{-3}$		652
$\Xi^-K^+\pi^+$		$(4.9 \pm 1.7) \times 10^{-3}$		564
$\Xi(1530)^0K^+$	[l]	$(2.6 \pm 1.0) \times 10^{-3}$		471

Semileptonic modes					
$\Lambda \ell^+ \nu_\ell$	[m]	(2.0 ± 0.6) %			–
$\Lambda e^+ \nu_e$		(2.1 ± 0.6) %			–
$\Lambda \mu^+ \nu_\mu$		(2.0 ± 0.7) %			–
e^+ anything		(4.5 ± 1.7) %			–
$p e^+$ anything		(1.8 ± 0.9) %			–
Λe^+ anything		—			–
$\Lambda \mu^+$ anything		—			–
$\Lambda \ell^+ \nu_\ell$ anything		—			–
Inclusive modes					
p anything		(50 ±16) %			–
p anything (no Λ)		(12 ±19) %			–
p hadrons		—			–
n anything		(50 ±16) %			–
n anything (no Λ)		(29 ±17) %			–
Λ anything		(35 ±11) %		S=1.4	–
$\Sigma^\pm$ anything	[n]	(10 ± 5) %			–
$\Delta C = 1$ weak neutral current (*C1*) modes, or Lepton number (*L*) violating modes					
$p \mu^+ \mu^-$	*C1*	< 3.4	$\times 10^{-4}$	CL=90%	936
$\Sigma^- \mu^+ \mu^+$	*L*	< 7.0	$\times 10^{-4}$	CL=90%	811

$\Lambda_c(2593)^+$

$I(J^P) = 0(\frac{1}{2}^-)$

The spin-parity follows from the fact that $\Sigma_c(2455)\pi$ decays, with little available phase space, are dominant.

Mass $m = 2593.9 \pm 0.8$ MeV
$m - m_{\Lambda_c^+} = 308.9 \pm 0.6$ MeV (S = 1.1)
Full width $\Gamma = 3.6^{+2.0}_{-1.3}$ MeV

$\Lambda_c^+ \pi\pi$ and its submode $\Sigma_c(2455)\pi$ — the latter just barely — are the only strong decays allowed to an excited Λ_c^+ having this mass; and the $\Lambda_c^+ \pi^+ \pi^-$ mode seems to be largely via $\Sigma_c^{++}\pi^-$ or $\Sigma_c^0 \pi^+$.

$\Lambda_c(2593)^+$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_c^+ \pi^+ \pi^-$	[o] ≈ 67 %	124
$\Sigma_c(2455)^{++}\pi^-$	24 ± 7 %	17
$\Sigma_c(2455)^0\pi^+$	24 ± 7 %	23
$\Lambda_c^+ \pi^+ \pi^-$ 3-body	18 ± 10 %	124
$\Lambda_c^+ \pi^0$	not seen	261
$\Lambda_c^+ \gamma$	not seen	290

$\Lambda_c(2625)^+$

$I(J^P) = 0(?^?)$

J^P is expected to be $3/2^-$.

Mass $m = 2626.6 \pm 0.8$ MeV (S = 1.2)
$m - m_{\Lambda_c^+} = 341.7 \pm 0.6$ MeV (S = 1.6)
Full width $\Gamma < 1.9$ MeV, CL = 90%

$\Lambda_c^+ \pi\pi$ and its submode $\Sigma(2455)\pi$ are the only strong decays allowed to an excited Λ_c^+ having this mass.

$\Lambda_c(2625)^+$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_c^+ \pi^+ \pi^-$	seen	184
$\Sigma_c(2455)^{++}\pi^-$	small	100
$\Sigma_c(2455)^0\pi^+$	small	101
$\Lambda_c^+ \pi^+ \pi^-$ 3-body	large	184
$\Lambda_c^+ \pi^0$	not seen	293
$\Lambda_c^+ \gamma$	not seen	319

$\Sigma_c(2455)$

$I(J^P) = 1(\frac{1}{2}^+)$

J^P not confirmed; $\frac{1}{2}^+$ is the quark model prediction.

$\Sigma_c(2455)^{++}$ mass $m = 2452.8 \pm 0.6$ MeV
$\Sigma_c(2455)^{+}$ mass $m = 2453.6 \pm 0.9$ MeV
$\Sigma_c(2455)^{0}$ mass $m = 2452.2 \pm 0.6$ MeV
$m_{\Sigma_c^{++}} - m_{\Lambda_c^+} = 167.87 \pm 0.19$ MeV
$m_{\Sigma_c^{+}} - m_{\Lambda_c^+} = 168.7 \pm 0.6$ MeV
$m_{\Sigma_c^{0}} - m_{\Lambda_c^+} = 167.30 \pm 0.20$ MeV
$m_{\Sigma_c^{++}} - m_{\Sigma_c^0} = 0.57 \pm 0.23$ MeV
$m_{\Sigma_c^{+}} - m_{\Sigma_c^0} = 1.4 \pm 0.6$ MeV

$\Lambda_c^+ \pi$ is the only strong decay allowed to a Σ_c having this mass.

Σ_c(2455) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_c^+ \pi$	≈ 100 %	90

$\Sigma_c(2520)$

$I(J^P) = 1(?^?)$

$\Sigma_c(2520)^{++}$ mass $m = 2519.4 \pm 1.5$ MeV
$\Sigma_c(2520)^{0}$ mass $m = 2517.5 \pm 1.4$ MeV
$m_{\Sigma_c(2520)^{++}} - m_{\Lambda_c^+} = 234.5 \pm 1.4$ MeV
$m_{\Sigma_c(2520)^{0}} - m_{\Lambda_c^+} = 232.6 \pm 1.3$ MeV
$m_{\Sigma_c(2520)^{++}} - m_{\Sigma_c(2520)^0} = 1.9 \pm 1.9$ MeV
$\Sigma_c(2520)^{++}$ full width $\Gamma = 18 \pm 5$ MeV
$\Sigma_c(2520)^{0}$ full width $\Gamma = 13 \pm 5$ MeV

Ξ_c^+

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

$I(J^P)$ not confirmed; $\frac{1}{2}(\frac{1}{2}^+)$ is the quark model prediction.

Mass $m = 2465.6 \pm 1.4$ MeV
Mean life $\tau = (0.35^{+0.07}_{-0.04}) \times 10^{-12}$ s
$c\tau = 106$ μm

Ξ_c^+ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda K^- \pi^+ \pi^+$	seen	784
$\Lambda \overline{K}^*(892)^0 \pi^+$	not seen	601
$\Sigma(1385)^+ K^- \pi^+$	not seen	676
$\Sigma^+ K^- \pi^+$	seen	808
$\Sigma^+ \overline{K}^*(892)^0$	seen	653
$\Sigma^0 K^- \pi^+ \pi^+$	seen	733
$\Xi^0 \pi^+$	seen	875
$\Xi^- \pi^+ \pi^+$	seen	850
$\Xi(1530)^0 \pi^+$	not seen	748
$\Xi^0 \pi^+ \pi^0$	seen	854
$\Xi^0 \pi^+ \pi^+ \pi^-$	seen	817
$\Xi^0 e^+ \nu_e$	seen	882

Ξ_c^0

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

$I(J^P)$ not confirmed; $\frac{1}{2}(\frac{1}{2}^+)$ is the quark model prediction.

Mass $m = 2470.3 \pm 1.8$ MeV (S = 1.3)
$m_{\Xi_c^0} - m_{\Xi_c^+} = 4.7 \pm 2.1$ MeV (S = 1.2)
Mean life $\tau = (0.098^{+0.023}_{-0.015}) \times 10^{-12}$ s
$c\tau = 29$ μm

Ξ_c^0 DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda \overline{K}^0$	seen	864
$\Xi^- \pi^+$	seen	875
$\Xi^- \pi^+ \pi^+ \pi^-$	seen	816
$p K^- \overline{K}^*(892)^0$	seen	406
$\Omega^- K^+$	seen	522
$\Xi^- e^+ \nu_e$	seen	882
$\Xi^- \ell^+$ anything	seen	–

$\Xi_c(2645)$

$I(J^P) = ?(?^?)$

$\Xi_c(2645)^+$ mass $m = 2644.6 \pm 2.1$ MeV (S = 1.2)
$\Xi_c(2645)^0$ mass $m = 2643.8 \pm 1.8$ MeV
$m_{\Xi_c(2645)^+} - m_{\Xi_c^0} = 174.3 \pm 1.1$ MeV
$m_{\Xi_c(2645)^0} - m_{\Xi_c^+} = 178.2 \pm 1.1$ MeV
$\Xi_c(2645)^+$ full width $\Gamma < 3.1$ MeV, CL = 90%
$\Xi_c(2645)^0$ full width $\Gamma < 5.5$ MeV, CL = 90%

$\Xi_c \pi$ is the only strong decay allowed to a Ξ_c resonance having this mass.

$\Xi_c(2645)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Xi_c^0 \pi^+$	seen	101
$\Xi_c^+ \pi^-$	seen	107

Ω_c^0

$I(J^P) = 0(\frac{1}{2}^+)$

$I(J^P)$ not confirmed; $0(\frac{1}{2}^+)$ is the quark model prediction.

Mass $m = 2704 \pm 4$ MeV (S = 1.8)
Mean life $\tau = (0.064 \pm 0.020) \times 10^{-12}$ s
$c\tau = 19\ \mu$m

Ω_c^0 DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Sigma^+ K^- K^- \pi^+$	seen	697
$\Xi^- K^- \pi^+ \pi^+$	seen	838
$\Omega^- \pi^+$	seen	827
$\Omega^- \pi^- \pi^+ \pi^+$	seen	759

BOTTOM BARYONS
$(B = -1)$

$\Lambda_b^0 = udb$, $\Xi_b^0 = usb$, $\Xi_b^- = dsb$

Λ_b^0

$I(J^P) = 0(\frac{1}{2}^+)$

$I(J^P)$ not yet measured; $0(\frac{1}{2}^+)$ is the quark model prediction.

Mass $m = 5624 \pm 9$ MeV (S = 1.8)

Mean life $\tau = (1.24 \pm 0.08) \times 10^{-12}$ s

$c\tau = 372$ μm

These branching fractions are actually an average over weakly decaying b-baryons weighted by their production rates in Z decay (or high-energy $p\overline{p}$), branching ratios, and detection efficiencies. They scale with the LEP Λ_b production fraction B($b \rightarrow \Lambda_b$) and are evaluated for our value B($b \rightarrow \Lambda_b$) = $(10.1^{+3.9}_{-3.1})$%.

The branching fractions B(b-baryon $\rightarrow \Lambda \ell^- \overline{\nu}_\ell$ anything) and B($\Lambda_b^0 \rightarrow \Lambda_c^+ \ell^- \overline{\nu}_\ell$ anything) are not pure measurements because the underlying measured products of these with B($b \rightarrow \Lambda_b$) were used to determine B($b \rightarrow \Lambda_b$), as described in the note "Production and Decay of b-Flavored Hadrons."

Λ_b^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$J/\psi(1S)\Lambda$		$(4.7\pm2.8) \times 10^{-4}$		1744
$\Lambda_c^+ \pi^-$		seen		2345
$\Lambda_c^+ a_1(1260)^-$		seen		2156
$\Lambda_c^+ \ell^- \overline{\nu}_\ell$ anything	[p]	$(9.0^{+3.1}_{-3.8})$ %		–
$p\pi^-$		$< 5.0 \times 10^{-5}$	90%	2732
pK^-		$< 5.0 \times 10^{-5}$	90%	2711

b-baryon ADMIXTURE (Λ_b, Ξ_b, Σ_b, Ω_b)

Mean life $\tau = (1.20 \pm 0.07) \times 10^{-12}$ s

These branching fractions are actually an average over weakly decaying *b*-baryons weighted by their production rates in Z decay (or high-energy $p\overline{p}$), branching ratios, and detection efficiencies. They scale with the LEP Λ_b production fraction B($b \to \Lambda_b$) and are evaluated for our value B($b \to \Lambda_b$) = $(10.1^{+3.9}_{-3.1})$%.

The branching fractions B(*b*-baryon $\to \Lambda \ell^- \overline{\nu}_\ell$ anything) and B($\Lambda_b^0 \to \Lambda_c^+ \ell^- \overline{\nu}_\ell$ anything) are not pure measurements because the underlying measured products of these with B($b \to \Lambda_b$) were used to determine B($b \to \Lambda_b$), as described in the note "Production and Decay of *b*-Flavored Hadrons."

b-baryon ADMIXTURE (Λ_b,Ξ_b,Σ_b,Ω_b)	Fraction (Γ_i/Γ)	p (MeV/c)
$p \mu^- \overline{\nu}$ anything	(4.9 ± 2.4) %	–
$\Lambda \ell^- \overline{\nu}_\ell$ anything	$(3.1^{+1.0}_{-1.2})$ %	–
$\Lambda/\overline{\Lambda}$ anything	(35^{+12}_{-14}) %	–
$\Xi^- \ell^- \overline{\nu}_\ell$ anything	$(5.5^{+2.0}_{-2.4}) \times 10^{-3}$	–

NOTES

[*a*] The masses of the p and n are most precisely known in u (unified atomic mass units). The conversion factor to MeV, 1 u $= 931.49432 \pm 0.00028$ MeV, is less well known than are the masses in u.

[*b*] The limit is from neutrality-of-matter experiments; it assumes $q_n = q_p + q_e$. See also the charge of the neutron.

[*c*] The first limit is geochemical and independent of decay mode. The second entry, a range of limits, assumes the dominant decay modes are among those investigated. For antiprotons the best limit, inferred from the observation of cosmic ray $\overline{p}$'s is $\tau_{\overline{p}} > 10^7$ yr, the cosmic-ray storage time, but this limit depends on a number of assumptions. The best direct observation of stored antiprotons gives $\tau_{\overline{p}}/\mathrm{B}(\overline{p} \to e^- \gamma) > 1848$ yr.

[*d*] There is some controversy about whether nuclear physics and model dependence complicate the analysis for bound neutrons (from which the best limit comes). The second limit here is from reactor experiments with free neutrons.

[*e*] The parameters g_A, g_V, and g_{WM} for semileptonic modes are defined by $\overline{B}_f[\gamma_\lambda(g_V + g_A\gamma_5) + i(g_{WM}/m_{B_i})\,\sigma_{\lambda\nu}\,q^\nu]B_i$, and ϕ_{AV} is defined by $g_A/g_V = \left|g_A/g_V\right|e^{i\phi_{AV}}$. See the "Note on Baryon Decay Parameters" in the neutron Particle Listings.

[*f*] Time-reversal invariance requires this to be 0° or 180°.

[*g*] The decay parameters γ and Δ are calculated from α and ϕ using

$$\gamma = \sqrt{1-\alpha^2}\,\cos\phi\,, \qquad \tan\Delta = -\frac{1}{\alpha}\,\sqrt{1-\alpha^2}\,\sin\phi\,.$$

See the "Note on Baryon Decay Parameters" in the neutron Particle Listings.

[*h*] See the Particle Listings for the pion momentum range used in this measurement.

[*i*] The error given here is only an educated guess. It is larger than the error on the weighted average of the published values.

[*j*] A theoretical value using QED.

[*k*] See the "Note on Λ_c^+ Branching Fractions" in the Branching Fractions of the Λ_c^+ Particle Listings.

[*l*] This branching fraction includes all the decay modes of the final-state resonance.

[*m*] An ℓ indicates an e or a μ mode, not a sum over these modes.

[*n*] The value is for the sum of the charge states of particle/antiparticle states indicated.

[*o*] Assuming isospin conservation, so that the other third is $\Lambda_c^+\pi^0\pi^0$.

[*p*] Not a pure measurement. See note at head of Λ_b^0 Decay Modes.

SEARCHES FOR MONOPOLES, SUPERSYMMETRY, COMPOSITENESS, etc.

Magnetic Monopole Searches

Isolated supermassive monopole candidate events have not been confirmed. The most sensitive experiments obtain negative results.

Best cosmic-ray supermassive monopole flux limit:

$< 1.0 \times 10^{-15}$ cm^{-2}sr^{-1}s^{-1} for $1.1 \times 10^{-4} < \beta < 0.1$

Supersymmetric Particle Searches

Limits are based on the Minimal Supersymmetric Standard Model.

Assumptions include: 1) $\widetilde{\chi}_1^0$ (or $\widetilde{\gamma}$) is lightest supersymmetric particle; 2) *R*-parity is conserved; 3) All scalar quarks (except $\widetilde{t}_L$ and $\widetilde{t}_R$) are degenerate in mass, and $m_{\widetilde{q}_R} = m_{\widetilde{q}_L}$. 4) Limits for selectrons and smuons refer to the $\widetilde{\ell}_R$ states.

See the Particle Listings for a Note giving details of supersymmetry.

$\widetilde{\chi}_i^0$ — neutralinos (mixtures of $\widetilde{\gamma}$, $\widetilde{Z}^0$, and $\widetilde{H}_i^0$)

Mass $m_{\widetilde{\chi}_1^0} >$ 10.9 GeV, CL = 95%

Mass $m_{\widetilde{\chi}_2^0} >$ 45.3 GeV, CL = 95% [tanβ >1]

Mass $m_{\widetilde{\chi}_3^0} >$ 75.8 GeV, CL = 95% [tanβ >1]

Mass $m_{\widetilde{\chi}_4^0} >$ 127 GeV, CL = 95% [tanβ >3]

$\widetilde{\chi}_i^\pm$ — charginos (mixtures of $\widetilde{W}^\pm$ and $\widetilde{H}_i^\pm$)

Mass $m_{\widetilde{\chi}_1^\pm} >$ 65.7 GeV, CL = 95% [$m_{\widetilde{\chi}_1^\pm} - m_{\widetilde{\chi}_1^0} \geq 2$ GeV]

Mass $m_{\widetilde{\chi}_2^\pm} >$ 99 GeV, CL = 95% [GUT relations assumed]

$\widetilde{\nu}$ — scalar neutrino (sneutrino)

Mass $m >$ 37.1 GeV, CL = 95% [one flavor]

Mass $m >$ 43.1 GeV, CL = 95% [three degenerate flavors]

$\widetilde{e}$ — scalar electron (selectron)

Mass $m >$ 58 GeV, CL = 95% $[m_{\widetilde{e}_R} - m_{\widetilde{\chi}_1^0} \geq 4$ GeV]

$\widetilde{\mu}$ — scalar muon (smuon)

Mass $m >$ 55.6 GeV, CL = 95% $[m_{\widetilde{\mu}_R} - m_{\widetilde{\chi}_1^0} \geq 4$ GeV]

$\widetilde{\tau}$ — scalar tau (stau)

Mass $m >$ 45 GeV, CL = 95% [if $m_{\widetilde{\chi}_1^0} < 38$ GeV]

$\widetilde{q}$ — scalar quark (squark)

These limits include the effects of cascade decays, evaluated assuming a fixed value of the parameters μ and tanβ. The limits are weakly sensitive to these parameters over much of parameter space. Limits assume GUT relations between gaugino masses and the gauge coupling; in particular that for $|\mu|$ not small, $m_{\widetilde{\chi}_1^0} \approx m_{\widetilde{g}}/6$.

Mass $m >$ 176 GeV, CL = 95% [any $m_{\widetilde{g}} <$300 GeV, $\mu = -250$ GeV, tan$\beta = 2$]

Mass $m >$ 224 GeV, CL = 95% [$m_{\widetilde{g}} \leq m_{\widetilde{q}}$, $\mu = -400$ GeV, tan$\beta = 4$]

$\widetilde{g}$ — gluino

There is some controversy on whether gluinos in a low-mass window ($1 \lesssim m_{\widetilde{g}} \lesssim 5$ GeV) are excluded or not. See the Supersymmetry Listings for details.

The limits summarised here refere to the high-mass region ($m_{\widetilde{g}} \gtrsim 5$ GeV), and include the effects of cascade decays, evaluated assuming a fixed value of the parameters μ and tanβ. The limits are weakly sensitive to these parameters over much of parameter space. Limits assume GUT relations between gaugino masses and the gauge coupling; in particular that for $|\mu|$ not small, $m_{\widetilde{\chi}_1^0} \approx m_{\widetilde{g}}/6$.

Mass $m >$ 173 GeV, CL = 95% [any $m_{\widetilde{q}}$, $\mu = -200$ GeV, tan$\beta = 2$]

Mass $m >$ 212 GeV, CL = 95% [$m_{\widetilde{g}} \geq m_{\widetilde{q}}$, $\mu = -250$ GeV, tan$\beta = 2$]

Quark and Lepton Compositeness, Searches for

Scale Limits Λ for Contact Interactions (the lowest dimensional interactions with four fermions)

If the Lagrangian has the form

$$\pm \frac{g^2}{2\Lambda^2} \overline{\psi}_L \gamma_\mu \psi_L \overline{\psi}_L \gamma^\mu \psi_L$$

(with $g^2/4\pi$ set equal to 1), then we define $\Lambda \equiv \Lambda^{\pm}_{LL}$. For the full definitions and for other forms, see the Note in the Listings on Searches for Quark and Lepton Compositeness in the full *Review* and the original literature.

$\Lambda^{+}_{LL}(e e e e)$	>	2.4 TeV, CL = 95%
$\Lambda^{-}_{LL}(e e e e)$	>	3.6 TeV, CL = 95%
$\Lambda^{+}_{LL}(e e \mu \mu)$	>	2.6 TeV, CL = 95%
$\Lambda^{-}_{LL}(e e \mu \mu)$	>	2.9 TeV, CL = 95%
$\Lambda^{+}_{LL}(e e \tau \tau)$	>	1.9 TeV, CL = 95%
$\Lambda^{-}_{LL}(e e \tau \tau)$	>	3.0 TeV, CL = 95%
$\Lambda^{+}_{LL}(\ell \ell \ell \ell)$	>	3.5 TeV, CL = 95%
$\Lambda^{-}_{LL}(\ell \ell \ell \ell)$	>	3.8 TeV, CL = 95%
$\Lambda^{+}_{LL}(e e q q)$	>	2.5 TeV, CL = 95%
$\Lambda^{-}_{LL}(e e q q)$	>	3.7 TeV, CL = 95%
$\Lambda^{+}_{LL}(e e b b)$	>	3.1 TeV, CL = 95%
$\Lambda^{-}_{LL}(e e b b)$	>	2.9 TeV, CL = 95%
$\Lambda^{+}_{LL}(\mu \mu q q)$	>	2.9 TeV, CL = 95%
$\Lambda^{-}_{LL}(\mu \mu q q)$	>	4.2 TeV, CL = 95%
$\Lambda^{\pm}_{LR}(\nu_\mu \nu_e \mu e)$	>	3.1 TeV, CL = 90%
$\Lambda^{\pm}_{LL}(q q q q)$	>	1.6 TeV, CL = 95%

Excited Leptons

The limits from $\ell^{*+}\ell^{*-}$ do not depend on λ (where λ is the $\ell\ell^*$ transition coupling). The λ-dependent limits assume chiral coupling, except for the third limit for e^* which is for nonchiral coupling. For chiral coupling, this limit corresponds to $\lambda_\gamma = \sqrt{2}$.

$e^{*\pm}$ — excited electron

Mass $m >$ 85.0 GeV, CL = 95% (from $e^{*+}e^{*-}$)
Mass $m >$ 91 GeV, CL = 95% (if $\lambda_Z > 1$)
Mass $m >$ 194 GeV, CL = 95% (if $\lambda_\gamma = 1$)

$\mu^{*\pm}$ — excited muon

Mass $m >$ 85.3 GeV, CL = 95% (from $\mu^{*+}\mu^{*-}$)
Mass $m >$ 91 GeV, CL = 95% (if $\lambda_Z > 1$)

$\tau^{*\pm}$ — excited tau

Mass $m >$ 84.6 GeV, CL = 95% (from $\tau^{*+}\tau^{*-}$)
Mass $m >$ 90 GeV, CL = 95% (if $\lambda_Z > 0.18$)

ν^* — excited neutrino

Mass $m >$ 84.9 GeV, CL = 95% (from $\nu^*\overline{\nu}^*$)
Mass $m >$ 91 GeV, CL = 95% (if $\lambda_Z > 1$)
Mass m = none 40–96 GeV, CL = 95% (from $ep \to \nu^* X$)

q^* — excited quark

Mass $m >$ 45.6 GeV, CL = 95% (from $q^*\overline{q}^*$)
Mass $m >$ 88 GeV, CL = 95% (if $\lambda_Z > 1$)
Mass $m >$ 570 GeV, CL = 95% ($p\overline{p} \to q^* X$)

Color Sextet and Octet Particles

Color Sextet Quarks (q_6)

Mass $m >$ 84 GeV, CL = 95% (Stable q_6)

Color Octet Charged Leptons (ℓ_8)

Mass $m >$ 86 GeV, CL = 95% (Stable ℓ_8)

Color Octet Neutrinos (ν_8)

Mass $m >$ 110 GeV, CL = 90% ($\nu_8 \to \nu g$)

TESTS OF CONSERVATION LAWS

Revised by L. Wolfenstein and T.G. Trippe, May 1998.

In keeping with the current interest in tests of conservation laws, we collect together a Table of experimental limits on all weak and electromagnetic decays, mass differences, and moments, and on a few reactions, whose observation would violate conservation laws. The Table is given only in the full *Review of Particle Physics*, not in the Particle Physics Booklet. For the benefit of Booklet readers, we include the best limits from the Table in the following text. Limits in this text are for CL=90% unless otherwise specified. The Table is in two parts: "Discrete Space-Time Symmetries," *i.e.*, C, P, T, CP, and CPT; and "Number Conservation Laws," *i.e.*, lepton, baryon, hadronic flavor, and charge conservation. The references for these data can be found in the the Particle Listings in the *Review*. A discussion of these tests follows.

CPT INVARIANCE

General principles of relativistic field theory require invariance under the combined transformation CPT. The simplest tests of CPT invariance are the equality of the masses and lifetimes of a particle and its antiparticle. The best test comes from the limit on the mass difference between K^0 and $\overline{K}^0$. Any such difference contributes to the CP-violating parameter ϵ. Assuming CPT invariance, ϕ_ϵ, the phase of ϵ should be very close to 44°. (See the "Note on CP Violation in K^0_L Decay" in the Particle Listings.) In contrast, if the entire source of CP violation in K^0 decays were a $K^0 - \overline{K}^0$ mass difference, ϕ_ϵ would be $44° + 90°$.

Assuming that there is no other source of CPT violation than this mass difference, it is possible to deduce that [1]

$$m_{\overline{K}^0} - m_{K^0} \approx \frac{2(m_{K^0_L} - m_{K^0_S})\,|\eta|\,(\frac{2}{3}\phi_{+-} + \frac{1}{3}\phi_{00} - \phi_0)}{\sin\phi_0} ,$$

where $\phi_0 = 43.5°$ with an uncertainty of less than 0.1°. Using our best values of the CP-violation parameters, we get $|(m_{\overline{K}^0} - m_{K^0})/m_{K^0}| \leq 10^{-18}$. Limits can also be placed on specific CPT-violating decay amplitudes. Given the small value of $(1 - |\eta_{00}/\eta_{+-}|)$, the value of $\phi_{00} - \phi_{+-}$ provides a measure of

CPT violation in $K^0_L \to 2\pi$ decay. Results from CERN [1] and Fermilab [2] indicate no CPT-violating effect.

CP AND *T* INVARIANCE

Given CPT invariance, CP violation and T violation are equivalent. So far the only evidence for CP or T violation comes from the measurements of η_{+-}, η_{00}, and the semileptonic decay charge asymmetry for K_L, *e.g.*, $|\eta_{+-}| = |A(K^0_L \to \pi^+\pi^-)/A(K^0_S \to \pi^+\pi^-)| = (2.285 \pm 0.019) \times 10^{-3}$ and $[\Gamma(K^0_L \to \pi^- e^+ \nu) - \Gamma(K^0_L \to \pi^+ e^- \overline{\nu})]/[\text{sum}] = (0.333 \pm 0.014)\%$. Other searches for CP or T violation divide into (a) those that involve weak interactions or parity violation, and (b) those that involve processes otherwise allowed by the strong or electromagnetic interactions. In class (a) the most sensitive are probably the searches for an electric dipole moment of the neutron, measured to be $< 1.0 \times 10^{-25}$ e cm, and the electron $(-0.18 \pm 0.16) \times 10^{-26}$ e cm. A nonzero value requires both P and T violation. Class (b) includes the search for C violation in η decay, believed to be an electromagnetic process, *e.g.*, as measured by $\Gamma(\eta \to \mu^+\mu^-\pi^0)/\Gamma(\eta \to \text{all}) < 5 \times 10^{-6}$, and searches for T violation in a number of nuclear and electromagnetic reactions.

CONSERVATION OF LEPTON NUMBERS

Present experimental evidence and the standard electroweak theory are consistent with the absolute conservation of three separate lepton numbers: electron number L_e, muon number L_μ, and tau number L_τ. Searches for violations are of the following types:

a) $\Delta L = 2$ for one type of lepton. The best limit comes from the search for neutrinoless double beta decay $(Z, A) \to (Z + 2, A) + e^- + e^-$. The best laboratory limit is $t_{1/2} > 1.1 \times 10^{25}$ yr (CL=90%) for ^{76}Ge.

b) Conversion of one lepton type to another. For purely leptonic processes, the best limits are on $\mu \to e\gamma$ and $\mu \to 3e$, measured as $\Gamma(\mu \to e\gamma)/\Gamma(\mu \to \text{all}) < 5 \times 10^{-11}$ and $\Gamma(\mu \to 3e)/\Gamma(\mu \to \text{all}) < 1.0 \times 10^{-12}$. For semileptonic processes, the best limit comes from the coherent conversion process in a muonic atom, $\mu^- + (Z, A) \to e^- + (Z, A)$, measured as $\Gamma(\mu^- \text{Ti} \to e^- \text{Ti})/\Gamma(\mu^- \text{Ti} \to \text{all}) < 4 \times 10^{-12}$. Of special interest is the case in which the hadronic flavor also changes, as in $K_L \to e\mu$ and $K^+ \to \pi^+ e^- \mu^+$, measured as $\Gamma(K_L \to e\mu)/\Gamma(K_L \to \text{all}) < 3.3 \times 10^{-11}$ and $\Gamma(K^+ \to \pi^+ e^- \mu^+)/\Gamma(K^+ \to \text{all}) < 2.1 \times 10^{-10}$. Limits on the conversion of τ into e or μ are found in τ decay and are much less stringent than

those for $\mu \to e$ conversion, *e.g.*, $\Gamma(\tau \to \mu\gamma)/\Gamma(\tau \to \text{all}) < 3.0 \times 10^{-6}$ and $\Gamma(\tau \to e\gamma)/\Gamma(\tau \to \text{all}) < 2.7 \times 10^{-6}$.

c) Conversion of one type of lepton into another type of antilepton. The case most studied is $\mu^- + (Z, A) \to e^+ + (Z-2, A)$, the strongest limit being $\Gamma(\mu^-\text{Ti} \to e^+\text{Ca})/\Gamma(\mu^-\text{Ti} \to \text{all}) < 9 \times 10^{-11}$.

d) Relation to neutrino mass. If neutrinos have mass, then it is expected even in the standard electroweak theory that the lepton numbers are not separately conserved, as a consequence of lepton mixing analogous to Cabibbo quark mixing. However, in this case lepton-number-violating processes such as $\mu \to e\gamma$ are expected to have extremely small probability. For small neutrino masses, the lepton-number violation would be observed first in neutrino oscillations, which have been the subject of extensive experimental searches. For example, searches for $\overline{\nu}_e$ disappearance, which we label as $\overline{\nu}_e \not\to \overline{\nu}_e$, give measured limits $\Delta(m^2) < 9 \times 10^{-4}$ eV^2 for $\sin^2(2\theta) = 1$, and $\sin^2(2\theta) < 0.02$ for large $\Delta(m^2)$, where θ is the neutrino mixing angle. Possible evidence for mixing has come from two sources. The deficit in the solar neutrino flux compared with solar model calculations could be explained by oscillations with $\Delta(m^2) \le 10^{-5}$ eV^2 causing the disappearance of ν_e. In addition underground detectors observing neutrinos produced by cosmic rays in the atmosphere have measured a ν_μ/ν_e ratio much less than expected and also a deficiency of upward going ν_μ compared to downward. This could be explained by oscillations leading to the disappearance of ν_μ with $\Delta(m^2)$ of the order 10^{-2}–10^{-3} eV^2.

CONSERVATION OF HADRONIC FLAVORS

In strong and electromagnetic interactions, hadronic flavor is conserved, *i.e.* the conversion of a quark of one flavor (d, u, s, c, b, t) into a quark of another flavor is forbidden. In the Standard Model, the weak interactions violate these conservation laws in a manner described by the Cabibbo-Kobayashi-Maskawa mixing (see the section "Cabibbo-Kobayashi-Maskawa Mixing Matrix"). The way in which these conservation laws are violated is tested as follows:

a) $\Delta S = \Delta Q$ rule. In the semileptonic decay of strange particles, the strangeness change equals the change in charge of the hadrons. Tests come from limits on decay rates such as $\Gamma(\Sigma^+ \to ne^+\nu)/\Gamma(\Sigma^+ \to \text{all}) < 5 \times 10^{-6}$, and from a detailed analysis of $K_L \to \pi e\nu$, which yields the parameter x,

measured to be $(\mathrm{Re}\,x, \mathrm{Im}\,x) = (0.006\pm0.018, -0.003\pm0.026)$. Corresponding rules are $\Delta C = \Delta Q$ and $\Delta B = \Delta Q$.

b) Change of flavor by two units. In the Standard Model this occurs only in second-order weak interactions. The classic example is $\Delta S = 2$ via $K^0 - \overline{K}^0$ mixing, which is directly measured by $m(K_S) - m(K_L) = (3.489 \pm 0.009)\times10^{-12}$ MeV. There is now evidence for $B^0-\overline{B}^0$ mixing ($\Delta B = 2$), with the corresponding mass difference between the eigenstates $(m_{B^0_{\mathrm{H}}} - m_{B^0_{\mathrm{L}}}) = (0.723\pm0.032)\Gamma_{B^0} = (3.05\pm0.12)\times10^{-10}$ MeV, and for B^0_s–$\overline{B}^0_s$ mixing, with $(m_{B^0_{sH}} - m_{B^0_{sL}}) > 14\Gamma_{B^0_s}$ or $> 6\times10^{-9}$ MeV (CL=95%). No evidence exists for $D^0 - \overline{D}^0$ mixing, which is expected to be much smaller in the Standard Model.

c) Flavor-changing neutral currents. In the Standard Model the neutral-current interactions do not change flavor. The low rate $\Gamma(K_L \to \mu^+\mu^-)/\Gamma(K_L \to \text{all}) = (7.2 \pm 0.5)\times10^{-9}$ puts limits on such interactions; the nonzero value for this rate is attributed to a combination of the weak and electromagnetic interactions. The best test should come from $K^+ \to \pi^+\nu\overline{\nu}$, which occurs in the Standard Model only as a second-order weak process with a branching fraction of $(1 \text{ to } 8)\times10^{-10}$. Observation of one event has been reported [4], yielding $\Gamma(K^+ \to \pi^+\nu\overline{\nu})/\Gamma(K^+ \to \text{all}) = (4.2^{+9.7}_{-3.5})\times10^{-10}$. Limits for charm-changing or bottom-changing neutral currents are much less stringent: $\Gamma(D^0 \to \mu^+\mu^-)/\Gamma(D^0 \to \text{all}) < 4\times10^{-6}$ and $\Gamma(B^0 \to \mu^+\mu^-)/\Gamma(B^0 \to \text{all}) < 7\times10^{-7}$. One cannot isolate flavor-changing neutral current (FCNC) effects in non leptonic decays. For example, the FCNC transition $s \to d + (\overline{u} + u)$ is equivalent to the charged-current transition $s \to u + (\overline{u} + d)$. Tests for FCNC are therefore limited to hadron decays into lepton pairs. Such decays are expected only in second-order in the electroweak coupling in the Standard Model.

References

1. R. Carosi *et al.*, Phys. Lett. **B237**, 303 (1990).
2. M. Karlsson *et al.*, Phys. Rev. Lett. **64**, 2976 (1990);
   L.K. Gibbons *et al.*, Phys. Rev. Lett. **70**, 1199 (1993).
3. B. Schwingenheuer *et al.*, Phys. Rev. Lett. **74**, 4376 (1995).
4. S. Adler *et al.*, Phys. Rev. Lett. **79**, 2204 (1997).

TESTS OF DISCRETE SPACE-TIME SYMMETRIES

CHARGE CONJUGATION (C) INVARIANCE

$\Gamma(\pi^0 \to 3\gamma)/\Gamma_{total}$		$<3.1 \times 10^{-8}$, CL = 90%
η C-nonconserving decay parameters		
$\pi^+\pi^-\pi^0$ left-right asymmetry parameter		$(0.09 \pm 0.17) \times 10^{-2}$
$\pi^+\pi^-\pi^0$ sextant asymmetry parameter		$(0.18 \pm 0.16) \times 10^{-2}$
$\pi^+\pi^-\pi^0$ quadrant asymmetry parameter		$(-0.17 \pm 0.17) \times 10^{-2}$
$\pi^+\pi^-\gamma$ left-right asymmetry parameter		$(0.9 \pm 0.4) \times 10^{-2}$
$\pi^+\pi^-\gamma$ parameter β (D-wave)		0.05 ± 0.06 (S = 1.5)
$\Gamma(\eta \to 3\gamma)/\Gamma_{total}$		$<5 \times 10^{-4}$, CL = 95%
$\Gamma(\eta \to \pi^0 e^+ e^-)/\Gamma_{total}$	[a]	$<4 \times 10^{-5}$, CL = 90%
$\Gamma(\eta \to \pi^0 \mu^+ \mu^-)/\Gamma_{total}$	[a]	$<5 \times 10^{-6}$, CL = 90%
$\Gamma(\omega(782) \to \eta\pi^0)/\Gamma_{total}$		$<1 \times 10^{-3}$, CL = 90%
$\Gamma(\omega(782) \to 3\pi^0)/\Gamma_{total}$		$<3 \times 10^{-4}$, CL = 90%
$\Gamma(\eta'(958) \to \pi^0 e^+ e^-)/\Gamma_{total}$	[a]	$<1.3 \times 10^{-2}$, CL = 90%
$\Gamma(\eta'(958) \to \eta e^+ e^-)/\Gamma_{total}$	[a]	$<1.1 \times 10^{-2}$, CL = 90%
$\Gamma(\eta'(958) \to 3\gamma)/\Gamma_{total}$		$<1.0 \times 10^{-4}$, CL = 90%
$\Gamma(\eta'(958) \to \mu^+\mu^-\pi^0)/\Gamma_{total}$	[a]	$<6.0 \times 10^{-5}$, CL = 90%
$\Gamma(\eta'(958) \to \mu^+\mu^-\eta)/\Gamma_{total}$	[a]	$<1.5 \times 10^{-5}$, CL = 90%

PARITY (P) INVARIANCE

e electric dipole moment	$(0.18 \pm 0.16) \times 10^{-26}$ $e$cm
μ electric dipole moment	$(3.7 \pm 3.4) \times 10^{-19}$ $e$cm
τ electric dipole moment (d_τ)	> -3.1 and $< 3.1 \times 10^{-16}$ $e$cm, CL = 95%
$\Gamma(\eta \to \pi^+\pi^-)/\Gamma_{total}$	$<9 \times 10^{-4}$, CL = 90%
$\Gamma(\eta'(958) \to \pi^+\pi^-)/\Gamma_{total}$	$<2 \times 10^{-2}$, CL = 90%
$\Gamma(\eta'(958) \to \pi^0\pi^0)/\Gamma_{total}$	$<9 \times 10^{-4}$, CL = 90%
p electric dipole moment	$(-4 \pm 6) \times 10^{-23}$ $e$cm
n electric dipole moment	$<0.97 \times 10^{-25}$ $e$cm, CL = 90%
Λ electric dipole moment	$<1.5 \times 10^{-16}$ $e$cm, CL = 95%

TIME REVERSAL (T) INVARIANCE

Limits on e, μ, τ, p, n, and Λ electric dipole moments under Parity Invariance above are also tests of Time Reversal Invariance.

μ decay parameters		
transverse e^+ polarization normal to plane of μ spin, e^+ momentum		0.007 ± 0.023
α'/A		$(0 \pm 4) \times 10^{-3}$
β'/A		$(2 \pm 6) \times 10^{-3}$
τ electric dipole moment (d_τ)		> -3.1 and $< 3.1 \times 10^{-16}$ $e$cm, CL = 95%
Im(ξ) in $K^\pm_{\mu 3}$ decay (from transverse μ pol.)		-0.017 ± 0.025
Im(ξ) in $K^0_{\mu 3}$ decay (from transverse μ pol.)		-0.007 ± 0.026
$n \to p e^- \nu$ decay parameters		
ϕ_{AV}, phase of g_A relative to g_V	[b]	$(180.07 \pm 0.18)^\circ$
triple correlation coefficient D		$(-0.5 \pm 1.4) \times 10^{-3}$
triple correlation coefficient D for $\Sigma^- \to n e^- \overline{\nu}_e$		0.11 ± 0.10

CP INVARIANCE

$\mathrm{Re}(d_\tau^w)$		$<0.56 \times 10^{-17}$ e cm, CL = 95%
$\mathrm{Im}(d_\tau^w)$		$<1.5 \times 10^{-17}$ e cm, CL = 95%
$\Gamma(\eta \to \pi^+\pi^-)/\Gamma_{\mathrm{total}}$		$<9 \times 10^{-4}$, CL = 90%
$\Gamma(\eta'(958) \to \pi^+\pi^-)/\Gamma_{\mathrm{total}}$		$<2 \times 10^{-2}$, CL = 90%
$\Gamma(\eta'(958) \to \pi^0\pi^0)/\Gamma_{\mathrm{total}}$		$<9 \times 10^{-4}$, CL = 90%
$K^\pm \to \pi^\pm\pi^+\pi^-$ rate difference/average		$(0.07 \pm 0.12)\%$
$K^\pm \to \pi^\pm\pi^0\pi^0$ rate difference/average		$(0.0 \pm 0.6)\%$
$K^\pm \to \pi^\pm\pi^0\gamma$ rate difference/average		$(0.9 \pm 3.3)\%$
$(g_{\tau^+} - g_{\tau^-})$ / $(g_{\tau^+} + g_{\tau^-})$ for $K^\pm \to \pi^\pm\pi^+\pi^-$		$(-0.7 \pm 0.5)\%$
CP-violation parameters in K_S^0 decay		
$\mathrm{Im}(\eta_{+-0}) = \mathrm{Im}(\mathrm{A}(K_S^0 \to \pi^+\pi^-\pi^0$, *CP*-violating) / $\mathrm{A}(K_L^0 \to \pi^+\pi^-\pi^0))$		-0.002 ± 0.008
$\mathrm{Im}(\eta_{000})^2 = \Gamma(K_S^0 \to 3\pi^0)$ / $\Gamma(K_L^0 \to 3\pi^0)$		<0.1, CL = 90%
charge asymmetry j for $K_L^0 \to \pi^+\pi^-\pi^0$		0.0011 ± 0.0008
$\lvert\epsilon'_{+-\gamma}\rvert/\epsilon$ for $K_L^0 \to \pi^+\pi^-\gamma$		<0.3, CL = 90%
$\Gamma(K_L^0 \to \pi^0\mu^+\mu^-)/\Gamma_{\mathrm{total}}$	[*c*]	$<5.1 \times 10^{-9}$, CL = 90%
$\Gamma(K_L^0 \to \pi^0 e^+ e^-)/\Gamma_{\mathrm{total}}$	[*c*]	$<4.3 \times 10^{-9}$, CL = 90%
$\Gamma(K_L^0 \to \pi^0\nu\overline{\nu})/\Gamma_{\mathrm{total}}$	[*d*]	$<5.8 \times 10^{-5}$, CL = 90%
$A_{CP}(K^+K^-\pi^\pm)$ in $D^\pm \to K^+K^-\pi^\pm$		-0.017 ± 0.027
$A_{CP}(K^\pm K^{*0})$ in $D^+ \to K^+\overline{K}^{*0}$ and $D^- \to K^-K^{*0}$		-0.02 ± 0.05
$A_{CP}(\phi\pi^\pm)$ in $D^\pm \to \phi\pi^\pm$		-0.014 ± 0.033
$A_{CP}(\pi^+\pi^-\pi^\pm)$ in $D^\pm \to \pi^+\pi^-\pi^\pm$		-0.02 ± 0.04
$A_{CP}(K^+K^-)$ in D^0, $\overline{D}^0 \to K^+K^-$		0.026 ± 0.035
$A_{CP}(\pi^+\pi^-)$ in D^0, $\overline{D}^0 \to \pi^+\pi^-$		-0.05 ± 0.08
$A_{CP}(K_S^0\phi)$ in D^0, $\overline{D}^0 \to K_S^0\phi$		-0.03 ± 0.09
$A_{CP}(K_S^0\pi^0)$ in D^0, $\overline{D}^0 \to K_S^0\pi^0$		-0.018 ± 0.030
$\lvert\mathrm{Re}(\epsilon_{B^0})\rvert$		0.002 ± 0.008
$[\alpha_-(\Lambda) + \alpha_+(\overline{\Lambda})]$ / $[\alpha_-(\Lambda) - \alpha_+(\overline{\Lambda})]$		-0.03 ± 0.06

CP VIOLATION OBSERVED

K^0_L branching ratios

charge asymmetry in $K^0_{\ell 3}$ decays

$\delta(\mu) = [\Gamma(\pi^- \mu^+ \nu_\mu) - \Gamma(\pi^+ \mu^- \overline{\nu}_\mu)]/\text{sum}$		$(0.304 \pm 0.025)\%$
$\delta(e) = [\Gamma(\pi^- e^+ \nu_e) - \Gamma(\pi^+ e^- \overline{\nu}_e)]/\text{sum}$		$(0.333 \pm 0.014)\%$

parameters for $K^0_L \rightarrow 2\pi$ decay

$\lvert\eta_{00}\rvert = \lvert A(K^0_L \rightarrow 2\pi^0) / A(K^0_S \rightarrow 2\pi^0)\rvert$		$(2.275 \pm 0.019) \times 10^{-3}$ (S = 1.1)
$\lvert\eta_{+-}\rvert = \lvert A(K^0_L \rightarrow \pi^+\pi^-) / A(K^0_S \rightarrow \pi^+\pi^-)\rvert$		$(2.285 \pm 0.019) \times 10^{-3}$
$\epsilon'/\epsilon \approx \text{Re}(\epsilon'/\epsilon) = (1-\lvert\eta_{00}/\eta_{+-}\rvert)/3$	[*e*]	$(1.5 \pm 0.8) \times 10^{-3}$ (S = 1.8)
ϕ_{+-}, phase of η_{+-}		$(43.5 \pm 0.6)^\circ$
ϕ_{00}, phase of η_{00}		$(43.4 \pm 1.0)^\circ$

parameters for $K^0_L \rightarrow \pi^+\pi^-\gamma$ decay

$\lvert\eta_{+-\gamma}\rvert = \lvert A(K^0_L \rightarrow \pi^+\pi^-\gamma$, *CP* violating$)/A(K^0_S \rightarrow \pi^+\pi^-\gamma)\rvert$		$(2.35 \pm 0.07) \times 10^{-3}$
$\phi_{+-\gamma}$ = phase of $\eta_{+-\gamma}$		$(44 \pm 4)^\circ$

$\Gamma(K^0_L \rightarrow \pi^+\pi^-)/\Gamma_{\text{total}}$		$(2.067 \pm 0.035) \times 10^{-3}$ (S = 1.1)
$\Gamma(K^0_L \rightarrow \pi^0\pi^0)/\Gamma_{\text{total}}$		$(9.36 \pm 0.20) \times 10^{-4}$

CPT INVARIANCE

$(m_{W^+} - m_{W^-})$ / m_{average}		-0.002 ± 0.007
$(m_{e^+} - m_{e^-})$ / m_{average}		$<4 \times 10^{-8}$, CL = 90%
$\lvert q_{e^+} + q_{e^-}\rvert / e$		$<4 \times 10^{-8}$
$(g_{e^+} - g_{e^-})$ / g_{average}		$(-0.5 \pm 2.1) \times 10^{-12}$
$(\tau_{\mu^+} - \tau_{\mu^-})$ / τ_{average}		$(2 \pm 8) \times 10^{-5}$
$(g_{\mu^+} - g_{\mu^-})$ / g_{average}		$(-2.6 \pm 1.6) \times 10^{-8}$
$(m_{\pi^+} - m_{\pi^-})$ / m_{average}		$(2 \pm 5) \times 10^{-4}$
$(\tau_{\pi^+} - \tau_{\pi^-})$ / τ_{average}		$(6 \pm 7) \times 10^{-4}$
$(m_{K^+} - m_{K^-})$ / m_{average}		$(-0.6 \pm 1.8) \times 10^{-4}$
$(\tau_{K^+} - \tau_{K^-})$ / τ_{average}		(0.11 ± 0.09)% (S = 1.2)
$K^{\pm} \to \mu^{\pm} \nu_{\mu}$ rate difference/average		(-0.5 ± 0.4)%
$K^{\pm} \to \pi^{\pm} \pi^0$ rate difference/average	[*f*]	(0.8 ± 1.2)%
$\lvert m_{K^0} - m_{\overline{K}^0}\rvert$ / m_{average}	[*g*]	$<10^{-18}$
phase difference $\phi_{00} - \phi_{+-}$		$(-0.1 \pm 0.8)^{\circ}$
CPT-violation parameters in K^0 decay		
real part of Δ		0.018 ± 0.020
imaginary part of Δ		0.02 ± 0.04
$(\lvert \frac{q_{\overline{p}}}{m_{\overline{p}}}\rvert - \frac{q_p}{m_p}) / \lvert \frac{q}{m}\rvert_{\text{average}}$		$(1.5 \pm 1.1) \times 10^{-9}$
$\lvert q_p + q_{\overline{p}}\rvert / e$		$<2 \times 10^{-5}$
$(\mu_p + \mu_{\overline{p}})$ / $\lvert\mu\rvert_{\text{average}}$		$(-2.6 \pm 2.9) \times 10^{-3}$
$(m_n - m_{\overline{n}})$ / m_{average}		$(9 \pm 5) \times 10^{-5}$
$(m_{\Lambda} - m_{\overline{\Lambda}})$ / m_{Λ}		$(-1.0 \pm 0.9) \times 10^{-5}$
$(\tau_{\Lambda} - \tau_{\overline{\Lambda}})$ / τ_{average}		0.04 ± 0.09
$(\mu_{\Sigma^+} + \mu_{\overline{\Sigma}^-})$ / $\lvert\mu\rvert_{\text{average}}$		0.014 ± 0.015
$(m_{\Xi^-} - m_{\overline{\Xi}^+})$ / m_{average}		$(1.1 \pm 2.7) \times 10^{-4}$
$(\tau_{\Xi^-} - \tau_{\overline{\Xi}^+})$ / τ_{average}		0.02 ± 0.18
$(m_{\Omega^-} - m_{\overline{\Omega}^+})$ / m_{average}		$(0 \pm 5) \times 10^{-4}$

TESTS OF NUMBER CONSERVATION LAWS

LEPTON FAMILY NUMBER

Lepton family number conservation means separate conservation of each of L_e, L_μ, L_τ.

$\Gamma(Z \to e^\pm \mu^\mp)/\Gamma_{total}$	[h]	$<1.7 \times 10^{-6}$, CL = 95%
$\Gamma(Z \to e^\pm \tau^\mp)/\Gamma_{total}$	[h]	$<9.8 \times 10^{-6}$, CL = 95%
$\Gamma(Z \to \mu^\pm \tau^\mp)/\Gamma_{total}$	[h]	$<1.2 \times 10^{-5}$, CL = 95%
limit on $\mu^- \to e^-$ conversion		
$\sigma(\mu^- \, ^{32}\text{S} \to e^- \, ^{32}\text{S})$ / $\sigma(\mu^- \, ^{32}\text{S} \to \nu_\mu \, ^{32}\text{P}^*)$		$<7 \times 10^{-11}$, CL = 90%
$\sigma(\mu^- \text{Ti} \to e^- \text{Ti})$ / $\sigma(\mu^- \text{Ti} \to \text{capture})$		$<4.3 \times 10^{-12}$, CL = 90%
$\sigma(\mu^- \text{Pb} \to e^- \text{Pb})$ / $\sigma(\mu^- \text{Pb} \to \text{capture})$		$<4.6 \times 10^{-11}$, CL = 90%
limit on muonium $\to$ antimuonium conversion $R_g = G_C / G_F$		<0.018, CL = 90%
$\Gamma(\mu^- \to e^- \nu_e \overline{\nu}_\mu)/\Gamma_{total}$	[i]	$<1.2 \times 10^{-2}$, CL = 90%
$\Gamma(\mu^- \to e^- \gamma)/\Gamma_{total}$		$<4.9 \times 10^{-11}$, CL = 90%
$\Gamma(\mu^- \to e^- e^+ e^-)/\Gamma_{total}$		$<1.0 \times 10^{-12}$, CL = 90%
$\Gamma(\mu^- \to e^- 2\gamma)/\Gamma_{total}$		$<7.2 \times 10^{-11}$, CL = 90%
$\Gamma(\tau^- \to e^- \gamma)/\Gamma_{total}$		$<2.7 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^- \gamma)/\Gamma_{total}$		$<3.0 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^- \pi^0)/\Gamma_{total}$		$<3.7 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^- \pi^0)/\Gamma_{total}$		$<4.0 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^- K^0)/\Gamma_{total}$		$<1.3 \times 10^{-3}$, CL = 90%
$\Gamma(\tau^- \to \mu^- K^0)/\Gamma_{total}$		$<1.0 \times 10^{-3}$, CL = 90%
$\Gamma(\tau^- \to e^- \eta)/\Gamma_{total}$		$<8.2 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^- \eta)/\Gamma_{total}$		$<9.6 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^- \rho^0)/\Gamma_{total}$		$<2.0 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^- \rho^0)/\Gamma_{total}$		$<6.3 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^- K^*(892)^0)/\Gamma_{total}$		$<5.1 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^- K^*(892)^0)/\Gamma_{total}$		$<7.5 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^- \overline{K}^*(892)^0)/\Gamma_{total}$		$<7.4 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^- \overline{K}^*(892)^0)/\Gamma_{total}$		$<7.5 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^- \phi)/\Gamma_{total}$		$<6.9 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^- \phi)/\Gamma_{total}$		$<7.0 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^- e^+ e^-)/\Gamma_{total}$		$<2.9 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^- \mu^+ \mu^-)/\Gamma_{total}$		$<1.8 \times 10^{-6}$, CL = 90%

$\Gamma(\tau^- \to e^+\mu^-\mu^-)/\Gamma_{\rm total}$	$<1.5 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^- e^+ e^-)/\Gamma_{\rm total}$	$<1.7 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^+ e^- e^-)/\Gamma_{\rm total}$	$<1.5 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^-\mu^+\mu^-)/\Gamma_{\rm total}$	$<1.9 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^-\pi^+\pi^-)/\Gamma_{\rm total}$	$<2.2 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^-\pi^+\pi^-)/\Gamma_{\rm total}$	$<8.2 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^-\pi^+ K^-)/\Gamma_{\rm total}$	$<6.4 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^-\pi^- K^+)/\Gamma_{\rm total}$	$<3.8 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^- K^+ K^-)/\Gamma_{\rm total}$	$<6.0 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^-\pi^+ K^-)/\Gamma_{\rm total}$	$<7.5 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^-\pi^- K^+)/\Gamma_{\rm total}$	$<7.4 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^- K^+ K^-)/\Gamma_{\rm total}$	$<1.5 \times 10^{-5}$, CL = 90%
$\Gamma(\tau^- \to e^-\pi^0\pi^0)/\Gamma_{\rm total}$	$<6.5 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^-\pi^0\pi^0)/\Gamma_{\rm total}$	$<1.4 \times 10^{-5}$, CL = 90%
$\Gamma(\tau^- \to e^-\eta\eta)/\Gamma_{\rm total}$	$<3.5 \times 10^{-5}$, CL = 90%
$\Gamma(\tau^- \to \mu^-\eta\eta)/\Gamma_{\rm total}$	$<6.0 \times 10^{-5}$, CL = 90%
$\Gamma(\tau^- \to e^-\pi^0\eta)/\Gamma_{\rm total}$	$<2.4 \times 10^{-5}$, CL = 90%
$\Gamma(\tau^- \to \mu^-\pi^0\eta)/\Gamma_{\rm total}$	$<2.2 \times 10^{-5}$, CL = 90%
$\Gamma(\tau^- \to e^-$ light boson$)/\Gamma_{\rm total}$	$<2.7 \times 10^{-3}$, CL = 95%
$\Gamma(\tau^- \to \mu^-$ light boson$)/\Gamma_{\rm total}$	$<5 \times 10^{-3}$, CL = 95%

ν oscillations. (For other lepton mixing effects in particle decays, see the Particle Listings.)

$\overline{\nu}_e \not\to \overline{\nu}_e$	
$\Delta(m^2)$ for $\sin^2(2\theta) = 1$	$<9 \times 10^{-4}$ eV^2, CL = 90%
$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$	<0.02, CL = 90%
$\nu_e \to \nu_\tau$	
$\Delta(m^2)$ for $\sin^2(2\theta) = 1$	<9 eV^2, CL = 90%
$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$	<0.25, CL = 90%
$\overline{\nu}_e \to \overline{\nu}_\tau$	
$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$	<0.7, CL = 90%
$\nu_\mu \to \nu_e$	
$\Delta(m^2)$ for $\sin^2(2\theta) = 1$	<0.09 eV^2, CL = 90%
$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$	$<3.0 \times 10^{-3}$, CL = 90%
$\overline{\nu}_\mu \to \overline{\nu}_e$	
$\Delta(m^2)$ for $\sin^2(2\theta) = 1$	<0.14 eV^2, CL = 90%
$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$	<0.004, CL = 95%
$\nu_\mu(\overline{\nu}_\mu) \to \nu_e(\overline{\nu}_e)$	
$\Delta(m^2)$ for $\sin^2(2\theta) = 1$	<0.075 eV^2, CL = 90%
$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$	$<1.8 \times 10^{-3}$, CL = 90%
$\nu_\mu \to \nu_\tau$	
$\Delta(m^2)$ for $\sin^2(2\theta) = 1$	<0.9 eV^2, CL = 90%
$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$	<0.004, CL = 90%
$\overline{\nu}_\mu \to \overline{\nu}_\tau$	

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$		<2.2 eV^2, CL = 90%
$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$		$<4.4 \times 10^{-2}$, CL = 90%
$\nu_\mu(\overline{\nu}_\mu) \rightarrow \nu_\tau(\overline{\nu}_\tau)$		
$\Delta(m^2)$ for $\sin^2(2\theta) = 1$		<1.5 eV^2, CL = 90%
$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$		$<8 \times 10^{-3}$, CL = 90%
$\nu_e \not\rightarrow \nu_e$		
$\Delta(m^2)$ for $\sin^2(2\theta) = 1$		<0.17 eV^2, CL = 90%
$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$		$<7 \times 10^{-2}$, CL = 90%
$\nu_\mu \not\rightarrow \nu_\mu$		
$\Delta(m^2)$ for $\sin^2(2\theta) = 1$		<0.23 or >1500 eV^2
$\sin^2(2\theta)$ for $\Delta(m^2) = 100$eV^2	[*j*]	<0.02, CL = 90%
$\overline{\nu}_\mu \not\rightarrow \overline{\nu}_\mu$		
$\Delta(m^2)$ for $\sin^2(2\theta) = 1$		<7 or >1200 eV^2
$\sin^2(2\theta)$ for 190 eV^2 $< \Delta(m^2) <$ 320 eV^2	[*k*]	<0.02, CL = 90%
$\Gamma(\pi^+ \rightarrow \mu^+ \nu_e)/\Gamma_{\text{total}}$	[*l*]	$<8.0 \times 10^{-3}$, CL = 90%
$\Gamma(\pi^+ \rightarrow \mu^- e^+ e^+ \nu)/\Gamma_{\text{total}}$		$<1.6 \times 10^{-6}$, CL = 90%
$\Gamma(\pi^0 \rightarrow \mu^+ e^- + e^- \mu^+)/\Gamma_{\text{total}}$		$<1.72 \times 10^{-8}$, CL = 90%
$\Gamma(\eta \rightarrow \mu^+ e^- + \mu^- e^+)/\Gamma_{\text{total}}$		$<6 \times 10^{-6}$, CL = 90%
$\Gamma(K^+ \rightarrow \mu^- \nu e^+ e^+)/\Gamma_{\text{total}}$		$<2.0 \times 10^{-8}$, CL = 90%
$\Gamma(K^+ \rightarrow \mu^+ \nu_e)/\Gamma_{\text{total}}$	[*l*]	$<4 \times 10^{-3}$, CL = 90%
$\Gamma(K^+ \rightarrow \pi^+ \mu^+ e^-)/\Gamma_{\text{total}}$		$<2.1 \times 10^{-10}$, CL = 90%
$\Gamma(K^+ \rightarrow \pi^+ \mu^- e^+)/\Gamma_{\text{total}}$		$<7 \times 10^{-9}$, CL = 90%
$\Gamma(K^0_L \rightarrow e^\pm \mu^\mp)/\Gamma_{\text{total}}$	[*h*]	$<3.3 \times 10^{-11}$, CL = 90%
$\Gamma(K^0_L \rightarrow e^\pm e^\pm \mu^\mp \mu^\mp)/\Gamma_{\text{total}}$	[*h*]	$<6.1 \times 10^{-9}$, CL = 90%
$\Gamma(D^+ \rightarrow \pi^+ e^+ \mu^-)/\Gamma_{\text{total}}$		$<1.1 \times 10^{-4}$, CL = 90%
$\Gamma(D^+ \rightarrow \pi^+ e^- \mu^+)/\Gamma_{\text{total}}$		$<1.3 \times 10^{-4}$, CL = 90%
$\Gamma(D^+ \rightarrow K^+ e^+ \mu^-)/\Gamma_{\text{total}}$		$<1.3 \times 10^{-4}$, CL = 90%
$\Gamma(D^+ \rightarrow K^+ e^- \mu^+)/\Gamma_{\text{total}}$		$<1.2 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \mu^\pm e^\mp)/\Gamma_{\text{total}}$	[*h*]	$<1.9 \times 10^{-5}$, CL = 90%
$\Gamma(D^0 \rightarrow \pi^0 e^\pm \mu^\mp)/\Gamma_{\text{total}}$	[*h*]	$<8.6 \times 10^{-5}$, CL = 90%
$\Gamma(D^0 \rightarrow \eta e^\pm \mu^\mp)/\Gamma_{\text{total}}$	[*h*]	$<1.0 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \rho^0 e^\pm \mu^\mp)/\Gamma_{\text{total}}$	[*h*]	$<4.9 \times 10^{-5}$, CL = 90%
$\Gamma(D^0 \rightarrow \omega e^\pm \mu^\mp)/\Gamma_{\text{total}}$	[*h*]	$<1.2 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \phi e^\pm \mu^\mp)/\Gamma_{\text{total}}$	[*h*]	$<3.4 \times 10^{-5}$, CL = 90%
$\Gamma(D^0 \rightarrow \overline{K}^0 e^\pm \mu^\mp)/\Gamma_{\text{total}}$	[*h*]	$<1.0 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \overline{K}^*(892)^0 e^\pm \mu^\mp)/\Gamma_{\text{total}}$	[*h*]	$<1.0 \times 10^{-4}$, CL = 90%
$\Gamma(B^+ \rightarrow \pi^+ e^+ \mu^-)/\Gamma_{\text{total}}$		$<6.4 \times 10^{-3}$, CL = 90%
$\Gamma(B^+ \rightarrow \pi^+ e^- \mu^+)/\Gamma_{\text{total}}$		$<6.4 \times 10^{-3}$, CL = 90%
$\Gamma(B^+ \rightarrow K^+ e^+ \mu^-)/\Gamma_{\text{total}}$		$<6.4 \times 10^{-3}$, CL = 90%
$\Gamma(B^+ \rightarrow K^+ e^- \mu^+)/\Gamma_{\text{total}}$		$<6.4 \times 10^{-3}$, CL = 90%
$\Gamma(B^+ \rightarrow \pi^- e^+ \mu^+)/\Gamma_{\text{total}}$		$<6.4 \times 10^{-3}$, CL = 90%
$\Gamma(B^+ \rightarrow K^- e^+ \mu^+)/\Gamma_{\text{total}}$		$<6.4 \times 10^{-3}$, CL = 90%

$\Gamma(B^0 \to e^{\pm}\mu^{\mp})/\Gamma_{total}$	[h]	$<5.9 \times 10^{-6}$, CL = 90%
$\Gamma(B^0 \to e^{\pm}\tau^{\mp})/\Gamma_{total}$	[h]	$<5.3 \times 10^{-4}$, CL = 90%
$\Gamma(B^0 \to \mu^{\pm}\tau^{\mp})/\Gamma_{total}$	[h]	$<8.3 \times 10^{-4}$, CL = 90%
$\Gamma(B \to e^{\pm}\mu^{\mp}s)/\Gamma_{total}$		$<2.2 \times 10^{-5}$, CL = 90%
$\Gamma(B_s^0 \to e^{\pm}\mu^{\mp})/\Gamma_{total}$	[h]	$<4.1 \times 10^{-5}$, CL = 90%

TOTAL LEPTON NUMBER

Violation of total lepton number conservation also implies violation of lepton family number conservation.

limit on $\mu^- \to e^+$ conversion		
$\sigma(\mu^- \, ^{32}S \to e^+ \, ^{32}Si^*)$ / $\sigma(\mu^- \, ^{32}S \to \nu_\mu \, ^{32}P^*)$		$<9 \times 10^{-10}$, CL = 90%
$\sigma(\mu^- \, ^{127}I \to e^+ \, ^{127}Sb^*)$ / $\sigma(\mu^- \, ^{127}I \to$ anything)		$<3 \times 10^{-10}$, CL = 90%
$\sigma(\mu^-$ Ti $\to e^+$ Ca) / $\sigma(\mu^-$ Ti $\to$ capture)		$<8.9 \times 10^{-11}$, CL = 90%
$\Gamma(\tau^- \to \pi^-\gamma)/\Gamma_{total}$		$<2.8 \times 10^{-4}$, CL = 90%
$\Gamma(\tau^- \to \pi^-\pi^0)/\Gamma_{total}$		$<3.7 \times 10^{-4}$, CL = 90%
$\Gamma(\tau^- \to e^+\pi^-\pi^-)/\Gamma_{total}$		$<1.9 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^+\pi^-\pi^-)/\Gamma_{total}$		$<3.4 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^+\pi^-K^-)/\Gamma_{total}$		$<2.1 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to e^+K^-K^-)/\Gamma_{total}$		$<3.8 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^+\pi^-K^-)/\Gamma_{total}$		$<7.0 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \mu^+K^-K^-)/\Gamma_{total}$		$<6.0 \times 10^{-6}$, CL = 90%
$\Gamma(\tau^- \to \overline{p}\gamma)/\Gamma_{total}$		$<2.9 \times 10^{-4}$, CL = 90%
$\Gamma(\tau^- \to \overline{p}\pi^0)/\Gamma_{total}$		$<6.6 \times 10^{-4}$, CL = 90%
$\Gamma(\tau^- \to \overline{p}\eta)/\Gamma_{total}$		$<1.30 \times 10^{-3}$, CL = 90%
$\nu_e \to (\overline{\nu}_e)_L$		
$\alpha\Delta(m^2)$ for $\sin^2(2\theta) = 1$		<0.14 eV^2, CL = 90%
$\alpha^2\sin^2(2\theta)$ for "Large" $\Delta(m^2)$		<0.032, CL = 90%
$\nu_\mu \to (\overline{\nu}_e)_L$		
$\alpha\Delta(m^2)$ for $\sin^2(2\theta) = 1$		<0.16 eV^2, CL = 90%
$\alpha^2\sin^2(2\theta)$ for "Large" $\Delta(m^2)$		<0.001, CL = 90%
$\Gamma(\pi^+ \to \mu^+\overline{\nu}_e)/\Gamma_{total}$	[l]	$<1.5 \times 10^{-3}$, CL = 90%
$\Gamma(K^+ \to \pi^-\mu^+e^+)/\Gamma_{total}$		$<7 \times 10^{-9}$, CL = 90%
$\Gamma(K^+ \to \pi^-e^+e^+)/\Gamma_{total}$		$<1.0 \times 10^{-8}$, CL = 90%
$\Gamma(K^+ \to \pi^-\mu^+\mu^+)/\Gamma_{total}$	[l]	$<1.5 \times 10^{-4}$, CL = 90%
$\Gamma(K^+ \to \mu^+\overline{\nu}_e)/\Gamma_{total}$	[l]	$<3.3 \times 10^{-3}$, CL = 90%
$\Gamma(K^+ \to \pi^0e^+\overline{\nu}_e)/\Gamma_{total}$		$<3 \times 10^{-3}$, CL = 90%
$\Gamma(D^+ \to \pi^-e^+e^+)/\Gamma_{total}$		$<1.1 \times 10^{-4}$, CL = 90%

$\Gamma(D^+ \to \pi^- \mu^+ \mu^+)/\Gamma_{\text{total}}$		$<8.7 \times 10^{-5}$, CL = 90%
$\Gamma(D^+ \to \pi^- e^+ \mu^+)/\Gamma_{\text{total}}$		$<1.1 \times 10^{-4}$, CL = 90%
$\Gamma(D^+ \to \rho^- \mu^+ \mu^+)/\Gamma_{\text{total}}$		$<5.6 \times 10^{-4}$, CL = 90%
$\Gamma(D^+ \to K^- e^+ e^+)/\Gamma_{\text{total}}$		$<1.2 \times 10^{-4}$, CL = 90%
$\Gamma(D^+ \to K^- \mu^+ \mu^+)/\Gamma_{\text{total}}$		$<1.2 \times 10^{-4}$, CL = 90%
$\Gamma(D^+ \to K^- e^+ \mu^+)/\Gamma_{\text{total}}$		$<1.3 \times 10^{-4}$, CL = 90%
$\Gamma(D^+ \to K^*(892)^- \mu^+ \mu^+)/\Gamma_{\text{total}}$		$<8.5 \times 10^{-4}$, CL = 90%
$\Gamma(D_s^+ \to \pi^- \mu^+ \mu^+)/\Gamma_{\text{total}}$		$<4.3 \times 10^{-4}$, CL = 90%
$\Gamma(D_s^+ \to K^- \mu^+ \mu^+)/\Gamma_{\text{total}}$		$<5.9 \times 10^{-4}$, CL = 90%
$\Gamma(D_s^+ \to K^*(892)^- \mu^+ \mu^+)/\Gamma_{\text{total}}$		$<1.4 \times 10^{-3}$, CL = 90%
$\Gamma(B^+ \to \pi^- e^+ e^+)/\Gamma_{\text{total}}$		$<3.9 \times 10^{-3}$, CL = 90%
$\Gamma(B^+ \to \pi^- \mu^+ \mu^+)/\Gamma_{\text{total}}$		$<9.1 \times 10^{-3}$, CL = 90%
$\Gamma(B^+ \to K^- e^+ e^+)/\Gamma_{\text{total}}$		$<3.9 \times 10^{-3}$, CL = 90%
$\Gamma(B^+ \to K^- \mu^+ \mu^+)/\Gamma_{\text{total}}$		$<9.1 \times 10^{-3}$, CL = 90%
$\Gamma(\Xi^- \to p \mu^- \mu^-)/\Gamma_{\text{total}}$		$<4 \times 10^{-4}$, CL = 90%
$\Gamma(\Lambda_c^+ \to \Sigma^- \mu^+ \mu^+)/\Gamma_{\text{total}}$		$<7.0 \times 10^{-4}$, CL = 90%

BARYON NUMBER

$\Gamma(\tau^- \to \overline{p}\gamma)/\Gamma_{\text{total}}$		$<2.9 \times 10^{-4}$, CL = 90%
$\Gamma(\tau^- \to \overline{p}\pi^0)/\Gamma_{\text{total}}$		$<6.6 \times 10^{-4}$, CL = 90%
$\Gamma(\tau^- \to \overline{p}\eta)/\Gamma_{\text{total}}$		$<1.30 \times 10^{-3}$, CL = 90%
p mean life		$>1.6 \times 10^{25}$ years

A few examples of proton or bound neutron decay follow. For limits on many other nucleon decay channels, see the Baryon Summary Table.

$\tau(N \to e^+ \pi)$		$>$ 130 (n), $>$ 550 (p) $\times 10^{30}$ years, CL = 90%
$\tau(N \to \mu^+ \pi)$		$>$ 100 (n), $>$ 270 (p) $\times 10^{30}$ years, CL = 90%
$\tau(N \to e^+ K)$		$>$ 1.3 (n), $>$ 150 (p) $\times 10^{30}$ years, CL = 90%
$\tau(N \to \mu^+ K)$		$>$ 1.1 (n), $>$ 120 (p) $\times 10^{30}$ years, CL = 90%
limit on $n\overline{n}$ oscillations (bound n)	[m]	$>1.2 \times 10^{8}$ s, CL = 90%
limit on $n\overline{n}$ oscillations (free n)		$>0.86 \times 10^{8}$ s, CL = 90%

ELECTRIC CHARGE (Q)

e mean life / branching fraction	[n]	$>4.3 \times 10^{23}$ yr, CL = 68%
$\Gamma(n \to p \nu_e \overline{\nu}_e)/\Gamma_{\text{total}}$		$<8 \times 10^{-27}$, CL = 68%

$\Delta S = \Delta Q$ RULE

Allowed in second-order weak interactions.

$\Gamma(K^+ \to \pi^+ \pi^+ e^- \overline{\nu}_e)/\Gamma_{total}$	$<1.2 \times 10^{-8}$, CL = 90%
$\Gamma(K^+ \to \pi^+ \pi^+ \mu^- \overline{\nu}_\mu)/\Gamma_{total}$	$<3.0 \times 10^{-6}$, CL = 95%
$x = A(\overline{K}^0 \to \pi^- \ell^+ \nu)/A(K^0 \to \pi^- \ell^+ \nu) = A(\Delta S{=}-\Delta Q)/A(\Delta S{=}\Delta Q)$	
real part of x	0.006 ± 0.018 (S = 1.3)
imaginary part of x	-0.003 ± 0.026 (S = 1.2)
$\Gamma(\Sigma^+ \to n \ell^+ \nu)/\Gamma(\Sigma^- \to n \ell^- \overline{\nu})$	<0.043
$\Gamma(\Sigma^+ \to n e^+ \nu_e)/\Gamma_{total}$	$<5 \times 10^{-6}$, CL = 90%
$\Gamma(\Sigma^+ \to n \mu^+ \nu_\mu)/\Gamma_{total}$	$<3.0 \times 10^{-5}$, CL = 90%
$\Gamma(\Xi^0 \to \Sigma^- e^+ \nu_e)/\Gamma_{total}$	$<9 \times 10^{-4}$, CL = 90%
$\Gamma(\Xi^0 \to \Sigma^- \mu^+ \nu_\mu)/\Gamma_{total}$	$<9 \times 10^{-4}$, CL = 90%

$\Delta S = 2$ FORBIDDEN

Allowed in second-order weak interactions.

$\Gamma(\Xi^0 \to p \pi^-)/\Gamma_{total}$	$<4 \times 10^{-5}$, CL = 90%
$\Gamma(\Xi^0 \to p e^- \overline{\nu}_e)/\Gamma_{total}$	$<1.3 \times 10^{-3}$
$\Gamma(\Xi^0 \to p \mu^- \overline{\nu}_\mu)/\Gamma_{total}$	$<1.3 \times 10^{-3}$
$\Gamma(\Xi^- \to n \pi^-)/\Gamma_{total}$	$<1.9 \times 10^{-5}$, CL = 90%
$\Gamma(\Xi^- \to n e^- \overline{\nu}_e)/\Gamma_{total}$	$<3.2 \times 10^{-3}$, CL = 90%
$\Gamma(\Xi^- \to n \mu^- \overline{\nu}_\mu)/\Gamma_{total}$	$<1.5 \times 10^{-2}$, CL = 90%
$\Gamma(\Xi^- \to p \pi^- \pi^-)/\Gamma_{total}$	$<4 \times 10^{-4}$, CL = 90%
$\Gamma(\Xi^- \to p \pi^- e^- \overline{\nu}_e)/\Gamma_{total}$	$<4 \times 10^{-4}$, CL = 90%
$\Gamma(\Xi^- \to p \pi^- \mu^- \overline{\nu}_\mu)/\Gamma_{total}$	$<4 \times 10^{-4}$, CL = 90%
$\Gamma(\Omega^- \to \Lambda \pi^-)/\Gamma_{total}$	$<1.9 \times 10^{-4}$, CL = 90%

$\Delta S = 2$ VIA MIXING

Allowed in second-order weak interactions, e.g. mixing.

$m_{K_L^0} - m_{K_S^0}$	$(0.5301 \pm 0.0014) \times 10^{10}$ $\hbar$ s^{-1}
$m_{K_L^0} - m_{K_S^0}$	$(3.489 \pm 0.009) \times 10^{-12}$ MeV

$\Delta C = 2$ VIA MIXING

Allowed in second-order weak interactions, e.g. mixing.

$\lvert m_{D_1^0} - m_{D_2^0}\rvert$	[o]	$<24 \times 10^{10}\ \hbar\ s^{-1}$, CL = 90%
$\lvert\Gamma_{D_1^0} - \Gamma_{D_2^0}\rvert/\Gamma_{D^0}$ mean life difference/average	[o]	<0.20, CL = 90%
$\Gamma(K^+ \ell^- \overline{\nu}_\ell (\text{via } \overline{D}^0))/\Gamma(K^- \ell^+ \nu_\ell)$		<0.005, CL = 90%
$\Gamma(K^+\pi^-$ or $K^+\pi^-\pi^+\pi^-$ (via $\overline{D}^0$))/$\Gamma(K^-\pi^+$ or $K^-\pi^+\pi^+\pi^-)$	[p]	< 0.0085 (or < 0.0037), CL = 90%
$\Gamma(D^0 \rightarrow K^+ \ell^- \overline{\nu}_\ell (\text{via } \overline{D}^0))/\Gamma_{\text{total}}$		$<1.7 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow K^+\pi^-$ or $K^+\pi^-\pi^+\pi^-$ (via $\overline{D}^0$))/Γ_{total}		$<1.0 \times 10^{-3}$, CL = 90%

$\Delta B = 2$ VIA MIXING

Allowed in second-order weak interactions, e.g. mixing.

χ_d	0.172 ± 0.010
$\Delta m_{B^0} = m_{B^0_H} - m_{B^0_L}$	$(0.464 \pm 0.018) \times 10^{12}\ \hbar\ s^{-1}$
$x_d = \Delta m_{B^0}/\Gamma_{B^0}$	0.723 ± 0.032
χ_B at high energy	0.118 ± 0.006
$\Delta m_{B^0_s} = m_{B^0_{sH}} - m_{B^0_{sL}}$	$>9.1 \times 10^{12}\ \hbar\ s^{-1}$, CL = 95%
$x_s = \Delta m_{B^0_s}/\Gamma_{B^0_s}$	>14.0, CL = 95%
χ_s	>0.4975, CL = 95%

$\Delta S = 1$ WEAK NEUTRAL CURRENT FORBIDDEN

Allowed by higher-order electroweak interactions.

$\Gamma(K^+ \rightarrow \pi^+ e^+ e^-)/\Gamma_{\text{total}}$	$(2.74 \pm 0.23) \times 10^{-7}$
$\Gamma(K^+ \rightarrow \pi^+ \mu^+ \mu^-)/\Gamma_{\text{total}}$	$(5.0 \pm 1.0) \times 10^{-8}$
$\Gamma(K^+ \rightarrow \pi^+ \nu \overline{\nu})/\Gamma_{\text{total}}$	$(4.2^{+9.7}_{-3.5}) \times 10^{-10}$
$\Gamma(K^0_S \rightarrow \mu^+ \mu^-)/\Gamma_{\text{total}}$	$<3.2 \times 10^{-7}$, CL = 90%
$\Gamma(K^0_S \rightarrow e^+ e^-)/\Gamma_{\text{total}}$	$<1.4 \times 10^{-7}$, CL = 90%
$\Gamma(K^0_S \rightarrow \pi^0 e^+ e^-)/\Gamma_{\text{total}}$	$<1.1 \times 10^{-6}$, CL = 90%
$\Gamma(K^0_L \rightarrow \mu^+ \mu^-)/\Gamma_{\text{total}}$	$(7.2 \pm 0.5) \times 10^{-9}$ (S = 1.4)
$\Gamma(K^0_L \rightarrow \mu^+ \mu^- \gamma)/\Gamma_{\text{total}}$	$(3.25 \pm 0.28) \times 10^{-7}$
$\Gamma(K^0_L \rightarrow e^+ e^-)/\Gamma_{\text{total}}$	$<4.1 \times 10^{-11}$, CL = 90%
$\Gamma(K^0_L \rightarrow e^+ e^- \gamma)/\Gamma_{\text{total}}$	$(9.1 \pm 0.5) \times 10^{-6}$

$\Gamma(K^0_L \rightarrow e^+ e^- \gamma\gamma)/\Gamma_{total}$	[q]	$(6.5 \pm 1.2) \times 10^{-7}$
$\Gamma(K^0_L \rightarrow \pi^+ \pi^- e^+ e^-)/\Gamma_{total}$	[q]	$<4.6 \times 10^{-7}$, CL = 90%
$\Gamma(K^0_L \rightarrow \mu^+ \mu^- e^+ e^-)/\Gamma_{total}$		$(2.9^{+6.7}_{-2.4}) \times 10^{-9}$
$\Gamma(K^0_L \rightarrow e^+ e^- e^+ e^-)/\Gamma_{total}$		$(4.1 \pm 0.8) \times 10^{-8}$ (S = 1.2)
$\Gamma(K^0_L \rightarrow \pi^0 \mu^+ \mu^-)/\Gamma_{total}$		$<5.1 \times 10^{-9}$, CL = 90%
$\Gamma(K^0_L \rightarrow \pi^0 e^+ e^-)/\Gamma_{total}$		$<4.3 \times 10^{-9}$, CL = 90%
$\Gamma(K^0_L \rightarrow \pi^0 \nu \overline{\nu})/\Gamma_{total}$		$<5.8 \times 10^{-5}$, CL = 90%
$\Gamma(\Sigma^+ \rightarrow p e^+ e^-)/\Gamma_{total}$		$<7 \times 10^{-6}$

$\Delta C = 1$ WEAK NEUTRAL CURRENT FORBIDDEN

Allowed by higher-order electroweak interactions.

$\Gamma(D^+ \rightarrow \pi^+ e^+ e^-)/\Gamma_{total}$	$<6.6 \times 10^{-5}$, CL = 90%
$\Gamma(D^+ \rightarrow \pi^+ \mu^+ \mu^-)/\Gamma_{total}$	$<1.8 \times 10^{-5}$, CL = 90%
$\Gamma(D^+ \rightarrow \rho^+ \mu^+ \mu^-)/\Gamma_{total}$	$<5.6 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow e^+ e^-)/\Gamma_{total}$	$<1.3 \times 10^{-5}$, CL = 90%
$\Gamma(D^0 \rightarrow \mu^+ \mu^-)/\Gamma_{total}$	$<4.1 \times 10^{-6}$, CL = 90%
$\Gamma(D^0 \rightarrow \pi^0 e^+ e^-)/\Gamma_{total}$	$<4.5 \times 10^{-5}$, CL = 90%
$\Gamma(D^0 \rightarrow \pi^0 \mu^+ \mu^-)/\Gamma_{total}$	$<1.8 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \eta e^+ e^-)/\Gamma_{total}$	$<1.1 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \eta \mu^+ \mu^-)/\Gamma_{total}$	$<5.3 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \rho^0 e^+ e^-)/\Gamma_{total}$	$<1.0 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \rho^0 \mu^+ \mu^-)/\Gamma_{total}$	$<2.3 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \omega e^+ e^-)/\Gamma_{total}$	$<1.8 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \omega \mu^+ \mu^-)/\Gamma_{total}$	$<8.3 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \phi e^+ e^-)/\Gamma_{total}$	$<5.2 \times 10^{-5}$, CL = 90%
$\Gamma(D^0 \rightarrow \phi \mu^+ \mu^-)/\Gamma_{total}$	$<4.1 \times 10^{-4}$, CL = 90%
$\Gamma(D^0 \rightarrow \pi^+ \pi^- \pi^0 \mu^+ \mu^-)/\Gamma_{total}$	$<8.1 \times 10^{-4}$, CL = 90%
$\Gamma(D^+_s \rightarrow K^+ \mu^+ \mu^-)/\Gamma_{total}$	$<5.9 \times 10^{-4}$, CL = 90%
$\Gamma(D^+_s \rightarrow K^*(892)^+ \mu^+ \mu^-)/\Gamma_{total}$	$<1.4 \times 10^{-3}$, CL = 90%
$\Gamma(\Lambda^+_c \rightarrow p \mu^+ \mu^-)/\Gamma_{total}$	$<3.4 \times 10^{-4}$, CL = 90%

$\Delta B = 1$ WEAK NEUTRAL CURRENT FORBIDDEN

Allowed by higher-order electroweak interactions.

$\Gamma(B^+ \to \pi^+ e^+ e^-)/\Gamma_{total}$	$<3.9 \times 10^{-3}$, CL = 90%
$\Gamma(B^+ \to \pi^+ \mu^+ \mu^-)/\Gamma_{total}$	$<9.1 \times 10^{-3}$, CL = 90%
$\Gamma(B^+ \to K^+ e^+ e^-)/\Gamma_{total}$	$<6 \times 10^{-5}$, CL = 90%
$\Gamma(B^+ \to K^+ \mu^+ \mu^-)/\Gamma_{total}$	$<1.0 \times 10^{-5}$, CL = 90%
$\Gamma(B^+ \to K^*(892)^+ e^+ e^-)/\Gamma_{total}$	$<6.9 \times 10^{-4}$, CL = 90%
$\Gamma(B^+ \to K^*(892)^+ \mu^+ \mu^-)/\Gamma_{total}$	$<1.2 \times 10^{-3}$, CL = 90%
$\Gamma(B^0 \to \gamma\gamma)/\Gamma_{total}$	$<3.9 \times 10^{-5}$, CL = 90%
$\Gamma(B^0 \to e^+ e^-)/\Gamma_{total}$	$<5.9 \times 10^{-6}$, CL = 90%
$\Gamma(B^0 \to \mu^+ \mu^-)/\Gamma_{total}$	$<6.8 \times 10^{-7}$, CL = 90%
$\Gamma(B^0 \to K^0 e^+ e^-)/\Gamma_{total}$	$<3.0 \times 10^{-4}$, CL = 90%
$\Gamma(B^0 \to K^0 \mu^+ \mu^-)/\Gamma_{total}$	$<3.6 \times 10^{-4}$, CL = 90%
$\Gamma(B^0 \to K^*(892)^0 e^+ e^-)/\Gamma_{total}$	$<2.9 \times 10^{-4}$, CL = 90%
$\Gamma(B^0 \to K^*(892)^0 \mu^+ \mu^-)/\Gamma_{total}$	$<2.3 \times 10^{-5}$, CL = 90%
$\Gamma(B^0 \to K^*(892)^0 \nu\overline{\nu})/\Gamma_{total}$	$<1.0 \times 10^{-3}$, CL = 90%
$\Gamma(B \to e^+ e^- s)/\Gamma_{total}$	$<5.7 \times 10^{-5}$, CL = 90%
$\Gamma(B \to \mu^+ \mu^- s)/\Gamma_{total}$	$<5.8 \times 10^{-5}$, CL = 90%
$\Gamma(\overline{b} \to \mu^+ \mu^- \text{ anything})/\Gamma_{total}$	$<3.2 \times 10^{-4}$, CL = 90%
$\Gamma(B^0_s \to \mu^+ \mu^-)/\Gamma_{total}$	$<2.0 \times 10^{-6}$, CL = 90%
$\Gamma(B^0_s \to e^+ e^-)/\Gamma_{total}$	$<5.4 \times 10^{-5}$, CL = 90%
$\Gamma(B^0_s \to \phi\nu\overline{\nu})/\Gamma_{total}$	$<5.4 \times 10^{-3}$, CL = 90%

NOTES

[*a*] *C* parity forbids this to occur as a single-photon process.

[*b*] Time-reversal invariance requires this to be 0° or 180°.

[*c*] Allowed by higher-order electroweak interactions.

[*d*] Violates *CP* in leading order. Test of direct *CP* violation since the indirect *CP*-violating and *CP*-conserving contributions are expected to be suppressed.

[*e*] ϵ'/ϵ is derived from $\left|\eta_{00}/\eta_{+-}\right|$ measurements using theoretical input on phases.

[*f*] Neglecting photon channels. See, *e.g.*, A. Pais and S.B. Treiman, Phys. Rev. **D12**, 2744 (1975).

[*g*] Derived from measured values of ϕ_{+-}, ϕ_{00}, $|\eta|$, $\left|m_{K_L^0} - m_{K_S^0}\right|$, and $\tau_{K_S^0}$, as described in the introduction to "Tests of Conservation Laws."

[*h*] The value is for the sum of the charge states of particle/antiparticle states indicated.

[*i*] A test of additive vs. multiplicative lepton family number conservation.

[*j*] $\Delta(m^2) = 100$ eV^2.

[*k*] 190 eV^2 $< \Delta(m^2) <$ 320 eV^2.

[*l*] Derived from an analysis of neutrino-oscillation experiments.

[*m*] There is some controversy about whether nuclear physics and model dependence complicate the analysis for bound neutrons (from which the best limit comes). The second limit here is from reactor experiments with free neutrons.

[*n*] This is the best "electron disappearance" limit. The best limit for the mode $e^- \to \nu\gamma$ is $> 2.35 \times 10^{25}$ yr (CL=68%).

[*o*] The D_1^0-D_2^0 limits are inferred from the D^0-$\overline{D}^0$ mixing ratio $\Gamma(K^+\ell^-\overline{\nu}_\ell(\text{via } \overline{D}^0))$ / $\Gamma(K^-\ell^+\nu_\ell)$.

[*p*] The larger limit (from E791) allows interference between the doubly Cabibbo-suppressed and mixing amplitudes; the smaller limit (from E691) doesn't. See the papers for details.

[*q*] See the K_L^0 Particle Listings for the energy limits used in this measurement.

TABLE OF THE ISOTOPES

Norman E. Holden

This table presents an evaluated set of values for the experimental quantities which characterize the decay of radioactive nuclides. A list of the major references used in this evaluation is given below. When uncertainties are not listed, they are assumed to be five or less in the last digit quoted. If they exceed five in the last digit, the value is prefaced by an approximate sign. The effective literature cutoff date for data in this edition of the Table is December, 2000.

Table Layout

Column No.	Column Title	Description
1	Isotope or Element	For elements, the atomic number and chemical symbol are listed. For nuclides, the mass number and chemical symbol are listed. Isomers are indicated by the addition of m, m1, or m2.
2	Isotopic Abundance	in atom percent.
3	Atomic Mass or Atomic Weight	Atomic mass relative to $^{12}C = 12$. Atomic weight is given on the same scale.
4	Half-life	Half-life in decimal notation. μs = microseconds; ms = milliseconds; s = seconds; m = minutes; h = hours; d = days; and y = years.
5	Decay Mode/Energy	Decay modes are α = alpha particle emission; β^- = negative beta emission; β^+ = positron emission; EC = orbital electron capture; IT = isomeric transition from upper to lower isomeric state; n = neutron emission; SF = spontaneous fission. Total disintegration energy in MeV units.
6	Particle Energy/Intensity	End point energies of beta transitions and discrete energies of alpha particles in MeV and their intensities in percent.
7	Spin and Parity	Nuclear spin or angular momentum of the nuclides in units of h/2π; parity is positive or negative.
8	Magnetic Dipole Moment	Magnetic dipole moments in nuclear magneton units.
9	Electric Quadrupole Moment	Electric quadrupole moments in barn units (10^{-24} cm^2).
10	Gamma Ray Energy/Intensity	Gamma ray energies in MeV and intensities in percent. Ann. rad. refers to the 511.006 keV photons emitted in the annihilation of positrons in matter.

General Nuclear Data References

The following references represent the major sources of the nuclear data presented, along with subsequent published journals and reports:

1. G. Audi, O. Bersillon, J. Blachot, A.H. Wapstra, *The Nubase Evaluation of Nuclear and Decay Properties,* Nuclear Physics A624, 1 (1997).
2. International Commission on Atomic Weights, *Atomic Weights of the Elements - 1999,* Pure & Applied Chemistry 73, to be published (2000).
3. J.R. Parrington, H.D. Knox, S. Breneman, E.M. Baum, F. Feiner, *Chart of the Nuclides, 15th Edition,* Knolls Atomic Power Lab. (1996).
4. N.E. Holden, *Total and Spontaneous Fission Half-lives for Uranium, Plutonium, Americium and Curium Nuclides,* Pure & Applied Chemistry 61, 1483 (1989).
5. N.E. Holden, *Half-lives of Selected Nuclides,* Pure & Applied Chemistry 62, 941 (1990).
6. N.E. Holden, *Review of Thermal Neutron Cross Sections and Isotopic Composition of the Elements,* BNL-NCS-42224 (March 1989).
7. P. Raghavan, *Table of Nuclear Moments,* Atomic Data Nuclear Data Tables 42, 189 (1989).
8. E. Brown, R. Firestone, *Radioactivity Handbook,* Wiley Interscience Press (1986).
9. J.K. Tuli, *Nuclear Wallet Cards,* Brookhaven National Laboratory (Jan. 2000).
10. N.E. Holden, D.C. Hoffman, *Spontaneous Fission Half-lives for Ground State Nuclides,* Pure & Applied Chemistry 72, 1525 (2000).
11. N. Stone, Table of New Nuclear Moments, private communication, www.nndc.bnl.gov/nndc/stone_moments/moments.html (Dec. 2000).

*This research was carried out under the auspices of the US Department of Energy Contract No. DE-AC02-98CH10886.

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
$_0$n		1.008664924	614. s	β^-/0.78235	0.782/100.	1/2+	-1.913043		
$_1$H		1.00794(7)							
^{1}H	99.985(1)	1.007825032				1/2+	+2.79285		
^{2}H	0.015(1)	2.014101778				1+	+0.85744	+2.86 mb	
^{3}H		3.016049268	12.33 y	β^-/0.01859	0.01860/100.	1/2+	+2.97896		
^{4}H		4.0278	$1.9x10^{-22}$ s	n/	/100	2-			
^{5}H		5.040	$8.x10^{-23}$ s	n/	/100				
^{6}H		6.0449	$3.x10^{-22}$ s						
$_2$He		4.002602(2)							
^{3}He	$1.37x10^{-4}$	3.016029309				1/2+	-2.12762		
^{4}He	≈100.	4.002603250				0+			
^{5}He		5.01222	$7.6x10^{-22}$ s	n, α		3/2-			
^{6}He		6.018888	0.807 s	β^-/3.508,d	3.510/100.	0+			
^{7}He		7.02803	$3.x10^{-21}$ s	n		(3/2)-			
^{8}He		8.03392	0.119 s	β^-/10.65, t	13/88.	0+			0.9807/84.
				n/	/12.				0.4776/5.
^{9}He		9.0438	$7.x10^{-21}$ s	n	/100	(1/2–)			
^{10}He		10.0524	$3.x10^{-21}$ s	2n	/100	0+			
$_3$Li		6.941(2)							
^{4}Li		4.0272	$9.x10^{-23}$ s	p/	/100	2-			
^{5}Li		5.01254	$≈3.x10^{-22}$ s	p/		3/2-			
^{6}Li	7.5(2)	6.0151223				1+	+0.82205	-0.8 mb	
^{7}Li	92.5(2)	7.0160041				3/2-	+3.25644	-0.041	
^{8}Li		8.022486	0.84 s	β^-/16.004	12.5/100.	2+	+1.6536	+0.032	
				α/	α(1.6)				
^{9}Li		9.026789	0.178 s	β^-/13.606	13.5/75.	3/2-	3.439	-0.027	
				β^-/	11/25.				
^{10}Li		10.03590	$4.x10^{-22}$ s	β^-/20.84					
^{11}Li		11.04380	8.4 ms	β^-/20.6		3/2(-)	3.668	-0.031	3.367/35.
				n,2n,3n,α	n//106.				(0.22-2.81)
^{12}Li		12.054	<0.01 μs						
$_4$Be		9.012182(3)							
^{5}Be		5.041							
^{6}Be		6.01973	$5.0x10^{-21}$ s	2p,α		0+			
^{7}Be		7.0169293	53.28 d	EC/0.8618		3/2-			0.4776/10.4
^{8}Be		8.00530509	$≈7.x10^{-17}$ s	2α/0.046		0+			
^{9}Be	100.	9.0121822				3/2-	-1.1776	+0.0529	
^{10}Be		10.0135338	$1.52x10^6$ y	β^-/0.5559	0.555/100.	0+			
^{11}Be		11.02166	13.8 s	β^-,β^-α/11.51	11.48/61.	1/2+			2.125/35.5
									(0.478-7.97)
^{12}Be		12.02692	24. ms	β^-,(n)/11.71	n//0.5	0+			(0.95 - 4.4)
^{13}Be		13.0361	$≈ 3.x10^{-21}$ s						
^{14}Be		14.0428	4.3 ms	β^-,(n)/16.2	n//100.	0+			
$_5$B		10.811(7)							
^{7}B		7.0299	$4.x10^{-22}$ s	p					
^{8}B		8.024607	0.770 s	β^+, 2α/17.979	13.7(β^+)/93.	2+	1.0355	0.068	ann.rad.
^{9}B		9.013329	$8x10^{-19}$ s	p2α/		3/2-			
^{10}B	19.9(2)	10.0129371				3+	+1.8006	+0.085	
^{11}B	80.1(2)	11.0093055				3/2-	+2.6886	+0.0406	
^{12}B		12.014352	0.0202 s	β^-/13.369		1+	+1.0027	0.0132	4.438/1.3
				β^- α/1.6/					3.215/0.00065
^{13}B		13.017780	0.0174 s	β^-/13.437	13.4	3/2-	+3.17778	0.037	3.68/7.6
				β^- n/0.25/	2.43(n)/0.09				
					3.55(n)/0.16				

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/Energy Intensity (MeV/%)
^{14}B		14.02540	14. ms	β^-/20.64		2-	1.185	0.0298	6.094/90.
^{15}B		15.03110	10.4 ms	β^-,(n)/19.09		(3/2-)	2.66	0.038	
^{16}B		16.0398	$<1.9\times10^{-10}$ s						
^{17}B		17.0469	5.1 ms	β^-,(n)/22.7			2.54		
^{18}B		18.056	<0.026 μs						
^{19}B		19.0637	3.3 ms	β^-,(n)/26.5	n//125.				
$_{6}$C		12.0107(8)							
^{8}C		8.03768	2.0×10^{-21} s	p		0+			
^{9}C		9.031040	127. ms	β^+,p, 2α/16.498		(3/2-)	-1.391		ann.rad.
^{10}C		10.0168532	19.3 s	β^+/3.648	1.865	0+			ann.rad.
									0.71829/100.
^{11}C		11.011433	20.3 m	β^+,EC/1.982	0.9608/99.	3/2-	-0.964	0.0333	ann.rad.
^{12}C	98.93(8)	12.000000000				0+			
^{13}C	1.07(8)	13.003354838				1/2-	+0.70241		
^{14}C		14.003241991	5715. y	β^-/0.15648	0.1565/100.	0+			
^{15}C		15.010599	2.45 s	β^-/9.772	4.51/68.	1/2+	1.32		5.298/68.
					9.82/32.				(7.30-9.05)
^{16}C		16.014701	0.75 s	β^-,n/8.012		0+			
^{17}C		17.02258	0.19 s	β^-,n/13.17					1.375
									1.849
									1.906
^{18}C		18.02676	0.09 s	β^-,n/11.81		0+			
^{19}C		19.0353	0.05 s	n					
^{20}C		20.0403	0.01 s			0+			
^{21}C		21.0493	<0.03 μs						
^{22}C		22.056	9 ms	β^-,n	n//99.	0+			
$_{7}$N		14.0067(2)							
^{10}N		10.0426							
^{11}N		11.0268	$5.\times10^{-22}$ s						
^{12}N		12.018613	11.00 ms	β^+,β^+α/17.338	16.38/95.	1+	+0.457	+10. mb	ann.rad.
									4.438/2.
^{13}N		13.0057386	9.97 m	β^+/2.2204	1.190/100.	1/2-	0.3222		
^{14}N	99.632(7)	14.003074007				1+	+0.40376	+0.0200	
^{15}N	0.368(7)	15.00010897				1/2-	-0.28319		
^{16}N		16.006100	7.13 s	β^-/10.419	4.27/68.	2-			6.129/68.8
					10.44/26.				7.115/4.7
				β^-, α	1.85/.0012				(0.99-8.87)
^{17}N		17.00845	4.17 s	β^-,β^- n/8.68	3.7/100.	1/2-	0.352		0.871/3.
				0.4-1.7n/95.					2.1842/0.3
				β^- α/	8.0, 8.2				
^{18}N		18.01408	0.62 s	β^-/13.90	9.4/100.	1-	0.328	0.012	0.822/61.
									1.65/60.5
									1.982/98.
									(0.535-7.13)
^{19}N		19.01703	0.32 s	β^-/12.53					(0.096-3.14)
^{20}N		20.02337	0.14 s	β^-/17.97					
^{21}N		21.0271	0.08 s						
^{22}N		22.0344	0.02 s						
^{23}N		23.0405	15 ms	β^-,n	n//80.				
^{24}N		24.050	<0.052 μs						
$_{8}$O		15.9994(3)							
^{12}O		12.03440	$\approx1.\times10^{-21}$ s	2p					
^{13}O		13.02481	8.9 ms	β^+,p/17.77	1.56 (p)/	(3/2-)	1.389	0.026	ann.rad.

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									4.438/0.56
^{14}O		14.0085953	70.60 s	β^{+}/5.1430	1.81/99.	0+			ann.rad.
									2.312/99.4
^{15}O		15.0030655	122.2 s	β^{+}/2.754	1.723/100.	1/2-	0.7195		ann.rad.
^{16}O	99.757(16)	15.99491462 2				0+			
^{17}O	0.038(1)	16.9991315				5/2+	-1.8938	-0.026	
^{18}O	0.205(14)	17.999160				0+			
^{19}O		19.003579	26.9 s	β^{-}/4.820	3.25/60.	5/2+	1.5320	3.7 mb	0.197/95.9
					4.60/40.				1.3569/50.4
									(0.11-4.18)
^{20}O		20.004076	13.5 s	β^{-}/3.814		0+			1.057/100.
^{21}O		21.00866	3.4 s	β^{-}/8.11					(0.28-4.6)
^{22}O		22.00997	2.2 s	β^{-}/6.5					(0.64-1.86)
^{23}O		23.0157	0.08 s						
^{24}O		24.0204	≈65 ms	β^{-},n	n//18.				1.83/28
									0.52/14.
									1.31/12.
^{25}O		25.029	<0.05 μs						
^{26}O		26.038	<0.04 μs						
$_{9}$F		18.9984032(5)							
^{14}F		14.036							
^{15}F		15.0180	5.x10^{-22} s	p		(1/2+)			
^{16}F		16.01147	≈1.x10^{-20} s	p		0-			
^{17}F		17.0020952	64.5 s	β^{+}/2.761	1.75/	5/2+	+4.721	0.058	ann.rad.
^{18}F		18.000938	1.830 h	β^{+},EC/1.656	0.635/97.	1+			ann.rad.
^{19}F	100.	18.9984032				1/2+	+2.62887	0.072	
^{20}F		19.9999813	11.00 s	β^{-}/7.0245	5.398/100.	2+	+2.0934	0.042	1.634/100.
									3.33/0.009
^{21}F		20.999949	4.16 s	β^{-}/5.684	3.7/8.	5/2+	3.9		0.3507/90.
					5.0/63.				1.395/15.
					5.4/29.				(1.746-4.684)
^{22}F		22.00300	4.23 s	β^{-}/10.82	3.48/15.	4+			1.2746/100.
					4.67/7.				2.0826/82.
					5.50/62.				(0.82-4.37)
^{23}F		23.00357	2.2 s	β^{-}/8.5		5/2+			1.701/48.
									2.129/34.
									(0.493-3.83)
^{24}F		24.0081	0.3 s	β^{-}/13.5					1.9816/
^{25}F		25.0121	≈50 ms	β^{-},(n)	n//14.				1.70/39.
									(0.57-2.19)
^{26}F		26.0196	10 ms	β^{-},(n)	n//11.				2.02/67.
									1.67/19.
^{27}F		27.0269	5. ms	β^{-},(n)	n//90.				
^{29}F		29.043	3. ms	β^{-},(n)	n//100.				
^{31}F									
$_{10}$Ne		20.1797(6)							
^{16}Ne		16.02575	4.x10^{-21} s	2p		0+			
^{17}Ne		17.01770	109. ms	β^{+} .p/14.53	1.4-10.6/	1/2-			ann.rad./
									0.495
^{18}Ne		18.005697	1.67 s	β^{+}/4.446	3.416/92.	0+			ann.rad./
									1.0413/7.8
									(0.658-1.70)
^{19}Ne		19.001880	17.22 s	β^{+}/3.238	2.24/99.	1/2+	-1.885		ann.rad./
									(0.11-1.55)
^{20}Ne	90.48(3)	19.99244017 6				0+			
^{21}Ne	0.27(1)	20.99384674				3/2+	-0.66180	+0.103	

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{22}Ne	9.25(3)	21.9913855				0+		-0.19	
^{23}Ne		22.9944673	37.2 s	β^-/4.376	3.95/32.	5/2+	-1.08		0.440/33.
					4.39/67.				(1.64-2.98)
^{24}Ne		23.99362	3.38 m	β^-/2.47	1.10/8.	0+			0.4723/100.
					1.98/92.				0.874/7.9
^{25}Ne		24.99779	0.61 s	β^-/7.30	6.3/	1/2+			0.0895/96.
					7.3/				(0.98-3.69)
^{26}Ne		26.00046	197 ms	β^-/7.3		0+			0.233/
^{27}Ne		27.0076	32 ms	β^-, n/12.7		(3/2+)			
^{28}Ne		28.0121	18. ms	β^-, n/12.3	n//11.	0+			2.06/19.
									0.86/3.
^{29}Ne		29.0194	15. ms	β^-,(n)/15.4	n//27.	(3/2+)			2.92/54.
									(0.22-1.18)
^{30}Ne		30.024	7. ms	β^-, (n)	n//9.	0+			
^{31}Ne		31.033	>0.26 μs						
^{32}Ne		32.040	>0.20 μs			0+			
$_{11}$Na		22.989770(2)							
^{18}Na		18.0272							
^{19}Na		19.01388	0.03 s	β^+,p/11.18					
^{20}Na		20.00735	0.446 s	β^+/13.89		2+	+0.3694		ann.rad./
				α	2.15/				1.634/79.
^{21}Na		20.997655	22.48 s	β^+/3.547	2.50/95.	3/2+	+2.3863	+0.05	ann.rad./
									0.351/5.
^{22}Na		21.9944366	2.605 y	β^+/90/2.842	0.545/90.	3+	+1.746		ann.rad./
				EC/10/					1.2745/99.9
^{23}Na	100.	22.9897697				3/2+	+2.21752	+0.104	
^{24m}Na			20.2 ms	I.T.,β^-		1+			0.4723/100.
^{24}Na		23.9909633	14.96 h	β^-/5.5158	1.389/>99.	4+	+1.690		1.3686/100.
									2.754/100.
									(0.997-4.238)
^{25}Na		24.989954	59.3 s	β^-/3.835	2.6/7.	5/2+	+3.683	-0.10	0.3897/12.7
					3.15/25.				0.5850/13.
					4.0/65.				0.9747/14.9
									(0.836-2.80)
^{26}Na		25.99259	1.07 s	β^-/9.31		3+	+2.851	-0.08	1.809/98.9
^{27}Na		26.99401	0.290 s	β^-/9.01	7.95/	5/2+	+3.90	0.24	0.9847/87.4
				β^-,n/					1.698/11.9
^{28}Na		27.9989	31. ms	β^-/14.0	12.3/	1+	+2.43	-0.02	1.473/37.
				β^-,n/					2.389/18.6
^{29}Na		29.0028	44. ms	β^-,n/13.3	11.5/	3/2+	+2.45	-1.3	2.560/36.
									(1.04-3.99)
^{30}Na		30.0092	50. ms	β^-/17.5		2	+2.08		1.483/46.
^{31}Na		31.0136	17.2 ms	/15.9		(3/2-)	+2.31		1.483/14.
				β^-,n					(0.05-3.54)
^{32}Na		32.0197	13.5 ms	β^-/19.1					0.886/60.
^{33}Na		33.027	8.1 ms	β^-/20.					0.886/16.
^{34}Na		34.035	5. ms	β^-/24.					0.886/60.
^{35}Na		35.044	1.5 ms	β^-/24					
$_{12}$Mg		24.3050(6)							
^{20}Mg		20.01886	96. ms	β^+,p/10.73		0+			
^{21}Mg		21.01171	122. ms	β^+,p/13.10		5/2+			0.332/51.
^{22}Mg		21.999574	3.86 s	β^+/4.786	3.05/	0+			0.0729/60.
									0.5820/100.
									(1.28-1.93)
^{23}Mg		22.994125	11.32 s	β^+/4.057	3.09/92.	3/2+	0.536	1.25	0.440/8.2
^{24}Mg	78.99(4)	23.9850419				0+			
^{25}Mg	10.00(1)	24.9858370				5/2+	-0.85545	+0.199	
^{26}Mg	11.01(3)	25.9825930				0+			
^{27}Mg		26.9843407	9.45 m	β^-/2.6103	1.59/41.	1/2+			0.17068/0.9

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
					1.75/58.				0.84376/72.
					2.65/0.3				1.01443/28.
^{28}Mg		27.983877	20.9 h	β^-/1.832	0.459/95.	0+			0.0306/95.
									0.4006/36.
									0.9418/36.
									1.342/54.
^{29}Mg		28.98855	1.3 s	β^-/7.55	5.4/	3/2+			0.960/15.
									1.398/16.
									2.224/36.
^{30}Mg		29.9905	0.32 s	β^-/7.0		0+			0.224/85.
^{31}Mg		30.9966	0.24 s	β^-/11.7		(3/2+)			1.61/26.
^{32}Mg		31.9992	0.12 s	β^-/10.3		0+			2.765/25.
^{33}Mg		33.0056	0.09 s	β^-/13.7					1.848/
^{34}Mg		34.0091	0.02 s	β^-/11.3		0+			
^{35}Mg		35.0175	0.07 s			(7/2-)			
^{36}Mg		36.022	>0.2 µs			0+			
^{37}Mg		37.031	>0.26 µs			(7/2-)			
^{38}Mg						0+			
$_{13}$Al		26.981538(2)							
^{21}Al		21.028	<0.035 µs						
^{22}Al		22.0195	59. ms	β^+/18.6		4+			ann.rad./
				β^+,p,2p,α/					
^{23m}Al			≈0.35 s	β^+,p/0.17					0.554
									0.839
^{23}Al		23.00727	0.47 s	β^+/12.24					ann.rad./
				β^+,p/					
^{24m}Al			0.129 s	I.T./0.4259					
				β^+	13.3	1+			1.3686/5.3
^{24}Al		23.999941	2.07 s	β^+/13.878,p	3.40/48.	4+			1.078(2)/16.
					4.42/41.				1.368(2)/96.
					6.80/3.				2.753(2)/43.
					8.74/8.				4.315(3)/15.
									5.392(3)/20.
									7.0662(2)/41.
^{25}Al		24.990429	7.17 s	β^+/4.277	3.27/	5/2+	3.646		ann.rad./
									1.6115(2)/100.
									0.975(2)/5.
^{26m}Al			6.345 s	β^+ /	3.2/	0+			ann.rad./
^{26}Al		25.9868917	7.1x10^5 y	β^+/82/4.0042	1.16/	5+	+2.804	+0.17	ann.rad./
				EC/18/					1.8087/99.8
^{27}Al	100.	26.9815384				5/2+	+3.64151	+0.140	
^{28}Al		27.9819102	2.25 m	β^-/4.6422	2.865/100.	3+	3.24	0.18	1.7778(6)/100.
^{29}Al		28.980445	6.5 m	β^-/3.680	1.4/30.	5/2+			1.2732(8)/89.
					2.5/70.				2.0282(8)/4.
									2.4262(8)/7.
^{30}Al		29.98296	3.68 s	β^-/8.56	5.05/	3+			1.26313(3)/35.
									2.23525(5)/65.
^{31}Al		30.98395	0.64 s	β^-/8.00	6.25/				0.75223(3)/18.
									1.69473(3)/59.
									2.31664(4)/73.
^{32}Al		31.9881	33. ms	β^-/13.0		1+			
^{33}Al		32.9909	41. ms						
^{34}Al		33.9969	≈42. ms	β^-/17.1					
^{35}Al		34.9999	30 ms						
^{36}Al		36.0064	0.09 s						
^{37}Al		37.010	>1 µs						
^{38}Al		38.0169	>0.2 µs						
^{39}Al		39.022	>0.2 µs						
^{40}Al									

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^{41}Al									
$_{14}$Si		28.0855(3)							
^{22}Si		22.0345	29. ms	β^+,p	1.99/20	0+			
^{23}Si		23.0255	40.7 ms	β^+,p/5.9	1.32,2.40,2.83				
^{24}Si		24.01155	0.14 s	β^+,p/10.81	1.51,4.09,1.73	0+			ann.rad./
					1.13-4.38				
^{25}Si		25.00411	221 ms	β^+,p/12.74		5/2+			ann.rad./
^{26}Si		25.992330	2.23 s	β^+/5.066	3.282/	0+			ann.rad./
									0.8294(8)/22.
^{27}Si		26.9867048	4.14 s	β^+/4.8118	3.85/100.	5/2+	-0.8554		ann.rad./
									2.211(5)/0.2
^{28}Si	92.22(2)	27.97692653				0+			
^{29}Si	4.69(1)	28.97649472				1/2+	-0.5553		
^{30}Si	3.09(1)	29.97377022				0+			
^{31}Si		30.9753633	2.62 h	β^-/1.4920	1.471/99.9	3/2+			1.2662(5)/0.05
^{32}Si		31.974148	1.6x10^2 y	β^-/0.224	0.213/100.	0+			
^{33}Si		32.97800	6.1 s	β^-/5.85	3.92	(3/2+)	1.21		1.4313(5)/13.
									1.8477/100.
									2.538(2)/10.
^{34}Si		33.97858	2.8 s	β^-/4.60	3.09/	0+			0.42907(5)/60.
									1.17852(2)/64.
									1.60756(5)/36.
^{35}Si		34.98458	0.9 s	β^-/10.50					
^{36}Si		35.9867	0.5 s	β^-/7.9		0^+			
^{37}Si		36.9930	≈0.09 s						
^{38}Si		37.9960	>1 µs			0^+			
^{39}Si		39.0023	>1 µs						
^{40}Si		40.0058	>0.2 µs			0^+			
^{41}Si		41.013	>0.2 µs						
^{42}Si		42.016	>0.2 µs			0^+			
$_{15}$P		30.973761(2)							
^{24}P		24.0344							
^{25}P		25.0203	<0.03 µs						
^{26}P		26.0118	≈20. ms	β^+,p/18.1		3+			
^{27}P		26.99919	0.3 s	β^+,p/11.63		1/2+			
^{28}P		27.992312	270. ms	β^+/14.332	3.94/13.	3+			ann.rad./
					5.25/13.				1.779(2)/98.
					6.96/16.				2.839(2)/2.8
					8.8/7.				3.040(2)/3.2
					11.49/52.				4.498(2)/12.
									7.537(2)/9.
^{29}P		28.981801	4.14 s	β^+/4.9431	3.945/98.	1/2+	1.2349		ann.rad./
									1.273/1.32
									2.426/0.39
^{30}P		29.9783138	2.50 m	β^+/4.2323	3.245/99.9	1+			ann.rad./
									2.230(3)/0.07
^{31}P	100.	30.9737615				1/2+	+1.13160		
^{32}P		31.9739071	14.28 d	β^-/1.7106	1.710/100.	1+	-0.2524		
^{33}P		32.971725	25.3 d	β^-/0.249	0.249/100.	1/2+			
^{34}P		33.973636	12.4 s	β^-/5.374	3.2/15.	1+			1.78-4.1/
					5.1/85.				2.127(5)/15.
^{35}P		34.973314	47. s	β^-/3.989	2.34/100.	1/2+			1.572(1)/100.
^{36}P		35.97826	5.7 s	β^-/10.41					0.902/77.
									3.291/100.
^{37}P		36.97961	2.3 s	β^-/7.90					0.6462/
									1.5829/
^{38}P		37.9845	0.6 s	β^-/12.4					1.2923/
									2.224/
^{39}P		38.9864	≈0.16 s						

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^{40}P		39.9911	≈0.26 s						
^{41}P		40.9948	0.12 s						
^{42}P		42.0001	0.11 s						
^{43}P		43.0033	33. ms	β^-,(n)/					
^{44}P		44.010	>0.2 μs						
^{45}P		45.015	>0.2 μs						
^{46}P		46.024	>0.2 μs						
$_{16}$S		32.065(5)							
^{26}S		26.0278	≈ 10 ms			0$^+$			
^{27}S		27.0188	21. ms	β^+, 2p/18.3					
^{28}S			0.13 s			0$^+$			
^{29}S		28.99661	0.188 s	β^+/13.79		5/2+			ann.rad./
				β^+,p/					
^{30}S		29.984903	1.18 s	β^+/6.138	4.42/78.	0+			ann.rad./
					5.08/20.				0.678/79.
^{31}S		30.979555	2.56 s	β^+/5.396	4.39/99.	1/2+	0.48793		ann.rad./
									1.2662(5)/1.2
^{32}S	94.93(31)	31.9720707				0+			
^{33}S	0.76(2)	32.9714585				3/2+	+0.64382	-0.68	
^{34}S	4.29(28)	33.9678668				0+			
^{35}S		34.9690321	87.2 d	β^-/0.1672	0.1674/100.	3/2+	+1.00	+0.047	
^{36}S	0.02(1)	35.9670809				0+			
^{37}S		36.9711257	5.05 m	β^-/4.8653	1.64/94.	7/2-			0.9083(4)/0.06
					4.75/5.6				3.1033(2)/94.2
^{38}S		37.97116	2.84 h	β^-/2.94	1.00/	0+			0.1962(4)/0.2
									1.9421(3)/84.
^{39}S		38.97514	11.5 s	β^-/6.64					1.301/52.
									1.697/44.
^{40}S		39.9755	9. s	β^-/4.7		0+			
^{41}S		40.9800	≈2.6 s						
^{42}S		41.9815	≈0.56 s	β,(n)/		0+			
^{43}S		42.987	0.22 s						
^{44}S		43.9883	0.12 s	β^-, n/9.		0+			
^{45}S		44.9948	0.08 s	β^-,n/					
^{46}S		45.9996	>0.2 μs			0+			
^{47}S		47.008	>0.2 μs						
^{48}S		48.013	>0.2 μs			0+			
^{49}S		49.022	<0.2 μs						
$_{17}$Cl		35.453(2)							
^{28}Cl		28.0285							
^{29}Cl		29.0141	<0.02 μs						
^{30}Cl		30.0048	<0.03 μs						
^{31}Cl		30.99242	0.15 s	β^+,p/11.98	1.52	3/2+			ann.rad./
^{32}Cl		31.98569	297. ms	β^+/12.69	4.75/25.	1+	1.11		ann.rad./
					6.18/10.				1.548(2)/3.5
					7.48/14.				2.2305(1)/92.
					9.47/50.				2.4638(1)/4.
					11.6/1.				2.885(1)/1.
									4.770(1)/20.
^{33}Cl		32.977452	2.511 s	β^+/5.583	4.51/98.	3/2+	+0.752		ann.rad./
									0.8409/0.52
									1.966/0.45
									2.866/0.44
^{34m}Cl			32.2 m	β^+/	1.35/24.	3+			ann.rad./
					2.47/28.				
				I.T./					0.1457(8)/42.
									2.1276(5)/42.
^{34}Cl		33.9737620	1.528 s	β^+/5.4922	4.50/100.	0+			ann.rad./
^{35}Cl	75.78(4)	34.96885271				3/2+	+0.82187	-0.0825	

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^{36}Cl		35.9683069	3.01x10^{5} y	β^-/0.7086	0.7093/98.	0+	+1.28547	-0.018	
				β^+,EC/1.1421	0.115/0.002				ann.rad./
^{37}Cl	24.22(4)	36.96590260				3/2+	+0.68412	-0.0649	
^{38m}Cl			0.715 s	I.T./		5-			0.6714/100
^{38}Cl		37.9680106	37.2 m	β^-/4.9168	1.11/31.	2-	2.05		1.64216(1)/31.
					2.77/11.				2.16760(2)/42.
					4.91/58.				
^{39}Cl		38.968008	55.6 m	β^-/3.442	1.91/85.	3/2+			0.25026(1)/47.
					2.18/8.				1.26720(5)/54.
					3.45/7.				0.986-1.517
^{40}Cl		39.97042	1.38 m	β^-/7.48		2-			0.6431(3)/6.
									1.4608(1)/77.
									2.8402(2)/17.
^{41}Cl		40.9707	34. s	β^-/5.7	3.8/				(0.167-1.359)
^{42}Cl		41.9732	6.8 s	β^-/9.4					
^{43}Cl		42.9742	3.3 s	β^-/8.0					
^{44}Cl		43.9785	≈0.43 s	β^-,n/12.3					
^{45}Cl		44.980	0.40 s	β^-, n/11.					
^{46}Cl		45.984	0.22 s	β^-, n/14.9					
^{47}Cl		46.988	>0.2 µs	β^-, n/15.					
^{48}Cl		47.995	>0.2 µs						
^{49}Cl		48.9999	>0.17 s						
^{50}Cl		50.008							
^{51}Cl		51.014	>0.2 µs						
$_{18}$Ar		39.948(1)							
^{30}Ar		30.0216	<0.02 µs			0+			
^{31}Ar		31.0121	≈14.1 ms	β^+/18.4	p/2.08/100.	5/2			
				β^+, 2p/<10^{-4}	p/1.42/37				
				β^+, 3p/<10^{-3}	p/0.45-11.67				
^{32}Ar		31.99766	98. ms	β^+,p/11.2		0+			ann.rad./
^{33}Ar		32.98993	174. ms	β^+/11.62	3.12/	1/2+	-0.72		ann.rad./
				β^+,p/					0.810(2)/48.
^{34}Ar		33.980270	0.844 s	β^+/6.061	5.0/95.	0+			ann.rad./
									0.6658(1)/2.5
									3.1290(1)/1.3
^{35}Ar		34.975257	1.77 s	β^+/5.965	4.94/93.	3/2+	+0.633	-0.08	ann.rad./
									1.2185(5)/1.22
									1.763(1)/0.25
									2.964(1)/0.2
^{36}Ar	0.3365(30)	35.9675463				0+			
^{37}Ar		36.9667759	35.0 d	EC/.813		3/2+	+1.15	+0.076	
^{38}Ar	0.0632(5)	37.9627322				0+			
^{39}Ar		38.964313	268. y	β^-/0.565	0.565/100.	7/2-	-1.59	-0.12	
^{40}Ar	99.6003(30)	39.962383123				0+			
^{41}Ar		40.964501	1.82 h	β^-/2.492	1.198/	7/2-			1.29364(5)/99.
									1.6770(3)/0.05
^{42}Ar		41.96305	33. y	β^-/0.60	0.60/100.	0+			
^{43}Ar		42.9657	5.4 m	β^-/4.6					0.4791(2)/10.
									0.7380(1)/43.
									0.9752(1)/100.
									1.4400(3)/39.
^{44}Ar		43.96537	11.87 m	β^-/3.55		0+			0.182-1.866
^{45}Ar		44.96809	21.5 s	β^-/6.9		7/2-			0.0610/25.
									1.020/35.
									3.707/34.
^{46}Ar		45.96809	8.4 s	β^-/5.70		0+			1.944/
^{47}Ar		46.9722	≈0.7 s	β^-					

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^{48}Ar		47.9751							
^{49}Ar		48.9822	>0.17 μs	β^-					
^{50}Ar		49.986	>0.17 μs	β^-					
^{51}Ar		50.993	>0.2 μs	β^-					
^{52}Ar		51.998	10 ms	β^-					
^{53}Ar		52.994		β^-					
$_{19}$K		39.0983(1)							
^{32}K		32.0219							
^{33}K		33.0073	<0.025 μs						
^{34}K		33.9984	<0.04 μs						
^{35}K		34.98801	0.19 s	β^+/11.88		3/2+			ann.rad./
				β^+,p/					1.751/14.
									2.5698/26.
									2.9827/51.
^{36}K		35.98129	0.342 s	β^+/12.81	5.3/42.	2+	+0.548		ann.rad./
					9.9/44.				1.97044(5)/82.
									2.20783(5)/30.
									2.43343(2)/32.
^{37}K		36.9733769	1.23 s	β^+/6.149	5.13/	3/2+	+0.2032		ann.rad./
									2.7944(8)/2.
									3.602(2)/0.05
^{38m}K			0.924 s	β^+/6.742	5.02/100.	0+			ann.rad./
^{38}K		37.969080	7.63 m	β^+/5.913	2.60/99.8	3+	+1.37		ann.rad./
									2.1675(3)/99.8
									3.9356(5)/0.2
^{39}K	93.2581(44)	38.9637069				3/2+	+0.39146	+0.049	
^{40}K	0.0117(1)	39.9639987	1.26x10^9 y	β^-/1.3111	1.312/89.	4-	-1.29810	-0.061	ann.rad./
				β^+,EC/1.505	1.50/10.7				1.4608/10.5
^{41}K	6.7302(44)	40.9618260				3/2+	+0.21487	+0.060	
^{42}K		41.9624031	12.36 h	β^-/3.525	1.97/19.	2-	-1.1425		0.31260(2)/0.3
					3.523/81.				1.5246(3)/18.
^{43}K		42.96072	22.3 h	β^-/1.82	0.465/8.	3/2+	+0.163		0.2211(2)/4.
					0.825/87.				0.3729(2)/88.
					1.24/3.5				0.3971(2)/11.
					1.814/1.3				0.6178(2)/81.
^{44}K		43.96156	22.1 m	β^-/5.66	5.66/34.	2-	-0.856		0.36821/2.2
									1.15700(1)/58.
									2.15079(2)/22.
^{45}K		44.96070	17.8 m	β^-/4.20	1.1/23.	3/2+	+0.173		0.1743(5)/80.
					2.1/69.				1.2607(8)/7.
					4.0/8.				1.7056(6)/69.
									2.3542(5)/14.
^{46}K		45.96198	1.8 m	β^-/7.72	6.3/	2-	-1.05		1.347(1)/91.
									3.700(5)/28.
^{47}K		46.96168	17.5 s	β^-/6.64	4.1/99.	1/2+	+1.93		0.56474(3)/15.
					6.0/1.				0.58575(3)/85.
									2.0131/100
^{48}K		47.96551	6.8 s	β^-/12.09	5.0/	(2-)			0.67122(1)/4.
									0.6723(5)/20.
									0.78016(1)/32.
									3.83153(7)/80.
^{49}K		48.9675	1.26 s	β^-/11.0					2.025/
									2.252/
^{50}K		49.9728	0.472 s	β^-/14.2					
^{51}K		50.9764	0.365 s	β^-/					
^{52}K		51.983	0.105 s	β^-					
^{53}K		52.987	30. ms	β^-		3/2+			
^{54}K		53.994	10. ms	β^-					

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$_{20}$Ca		40.078(4)							
^{34}Ca		34.0141	<0.035 μs						
^{35}Ca		35.0048	25.7 ms	β^+,p/15.6	p/1.43/49				
					1.9-8.8				
^{36}Ca		35.99309	0.10 s	β^+,(p)/10.99	2.52				ann.rad./
				β^+,n/					
^{37}Ca		36.98587	0.18 s	β^+/11.64	3.103	3/2+			ann.rad./
				β^+,n/					1.369
^{38}Ca		37.976319	0.44 s	β^+/6.74		0+			ann.rad./
									1.5677(5)/25.
									3.210(2)/1.
^{39}Ca		38.970718	0.861 s	β^+/6.531	5.49/100.	3/2+	1.02168		ann.rad./
^{40}Ca	96.941(156)	39.9625912				0+			
^{41}Ca		40.9622783	1.02x10^5 y	EC/0.4214		7/2-	-1.5948	-0.08	
^{42}Ca	0.647(23)	41.9586183				0+			
^{43}Ca	0.135(10)	42.9587668				7/2-	-1.3173	-0.05	
^{44}Ca	2.086(110)	43.955481				0+			
^{45}Ca		44.956186	162.7 d	β^-/0.257	0.257/100.	7/2-	-1.327	+0.05	
^{46}Ca	0.004(3)	45.953693	>0.4×10^{16} y	$\beta^-\beta^-$		0+			
^{47}Ca		46.954546	4.536 d	β^-/1.992	0.684/84.	7/2-	-1.38	+0.02	1.297/75
					1.98/16.				(0.041-1.88)
^{48}Ca	0.187(21)	47.952533	4.3×10^{19} y	$\beta^-\beta^-$		0+			
^{49}Ca		48.955673	8.72 m	β^-/5.262	0.89/7.	3/2-			3.0844(1)/92.
					1.95/92.				4.0719(1)/7.
^{50}Ca		49.95752	14. s	β^-/4.97	3.12/	0+			0.2569/98.
									(0.0715 -1.59)
^{51}Ca		50.9615	10. s	β^-/7.3		(3/2-)			
^{52}Ca		51.9651	4.6 s	β^-/8.0					
^{53}Ca		52.9701	0.09 s	β^-/10.9					
^{54}Ca		53.975							
^{55}Ca		54.981							
^{56}Ca		55.986							
$_{21}$Sc		44.955910(8)							
^{36}Sc		36.0149							
^{37}Sc		37.0030							
^{38}Sc		37.9947	<0.3 μs						
^{39}Sc		38.98479	<0.3 μs	p					
^{40}Sc		39.977964	0.182 s	β^+/14.320	5.73/50.	4-			ann.rad./
					7.53/15.				0.752/41.
					8.76/15.				3.732/99.5
					9.58/20.				(1.12-3.92)
^{41}Sc		40.9692513	0.596 s	β^+/6.4953	5.61/100.	7/2-	+5.431	-0.156	ann.rad./
^{42m}Sc			61.6 s	β^+/	2.82/	7+			ann.rad./
									0.4375(5)/100.
									1.2270(5)/100.
									1.5245(5)/100.
^{42}Sc		41.9655168	0.682 s	β^+/6.4259	5.32/100.	0+			ann.rad./
^{43}Sc		42.961151	3.89 h	β^+,EC/2.221	0.82/22.	7/2-	+4.62	-0.26	ann.rad./
					1.22/78.				0.3729(1)/22.
^{44m}Sc			58.2 h	I.T./0.27		6+	+3.88		0.27124(1)/87.
				EC/3.926					(1.00-1.16)
^{44}Sc		43.959403	3.93 h	β^+, EC/3.653	1.47/	2+	+2.56	+0.10	ann.rad./
									1.157/100
^{45}Sc	100.	44.955910				7/2-	+4.75649	-0.220	
^{46m}Sc			18.7 s	I.T./0.14253		1-			0.14253(2)/62.
^{46}Sc		45.955170	83.81 d	β^-/2.367	0.357/100.	4+	+3.03	+0.12	0.8893/100
									1.121/100

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^{47}Sc		46.952408	3.349 d	β^-/0.600	0.439/69.	7/2-	+5.34	-0.22	0.15938(1)/68.
					0.601/31.				
^{48}Sc		47.95224	43.7 h	β^-/3.99	0.655/	6+			0.9835/100
									1.03750(1)/97.
									1.3121/100
^{49}Sc		48.950024	57.3 m	β^-/2.006	2.00/99.9.	7/2-			1.7619(3)/0.05
^{50}Sc		49.95219	1.71 m	β^-/6.89	3.05/76.	(5+)			0.5235(1)/88.
					3.60/24.				1.1210(1)/100.
									1.5537(2)/100.
^{51}Sc		50.95360	12.4 s	β^-/6.51	4.4/	7/2-			1.4373(4)/52.
					5.0/				0.718-2.144
^{52}Sc		51.9566	8.2 s	β^-/9.0		(3+)			
^{53}Sc		52.9592	> 3. ms	β^-/8.1					
^{54m}Sc			≈ 7 µs			(5+)			0.110/IT
^{54}Sc		53.9630	0.23 s	β^-/11.6					0.100/50
									1.70/40
									0.50/40
^{55}Sc		54.967	0.12 s	β^-/13					
^{56}Sc		55.973							
^{57}Sc		56.977							
^{58}Sc		57.983							
$_{22}$Ti		47.867(1)							
^{38}Ti		38.0098	<0.12 µs						
^{39}Ti		39.0013	28. ms	β^+/15.4					
^{40}Ti		39.9905	52. ms	β^+/11.7	p/2.17/28				
				β^+,p	3.73/23				
					1.7/22				
					0.242-5.74				
^{41}Ti		40.98313	80. ms	β^+,p/12.93	p/4.73/107	3/2+			ann.rad./
					3.10/67				
					3.75/39				
					0.744-6.73				
^{42}Ti		41.97303	0.20 s	β^+/7.000	6.0/				ann.rad./
									0.6107(5)/56.
^{43}Ti		42.96852	0.50 s	β^+/6.87	5.80/	7/2-	0.85		ann.rad./
^{44}Ti		43.959690	60. y	EC/0.268		0+			0.06787/91
									0.07832/97
^{45}Ti		44.958124	3.078 h	β^+/86/2.062	1.04	7/2-	0.095	0.015	ann.rad./
				EC/14/					(0.36-1.66)
^{46}Ti	8.25(3)	45.952630				0+			
^{47}Ti	7.44(2)	46.951764				5/2-	-0.78848	+0.30	
^{48}Ti	73.72(3)	47.947947				0+			
^{49}Ti	5.41(2)	48.947871				7/2-	-1.10417	+0.24	
^{50}Ti	5.18(2)	49.944792				0+			
^{51}Ti		50.946616	5.76 m	β^-/2.471	1.50/92.	3/2-			0.3197(2)/93.
					2.13/				0.6094-0.9291
^{52}Ti		51.94690	1.7 m	β^-/1.97	1.8/100.	0+			0.0170(5)/100.
									0.1245/100
^{53}Ti		52.9497	33. s	β^-/5.0	(2.2-3)/	3/2-			0.1008(1)/20.
									0.1276(1)/45.
									0.2284(1)/39.
									1.6755(5)/45.
									(1.72-2.8)/
^{54}Ti		53.9509	1.5 s	β^-/4.3					
^{55}Ti		54.9551	0.32 s	β^-/7.4					
^{56}Ti		55.9580	0.19 s	β^-/7.0					
^{57}Ti		56.963	0.06 s	β^-/11.					
^{58}Ti		57.966	≈47 ms						
^{59}Ti		58.972	0.06 s						

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^{60}Ti		59.976	>0.15 µs						
^{61}Ti		60.982	>0.15 µs						
$_{23}$V		50.9415(1)							
^{40}V		40.0111							
^{41}V		40.9997							
^{42}V		41.9912	<0.055 µs						
^{43}V		42.9807	>0.8 s	β$^+$/11.3					
^{44}V		43.9744	0.09 s	β$^+$,α/13.7					ann.rad./
^{45}V		44.96578	0.54 s	β$^+$/7.13		7/2-			
^{46}V		45.960200	0.4223 s	β$^+$/7.051	6.03/100.	0+			ann.rad./
^{47}V		46.954907	32.6 m	β$^+$,EC/2.928	1.90/99.+	3/2-			ann.rad./
									1.7949(8)/0.19
									(0.2-2.16)
^{48}V		47.952254	15.98 d	β$^+$/4.012	0.698/50.	4+	2.01		ann.rad./
									0.9835/100
									(1.3-2.4)
^{49}V		48.948517	337. d	EC/0.602		7/2-	4.47		
^{50}V	0.250(4)	49.947163	>1.4x10^{17} y	EC, β$^-$		6+	+3.34569	+0.21	
^{51}V	99.750(4)	50.943964				7/2-	+5.148706	-0.04	
^{52}V		51.944780	3.76 m	β$^-$/3.976	2.47/	3+			1.4341(1)/100.
^{53}V		52.944342	1.56 m	β$^-$/3.436	2.52/	7/2-			1.0060(5)/90.
									1.2891(3)/10.
^{54m}V			0.9 µs			(5+)			0.108/IT
^{54}V		53.94644	49.8 s	β$^-$/7.04	1.00/5.	3+			0.8348/97.
					2.00/12.				0.9887/80.
					2.95/45.				2.259/46.
					5.20/11.				(0.56-3.38)
^{55}V		54.9472	6.5 s	β$^-$/6.0	6.0/	(7/2-)			0.5177/73.
									(0.224-1.21)
^{56}V		55.9504	0.23 s	β$^-$/9.1					0.70/50.
									0.34/40.
									1.00/30.
^{57}V		56.9524	0.33 s	β$^-$/8.1					0.30/60.
									0.60/30.
									0.80/30.
^{58}V		57.9567	0.20 s	β$^-$/11.6					
^{59}V		58.9593	0.13 s	β$^-$/9.9					0.90/80.
^{60}V		59.965	0.20 s	β$^-$/14.					0.102-0.208
^{61}V		60.967	0.04 s						0.646
^{62}V		61.973	≈ 65 ms						
^{63}V		62.977	>0.15 µs						
^{64}V			>0.15 µs						
$_{24}$Cr		51.9961(6)							
^{42}Cr		42.0064	>0.35 µs						
^{43}Cr		42.9977	21. ms						
^{44}Cr		43.9855	53. ms	β$^+$,(p)/10.3	p/0.95-3.1				
^{45}Cr		44.9792	0.05 s	β$^+$,p/12.5		7/2-			ann.rad./
^{46}Cr		45.96836	0.3 s	β$^+$/7.60					ann.rad./
^{47}Cr		46.96291	0.51 s	β$^+$/7.45		3/2-			ann.rad./
^{48}Cr		47.95404	21.6 h	EC/1.66					ann.rad./
									0.116(2)/95.
									0.305(10)/100.
^{49}Cr		48.951341	42.3 m	β$^+$,EC/2.631	1.39/	5/2-	0.476		ann.rad./
					1.45/				0.09064(1)/51.
					1.54/				0.15293(1)/27.
									(0.062-1.6)
^{50}Cr	4.345(13)	49.946050				0+			

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^{51}Cr		50.944772	27.70 d	EC/0.7527		7/2-	-0.934		0.3201/10.2
^{52}Cr	83.789(18)	51.940512				0+			
^{53}Cr	9.501(17)	52.940653				3/2-	-0.47454	-0.15	
^{54}Cr	2.365(7)	53.938885				0+			
^{55}Cr		54.940844	3.497 m	β^-/2.603	2.5/	3/2-			1.5282(2)/0.04
									(0.13-2.37)
^{56}Cr		55.94065	5.9 m	β^-/1.62	1.50/100.	0+			0.026(2)/100.
									0.083(3)/100.
^{57}Cr		56.9438	21. s	β^-/5.1	3.3/	3/2-	0.0834		0.850/8.
					3.5/				(0.083-2.62)
^{58}Cr		57.9443	7.0 s	β^-/4.0					(0.131-0.683)
^{59m}Cr			0.10 ms			(9/2+)			0.208/IT
									0.193
									0.102
^{59}Cr		58.9487	1.0 s	β^-/7.7					1.236
^{60}Cr		59.9497	0.6 s	β^-/6.0					
^{61}Cr		60.9541	0.26 s	β^-/8.8					0.354-1.860
^{62}Cr		61.9558	0.19 s	β^-/7.3					0.285
^{63}Cr		62.962	0.11 s						
^{64}Cr		63.964	0.04 s						
^{65}Cr		64.970	>0.15 µs						
^{66}Cr			>0.15 µs						
^{67}Cr									
$_{25}$Mn		54.938049(9)							
^{44}Mn		44.0069	<0.105 µs						
^{45}Mn		44.9945	<0.07 µs						
^{46}Mn		45.9867	≈41. ms	β^+/17.1					
^{47}Mn		46.9761	≈0.1 s	β^+/12.3					
^{48}Mn		47.9689	0.15 s	β^+/13.5	5.79/58.	4+			
					4.43/10.				
^{49}Mn		48.95962	0.38 s	β^+/7.72	6.69/	5/2-			ann.rad./
^{50m}Mn			1.74 m	β^+/7.887	3.54/	5+			ann.rad./
									1.0980/94.
									0.783/91.
									(0.66-3.11)
^{50}Mn		49.954244	0.283 s	β^+/7.6330	6.61/	0+			ann.rad./
^{51}Mn		50.948215	46.2 m	β^+,EC/3.208	2.2/	5/2-	3.568	0.4	ann.rad./
									0.7491(1)/0.26
									(1.148-1.164)
^{52m}Mn			21.1 m	β^+/98/5.09	2.631/	2+	0.0076		ann.rad./
				I.T./2/0.378					0.3778 (I.T.)
									1.43406(1)/98.
									(0.7-4.8)
^{52}Mn		51.945570	5.591 d	β^+/4.712	0.575/	6+	+3.063	+0.5	ann.rad./
				EC/					0.74421(1)/90.
									1.4341/100
^{53}Mn		52.941294	$3.7x10^6$ y	EC/0.5970		7/2-	5.024		
^{54}Mn		53.940363	312.1 d	EC/1.377		3+	+3.282	+0.33	0.8340/100
^{55}Mn	100.	54.938049				5/2-	+3.4687	+0.32	
^{56}Mn		55.938909	2.579 h	β^-/3.6954	0.718/18.	3+	+3.2266		0.84675/99
					1.028/34.				1.81072(4)/27.
									2.113/14.5
^{57}Mn		56.938287	1.45 m	β^-/2.691		5/2-			
^{58}Mn		57.93999	65 s	β^-/6.25	3.8/	3+			0.45916(2)/20.
					5.1/				0.81076(1)/82.
									1.32309(5)/53.
^{59}Mn		58.94045	4.6 s	β^-/5.19	4.5/				0.471/
									0.531-0.726
^{60m}Mn			1.77 s	β^-/IT	5.7/	3+			0.824/

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^{60}Mn		59.9433	50. s	β^-/8.6		0+			1.969/
^{61}Mn		60.9446	0.67 s	β^-/7.4		(5/2)-			
^{62}Mn		61.9480	0.67 s	β^-/10.4		(3+)			0.877/
									0.942-1.299
^{63}Mn		62.9498	0.28 s	β^-/8.8					0.356,0.450
^{64m}Mn			> 0.1 ms						0.135/IT
^{64}Mn		63.9537	87 ms	β^-/11.8					0.746
^{65}Mn		64.9561	0.09 s	β^-/10.					0.366
^{66}Mn		65.961	66 ms						0.471
^{67}Mn		66.964	42 ms						
^{68}Mn			28 ms						
^{69}Mn			14 ms						
$_{26}$Fe		55.845(2)							
^{45}Fe		45.0146	>0.35 μs						
^{46}Fe		46.0008	≈0.02 s	β^+/13.1					
^{47}Fe		46.9929	≈0.03 s	β^+/15.6					
^{48}Fe		47.9806	≈ 44. ms	β^+/11.2					
^{49}Fe		48.9763	70. ms	β^+/13.0		(7/2-)			ann.rad./
^{50}Fe		49.9630	0.15 s	β^+/8.2					0.651
^{51}Fe		50.95683	0.31 s	β^+/8.02		(5/2-)			ann.rad./
^{52m}Fe			46. s	β^+/4.4		(12+)			ann.rad./
									(0.622-2.286)/
^{52}Fe		51.94812	8.28 h	β^+/57/2.37	0.804/	0+			ann.rad./
				EC/43/					0.16868(1)/99.
				I.T./					0.377 (I.T.)/
^{53m}Fe			2.6 m	I.T./3.0407		19/2-			0.7011(1)/99.
									1.0115(1)/87.
									1.3281(1)/87.
									2.3396(1)/13.
^{53}Fe		52.945312	8.51 m	β^+/3.743	2.40/42.	7/2-			ann.rad./
					2.80/57.				0.3779(1)/42.
									(1.2 - 3.2)
^{54}Fe	5.845(35)	53.939615				0+			
^{55}Fe		54.938298	2.73 y	EC/0.2314		3/2-			
^{56}Fe	91.754(36)	55.934942				0+			
^{57}Fe	2.119(10)	56.935398				1/2-	+0.0906	0.16	
^{58}Fe	0.282(4)	57.933280				0+			
^{59}Fe		58.934880	44.51 d	β^-/1.565	0.273/48.	3/2-	- 0.336		1.099/57
					0.475/51.				1.292/43.
									(0.14-1.48)
^{60}Fe		59.934077	1.5x10^{6} y	β^-/0.237	0.184/100.	0+			0.0586/100
^{61m}Fe			0.25 μs			(9/2+)			0.654/IT
									0.207
^{61}Fe		60.93675	6.0 m	β^-/3.98	2.5/13.				1.205/44.
					2.63/54.				1.028/43.
					2.80/31.				(0.12-3.37)
^{62}Fe		61.93677	68. s	β^-/2.53	2.5/100.	0+			0.5061(1)/100.
^{63}Fe		62.9404	6. s	β^-/6.3		5/2-			0.995/
									(1.365-1.427)
^{64}Fe		63.9411	2.0 s	β^-/4.9					
^{65m}Fe			0.4 μs			(5/2-)			0.364/IT
^{65}Fe		64.9449	1.3 s	β^-/7.9					
^{66}Fe		65.9460	0.44 s	β^-/5.7					0.471-1.425
^{67m}Fe			≈0.04 ms			(5/2-)			0.367/IT
^{67}Fe		66.9500	0.48 s	β^-/8.8					0.189
^{68}Fe		67.953	0.15 s	β^-/≈7.6					
^{69}Fe		68.958	0.17 s						
^{70}Fe			>0.15 μs						
^{71}Fe			>0.15 μs						

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^{72}Fe			>0.15 μs						
$_{27}$Co		58.933200(9)							
^{48}Co		48.0018							
^{49}Co		48.990	<0.035 μs						
^{50}Co		49.9812	44. ms	β^+/17.0	2.03-2.79				
^{51}Co		50.9705	>0.2 μs	β^+/12.8					
^{52}Co		51.9632	0.12 s	β^+/14.0					0.849-1.942
^{53m}Co			0.25 s	β^+,p/		19/2-			ann.rad./
^{53}Co		52.95423	0.26 s	β^+/8.30		7/2-			ann.rad./
^{54m}Co			1.46 m	β^+/8.44	4.25/100.	7+			ann.rad./
									0.411(1)/99.
									1.130(1)/100.
									1.408(1)/100.
^{54}Co		53.948464	0.1932 s	β^+/8.2430	7.34/100.	0+			ann.rad./
^{55}Co		54.942003	17.53 h	β^+/3.4513	0.53/	7/2-	+4.822		ann.rad./
				EC/	1.03/				0.9312/75.
					1.50/				0.4772/20.
									(0.092-3.11)
^{56}Co		55.939844	77.3 d	β^+/4.566	1.459/18.	4+	3.85	+0.25	ann.rad./
				EC/					0.8468/99.9
									1.2383/68.
									(0.26-3.61)
^{57}Co		56.936296	271.8 d	EC/0.8361		7/2-	+4.72	+0.5	0.12206/86
									(0.014-0.706)
^{58m}Co			9.1 h	I.T./		5+			0.02489/0.035
^{58}Co		57.935757	70.88 d	β^+/2.307		2+	+4.04	+0.22	ann.rad./
				EC/					0.81076/99
^{59}Co	100.	58.933200				7/2-	+4.63	+0.41	
^{60m}Co			10.47 m	I.T./99.8/0.059		2+	+4.40	+0.3	0.0586/2.0
				β^-/0.2/1.56					
^{60}Co		59.933822	5.271 y	β^-/2.824	0.315/99.7	5+	+3.799	+0.44	1.1732/100
									1.3325/100
^{61}Co		60.932479	1.650 h	β^-/1.322	1.22/95.	7/2-			0.0674/86.
									0.842-0.909
^{62m}Co			13.9 m	β^-/	0.88/25.	5+			1.1635(3)/70.
					2.88/75.				1.1730(3)/98.
									2.0039(3)/19.
^{62}Co		61.93405	1.50 m	β^-/5.32	1.03/10.	2+			1.1292(3)/13.
					1.76/5.				1.1730(3)/83.
					2.9/20.				1.9851(1)/3.
					4.05/60.				2.3020(1)/19.
^{63}Co		62.93362	27.5 s	β^-/3.67	3.6/	7/2-			0.08713(1)/49.
									0.9817(3)/2.6
									0.156-2.17
^{64}Co		63.93581	0.30 s	β^-/7.31	7.0/	1+			
^{65}Co		64.93648	1.14 s	β^-/5.96		(7/2)-			
^{66m2}Co			>0.1 ms			(8-)			0.252/IT
									0.214
									0.175
^{66m1}Co			1.2 μs			(5+)			0.175/IT
^{66}Co		65.9398	0.25 s	β^-/10.0					(1.245-1.425)
^{67}Co		66.9406	0.43 s	β^-/8.4					0.694
^{68}Co		67.9444	0.19 s	β^-/11.7					
^{69}Co		68.9452	0.20 s	β^-/9.3					
^{70}Co		69.950	0.09 s	β^- 13.					
^{71}Co		70.952	0.21 s	β					
^{72}Co		71.956	0.09 s	β					
^{73}Co			>0.15 μs						
^{74}Co			>0.15 μs						

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{75}Co			>0.15 µs						
$_{28}$Ni		58.6934(2)							
^{49}Ni			>0.35 µs						
^{50}Ni		49.9959	>0.3 µs						
^{51}Ni		50.9877	>0.2 µs	β^+/16.0					
^{52}Ni		51.9757	38. ms	β^+/11.7					
^{53}Ni		52.9685	0.05 s	β^+,p/13.3		7/2-			ann.rad./
^{54}Ni		53.95791	0.14 s	β^+/8.80					0.937
^{55}Ni		54.95134	0.20 s	β^+/8.70	7.66/	7/2-			ann.rad./
^{56}Ni		55.94214	6.08 d	EC/2.14		0+			0.15838/99
				β^+/< 10^{-6}					0.81185(3)/87.
									0.2695-0.7500
^{57}Ni		56.939800	35.6 h	β^+/3.264	0.712/10.	3/2-	- 0.798		ann.rad./
				EC/	0.849/76.				1.3776/78.
									(0.127-3.177)
^{58}Ni	68.0769(89)		57.93534 8			0+			
^{59}Ni		58.934351	≈7.6x10^4 y	EC/		3/2-			
^{60}Ni	26.2231(77)		59.93079 0			0+			
^{61}Ni	1.1399(6)	60.931060				3/2-	-0.75002	+0.16	
^{62}Ni	3.6345(17)	61.928348				0+			
^{63}Ni		62.929673	100. y	β^-/0.066945	0.065/	1/2-			
^{64}Ni	0.9256(9)	63.927969				0+			
^{65}Ni		64.930088	2.517 h	β^-/2.137	0.65/30.	5/2-	0.69		0.36627(3)/5.
					1.020/11.				1.11553(4)/16.
					2.140/58.				1.48184(5)/23.
^{66}Ni		65.92912	54.6 h	β^-/0.23		0+			
^{67m}Ni			13.3 µs			9/2+			0.313/IT
									0.694
^{67}Ni		66.93157	21. s	β^-/3.56	3.8/	1/2-	+0.601		1.0722/100.
									1.6539/100.
									(0.10-1.98)
^{68m2}Ni			0.34 µs			0+			0.511
^{68m1}Ni			0.86 ms			(5-)			0.814/IT
									2.033
^{68}Ni		67.93185	29. s	β^-/2.06					
^{69m2}Ni			0.44 µs			(17/2)			0.148/IT
									0.593
									1.959
^{69m1}Ni			3.5 s						
^{69}Ni		68.9352	11. s	β^-/5.4					0.6807(3)/100.
									(0.207-1.213)
^{70m}Ni			0.21 µs			(8+)			0.183/IT
									0.448
									0.970
									1.259
^{70}Ni		69.9361	6.0 s	β^-/3.5					
^{71}Ni		70.9400	2.56 s	β^-/6.9					
^{72}Ni		71.9413	1.6 s	β^-/5.2					
^{73}Ni		72.946	0.84 s	β^-/9.					
^{74}Ni		73.948	1.1 s	β^-/7.					
^{75}Ni		74.953	≈ 0.47 s						
^{76}Ni		75.955	≈ 0.24 s						
^{77}Ni		76.961	>0.15 µs						
^{78}Ni		77.964	>0.15 µs						
$_{29}$Cu		63.546(3)							
^{52}Cu		51.9972							

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^{53}Cu		52.9856	<0.3 μs						
^{54}Cu		53.9767	<0.075 μs						
^{55}Cu		54.9655	>0.2 μs	β^+/13.2					
^{56}Cu		55.9586	0.08 s	β^+/15.3					0.511/233
									2.700/100
									1.23-2.78
^{57}Cu		56.94922	196. ms	β^+/8.77		3/2-			0.77-3.01
^{58}Cu		57.944541	3.21 s	β^+/8.563	4.5/15.	1+			ann.rad./
				EC/	7.439/83.				0.0403(4)/5.
									1.4483(2)/11.
									1.4546(2)/16.
^{59}Cu		58.939504	1.36 m	β^+/4.800	1.9/	3/2-			ann.rad./
					3.75/				0.3393(1)/8.
									0.8780(1)/12.
									1.3015(1)/15.
									(0.4 - 2.6)
^{60}Cu		59.937368	23.7 m	β^+/6.127	2.00/69.	2+	+1.219		ann.rad./
				EC/	3.00/18.				1.3325/88.
					3.92/6.				1.7915/45.
									(0.12-5.048)
^{61}Cu		60.933462	3.35 h	β^+/2.237	0.56/3.	3/2-	+2.14		ann.rad./
					0.94/5.				0.2830/13.
					1.15/2.				0.6560/11.
					1.220/51.				(0.067-2.123)
^{62}Cu		61.932587	9.67 m	β^+/98/3.948	2.93/98.	1+	-0.380		ann.rad./
				EC/					1.17302(1)/0.6
									(0.87-3.37)
^{63}Cu	69.17(3)	62.929601				3/2-	+2.2233	-0.211	
^{64}Cu		63.929768	12.701 h	β^-/39/0.579	0.578/	1+	-0.217		ann.rad./
				β^+/19/1.6751	0.65/				1.3459(3)/0.6
				EC/41/					
^{65}Cu	30.83(3)	64.927794				3/2-	+2.3817	-0.195	
^{66}Cu		65.928873	5.09 m	β^-/2.642	1.65/6.	1+	-0.282		0.8330(1)/0.22
					2.7/94.				1.0392(2)/9.2
^{67}Cu		66.92775	2.580 d	β^-/0.58	0.395/56.	3/2-			0.09125(1)/7.
					0.484/23.				0.09325(1)/17.
					0.577/20.				0.18453(1)/47.
^{68m}Cu			3.79 m	I.T./86/		6-			0.0843(5)/70.
				β^-/14/1.8					0.1112(5)/18.
									0.5259(5)/74.
									(0.64-1.34)
^{68}Cu		67.92964	31. s	β^-/4.46	3.5/40.	1+			1.0774(5)/58.
					4.6/31.				1.2613(5)/17.
									(0.15-2.34)
^{69m}Cu			0.36 μs			(13/ 2+)			0.075/IT
									0.190/IT
									0.680
									1.871
^{69}Cu		68.92943	2.8 m	β^-/2.68	2.48/80.	3/2-	+2.84		0.5307(3)/3.
									0.8340(5)/6.
									1.0065(8)/10.
^{70m}Cu			47. s	β^-/	2.52/10.	5-			0.8848(2)/100.
									0.9017(2)/90.
									1.2517(5)/60.
									(0.39-3.06)
^{70}Cu		69.93241	5. s	β^-/6.60	5.42/54.	1+			0.8848(2)/54.
					6.09/46.				

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^{71m}Cu			0.28 µs			(19/2)			0.133/IT
									0.494
									0.939
									1.189
^{71}Cu		70.93262	20. s	β^-/4.56		3/2-			0.490/
^{72m}Cu			1.76 µs			(4-)			0.051/IT
									0.082
									0.138
^{72}Cu		71.9357	6.6 s	β^-/8.2		(1+)			0.652/
^{73}Cu		72.9365	4.2 s	β^-/6.3	5.8/43				0.450/100
					6.25/42				0.307-1.559
^{74}Cu		73.9401	1.6 s	β^-/9.9					
^{75}Cu		74.9414	1.2 s	β^-/7.9					
^{76}Cu		75.9455	0.64 s	β^-/11.					
^{77}Cu		76.947	0.47 s	β^-/≈10.					
^{78}Cu		77.952	0.34 s	β^-/12.					
^{79}Cu		78.954	0.19 s	β^-/11.					
^{80}Cu		79.962	>0.15 µs						
$_{30}$Zn		65.39(2)							
^{54}Zn		53.9929							
^{55}Zn		54.9840							
^{56}Zn		55.9724	0.04 s						
^{57}Zn		56.9649	0.04 s	β^+,p/14.6		(7/2-)			ann.rad./
^{58}Zn		57.9546	0.09 s	β^+					
^{59}Zn		58.94927	183. ms	β^+,p/9.09	8.1/	3/2-			ann.rad./
									(0.491-0.914)
^{60}Zn		59.94183	2.40 m	β^+/97/4.16		0+			ann.rad./
				EC/3/					0.669/47.
									(0.062-0.947)
^{61}Zn		60.93951	1.485 m	β^+/5.64	4.38/68.	3/2-			ann.rad./
									0.4748/17.
									(0.15-3.52)
^{62}Zn		61.93433	9.22 h	β^+/3/1.63	0.66/7.	0+			ann.rad./
				EC/93/					0.0408/25
									0.5967/26.
									(0.20-1.526)/
^{63}Zn		62.933215	38.5 m	β^+/93/3.367	1.02/	3/2-	-0.28164	+0.29	ann.rad./
				EC/7/	1.40/				0.66962(5)/8.4
					1.71/				0.96206(5)/6.6
					2.36/84.				(0.24-3.1)
^{64}Zn	48.63(60)	63.929146				0+			
^{65}Zn		64.929245	243.8 d	β^+/98/1.3514	0.325/	5/2-	+0.7690	-0.023	ann.rad./
				EC/1.5/					1.116/50.8
^{66}Zn	27.90(27)	65.926036				0+			
^{67}Zn	4.10(13)	66.927131				5/2-	+0.8755	+0.15	
^{68}Zn	18.75(51)	67.924847				0+			
^{69m}Zn			13.76 h	I.T./99+/0.439		9/2+			0.4390(2)/95.
^{69}Zn		68.926553	56. m	β^-/0.906	0.905/99.9	1/2-			0.318/
^{70}Zn	0.62(3)	69.925325				0+			
^{71m}Zn			3.97 h	β^-/	1.45/	9/2+			0.3864/93.
									0.4874/62.
									0.6203/57.
									(0.099-2.489)
^{71}Zn		70.92773	2.4 m	β^-/2.81		1/2-			0.5116(1)/30.
									0.9103(1)/7.5
									(0.12-2.29)
^{72}Zn		71.92686	46.5 h	β^-/0.46	0.25/14.	0+			0.0164(3)/8.
					0.30/86.				0.1447(1)/83.
									0.1915(2)/9.4

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^{73m}Zn			6. s		I.T./0.196	(7/2+)			0.042
^{73}Zn		72.92978	24. s	β^-/4.29	4.7/	(1/2-)			0.216(1)/100.
									0.496-0.911
^{74}Zn		73.92946	1.60 m	β^-/2.3	2.1/				0.0565/
									0.1401/
									(0.05-0.35)
^{75}Zn		74.9329	10.2 s	β^-/6.0					0.229/
^{76}Zn		75.9334	5.7 s	β^-/4.2	3.6/				0.119/
^{77m}Zn			1.0 s	β^-/		(1/2-)			0.772
^{77}Zn		76.9371	2.1 s	β^-/7.3	4.8/				0.189/
^{78m}Zn			>0.03 ms						1.070
^{78}Zn		77.9386	1.5 s	β^-/6.4					0.225/
^{79}Zn		78.9421	1.0 s	β^-/8.6					0.702/
^{80}Zn		79.9444	0.54 s	β^-/7.3					0.713/
									0.2248/
^{81}Zn		80.9505	0.29 s	β^-/11.9					
^{82}Zn		81.9548	>0.15 µs						
^{83}Zn			>0.15 µs						
$_{31}$Ga		69.723(1)							
^{56}Ga		55.9949							
^{57}Ga		56.9829							
^{58}Ga		57.9742							
^{59}Ga		58.9634							
^{60}Ga		59.9571							
^{61}Ga		60.9492	0.15 s	β^+/9.0		3/2-			
^{62}Ga		61.94418	0.116 s	β^+/9.17	8.3/	0+			ann.rad./
				EC/					
^{63}Ga		62.9391	32. s	β^+/5.5	4.5/				ann.rad./
				EC/					0.6271(2)/10.
									0.6370(2)/11.
									1.0652(4)/45.
^{64m}Ga			0.022 ms						0.0429
^{64}Ga		63.936838	2.63 m	β^+/7.165	2.79/	0+			ann.rad./
					6.05/				0.80785(1)/14.
									0.99152(1)/43.
									1.38727(1)/12.
									3.3659(1)/13.
^{65}Ga		64.9394	15.2 m	β^+/86/3.255	0.82/10.	3/2-			ann.rad./
				EC/	1.39/19.				0.1151(2)/55.
					2.113/56.				0.1530(2)/96.
					2.237/15.				0.2069(2)/39.
									(0.06-2.4)
^{66}Ga		65.931592	9.5 h	β^+/56/5.175	0.74/1.	0+			ann.rad./
				EC/43/	1.84/54.				1.03935(8)/38.
					4.153/51.				2.7523(1)/23.
									(0.28-5.01)
^{67}Ga		66.928205	3.260 d	EC/1.001		3/2-	+1.8507	0.20	0.09332/37.
									0.18459/20.
									0.30024/17.
									(0.091-0.89)
^{68}Ga		67.927983	1.130 h	β^+/90/2.921	1.83/	1+	0.01175	0.028	ann.rad./
				EC/10/					1.0774(1)/3.
									(0.57-2.33)/
^{69}Ga	60.108(9)	68.925581				3/2-	+2.01659	+0.17	
^{70}Ga		69.926027	21.1 m	EC/0.2/0.655		1+			0.1755(5)/0.15
				β^-/99.8/1.656	1.65/99.				1.042(5)/0.48
^{71}Ga	39.892(9)	70.924707				3/2-	+2.56227	+0.11	
^{72}Ga		71.926372	14.10 h	β^-/4.001	0.64/40.	3-	-0.13224	+0.5	0.62986(5)/24.

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					1.51/9.				2.2016(2)/26.
					2.52/8.				2.5077(2)/12.8
					3.15/11.				(0.11-3.3)/
^{73}Ga		72.92517	74.87 h	β^-/1.59		3/2-			0.05344(5)/10.
									0.29732(5)/47.
									(0.01-1.00)/
^{74m}Ga			10. s	I.T./		1+			0.0565(1)/75.
^{74}Ga		73.92694	8.1 m	β^-/5.4	2.6/	3-			0.5959/92.
									2.354/45.
									(0.23-3.99)
^{75}Ga		74.92650	2.10 m	β^-/3.39	3.3/	3/2-			0.2529/
									0.5746/
									(0.12-2.10)
^{76}Ga		75.9289	29. s	β^-/7.0		3-			0.5629/66.
									0.5455/26.
									(0.34-4.25)
^{77}Ga		76.9293	13.0 s	β^-/5.3	5.2/				0.469/
									0.459/
^{78}Ga		77.9317	5.09 s	β^-/8.2		3+			0.619/77.
									1.187/20.
^{79}Ga		78.9329	2.85 s	β^-/7.0	4.6/				0.465/
^{80}Ga		79.9366	1.68 s	β^-/10.4	10./				0.659/
^{81}Ga		80.9377	1.22 s	β^-/8.3	5.1/				0.217/
^{82}Ga		81.9432	0.599 s	β^-/12.6					1.348/
^{83}Ga		82.9469	0.308 s	β^-/≈ 11.5					
^{84}Ga		83.952	≈0.085 s	β^-/14					
^{85}Ga			>0.15 μs						
^{86}Ga			>0.15 μs						
$_{32}$Ge		72.64(1)							
^{58}Ge		57.9910							
^{59}Ge		58.9817							
^{60}Ge		59.9702							
^{61}Ge		60.9638	0.04 s	β^+/13.6					
^{63}Ge		62.9496	0.10 s	β^-/9.8					
^{64}Ge		63.9416	1.06 m	β^+/4.4	3.0/	0+			ann.rad./
				EC/					0.1282(2)/11.
				β^+,p					0.4270(3)/37.
									0.6671(3)/17.
^{65}Ge		64.9394	31. s	β^+/6.2	0.82/10.				ann.rad./
				EC/	1.39/19.				0.0620/27.
				EC,p	2.113/56.				0.6497/33.
					2.237/15.				0.8091/21.
									(0.19-3.28)
^{66}Ge		65.93385	2.26 h	β^+/27/2.10		0+			ann.rad./
				EC/73/					0.0438/29.
									0.3819/28.
									(0.022-1.77)
^{67}Ge		66.932738	19.0 m	β^+/96/4.225	1.6/	1/2-			ann.rad./
				EC/4/	2.3/				0.1670/84.
					3.15/				(0.25-3.73)
^{68}Ge		67.92810	270.8 d	EC/0.11		0+			Ga k x-ray/39.
^{69}Ge		68.927973	1.63 d	β^+/36/2.2273	0.70/	5/2-	0.735	0.02	ann.rad./
				EC/64/	1.2/				0.574/13.
									1.1068/36.
									(0.2-2.04)
^{70}Ge	20.84(87)	69.924250				0+			
^{71m}Ge			20.4 ms		I.T./0.0234	9/2+			0.1749
^{71}Ge		70.924954	11.2 d	EC/0.229		1/2-	+0.547		
^{72}Ge	27.54(34)	71.922076				0+			

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{73}Ge	7.73(5)	72.923460				9/2+	-0.879467	-0.17	
^{74}Ge	36.28(73)	73.921178				0+			
^{75m}Ge			48. s	I.T./		7/2+			0.13968(3)/39.
^{75}Ge		74.922860	1.380 h	β^-/1.177	1.19/	1/2-	+0.510		0.26461(5)/11.
									0.41931(5)/0.2
^{76}Ge	7.61(38)	75.921403	≈1×10^{21}y	$\beta^-\beta^-$		0+			
^{77m}Ge			53. s	I.T./20/		1/2-			1.605/0.22
				β^-/80/2.861	2.9/				1.676/0.16
									0.195-1.482
^{77}Ge		76.923549	11.25 h	β^-/2.702	0.71/23.	7/2+			0.2110/29.
					1.38/35.				0.2155/27.
					2.19/42.				0.2644/51.
									(0.15-2.35)
^{78}Ge		77.922853	1.45 h	β^-/0.95	0.70/	0+			0.2773(5)/96.
									0.2939(5)/4.
^{79m}Ge			39. s	β^-/IT		7/2+			
^{79}Ge		78.9254	19.1 s	β^-/4.2	4.0/20.	1/2-			0.1096/21.
					4.3/80.				(0.10-2.59)
									0.5427(4)/15.
^{80}Ge		79.92545	29.5 s	β^-/2.67	2.4/	0+			0.1104(4)/6.
									0.2656(4)/25.
^{81m}Ge			≈7.6 s	β^-/	3.75/	1/2+			0.3362(4)/
									0.7935(4)/
^{81}Ge		80.9288	≈7.6 s	β^-/6.2	3.44/	9/2+			0.1976(4)/21.
									0.3362(4)/100.
^{82}Ge		81.9296	4.6 s	β^-/4.7		0+			1.093/
^{83}Ge		82.9345	1.9 s	β^-/8.9					
^{84}Ge		83.9373	0.98 s	β^-/7.7					
^{85}Ge		84.943	0.54 s	β^-/10.					
^{86}Ge		85.946	>0.15 μs						
^{87}Ge			>0.15 μs						
^{88}Ge			>0.15 μs						
^{89}Ge			>0.15 μs						
$_{33}$As		74.92160(2)							
^{60}As		59.993							
^{61}As		60.981							
^{62}As		61.9732							
^{63}As		62.9637							
^{64}As		63.9576	>1.2 μs						
^{65}As		64.9495	0.19 s	β^+/9.4					
^{66m2}As			1.9 μs						
^{66m1}As			0.018 ms						
^{66}As		65.94410	95.8 ms	β^+/9.55					
^{67}As		66.9392	42. s	β^+/6.0	5.0/	5/2-			0.121/
				EC/					0.123/
									0.244/
^{68}As		67.9368	2.53 m	β^+/8.1		3+			ann.rad./
									0.652/32.
									0.762/33.
									1.016/77.
									(0.61-3.55)
^{69}As		68.93228	15.2 m	β^+/98/4.01	2.95/	5/2-	1.6		ann.rad./
				EC/2/					0.0868(5)/1.5
									0.1458(3)/2.4
^{70}As		69.93093	52.6 m	β^+/84/6.22	1.44/	4+	+2.1061	+0.09	ann.rad./
				EC/16/2.14					1.0395(7)/82.
				/2.89					(0.17-4.4)/
^{71}As		70.927114	2.72 d	β^+/32/2.013		5/2-	+1.6735	-0.02	ann.rad./
				EC/68/					0.1749(2)/84.

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/Energy Intensity (MeV/%)
									1.0957(2)/4.2
^{72}As		71.926753	26.0 h	β⁺/77/4.356	0.669/5.	2-	-2.1566	-0.08	ann.rad./
					1.884/12.				0.83395(5)/80.
					2.498/62.				1.0507(1)/9.6
					3.339/19.				(0.1-4.0)
^{73}As		72.923825	80.3 d	EC/0.341		3/2-			0.0133/0.1
									0.0534/10.5
									Se k x-ray/90.
^{74}As		73.923829	17.78 d	β⁺/31/2.562	0.94/26.	2-	-1.597		ann.rad./
				EC/37/	1.53/3.				0.59588(1)/60.
				β⁻/1.353	0.71/16.				0.6084(1)/0.6
					1.35/16.				0.6348(1)/15.
^{75m}As			0.017 s						
^{75}As	100.	74.921597				3/2-	+1.43947	+0.31	
^{76}As		75.922394	26.3 h	β⁻/2.962	0.54/3.	2-	-0.903		0.5591(1)/45.
					1.785/8.				0.65703(5)/6.2
					2.410/36.				1.21602(1)/3.4
					2.97/51.				(0.3-2.67)
^{77}As		76.920648	38.8 h	β⁻/0.683	0.70/98.	3/2-	+1.295		0.2391(2)/1.6
									0.2500(3)/0.4
									0.5208/0.43
^{78}As		77.92183	1.512 h	β⁻/4.21	3.00/12.	2-			0.6136(3)/54.
					3.70/17.				0.6954(3)/18.
					4.42/37.				1.3088(3)/10.
^{79m}As			1.21 μs			9/2+			0.542/IT
									0.231
^{79}As		78.92095	9.0 m	β⁻/2.28	1.80/95.	3/2-			0.0955(5)/16.
									0.3645(5)/1.9
^{80}As		79.92258	16. s	β⁻/5.64	3.38/	1+			0.6662(2)/42.
									(2.5-3.0)
^{81}As		80.92213	33. s	β⁻/3.856		3/2-			0.4676(2)/20.
									0.4911(2)/8.
^{82m}As			13.7 s	β⁻/	3.6/	5-			0.6544(1)/72.
									0.8186(4)/27.
									1.7313(2)/27.
									1.8954(2)/38.
^{82}As		81.9246	19. s	β⁻/7.4	7.2/80.	1+			0.6544(1)/15.
^{83}As		82.9250	13.4 s	β⁻/5.5					0.7345/100.
									1.1131/34.
									2.0767/28.
^{84m}As			0.6 s	β⁻					
^{84}As		83.9291	4. s	β⁻, n/7.2		1-			0.6671(2)/21.
									1.4439(5)/49.
									(0.325-5.150)
^{85}As		84.9318	2.03 s	β⁻, n/8.9		3/2-			0.667(1)/42.
									1.4551(2)/100.
^{86}As		85.9362	0.95 s	β⁻, n/11.4					0.704/
^{87}As		86.9396	0.49 s	β⁻, n/10.					0.704/
^{88}As		87.945	>0.15 μs						
^{89}As		88.949	>0.15 μs						
^{90}As			>0.15 μs						
^{91}As			>0.15 μs						
^{92}As			>0.15 μs						
$_{34}$Se		78.96(3)							
^{65}Se		64.965	0.011 s	β⁺/60/14.					
				β⁺, p	3.55/				
^{66}Se		65.9552							
^{67}Se		66.9501	0.06 s	β⁺/10.2					ann.rad./
				β⁺,(p)/					0.352

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{68}Se		67.9419	36. s	β^+/4.7					ann.rad./
									(0.050-0.426)
^{69}Se		68.93956	27.4 s	β^+/6.78	5.006/				ann.rad./
				EC/					0.0664(4)/27.
									0.0982(4)/63.
^{70}Se		69.9335	41.1 m	β^+/2.4		0+			ann.rad
									0.04951(5)/35.
									0.4262(2)/29.
^{71}Se		70.9319	4.7 m	β^+/4.4	3.4/36.	5/2-			ann.rad
				EC/					0.1472(3)/47.
									0.8309(3)/13.
									1.0960(3)/10.
^{72}Se		71.92711	8.5 d	EC/0.34		0+			0.0460(2)/57.
^{73m}Se			40. m	I.T./73/0.0257	0.85	3/2-			ann.rad.
				β^+/27/2.77	1.45/				0.0257(2)/27.
					1.70/				0.2538(1)/2.5
^{73}Se		72.92678	7.1 h	β^+/65/2.74	0.80/	9/2+	0.86		ann.rad
				EC/35/	1.32/95.				0.0670(1)/72.
					1.68/1.				0.3609(1)/97.
									(0.6-1.5)
^{74}Se	0.89(4)	73.922477				0+			
^{75}Se		74.922524	119.78 d	EC/0.864		5/2+	0.67	1.0	0.13600/55
									0.26465/58
									(0.024-0.821)
^{76}Se	9.37(29)	75.919214				0+			
^{77m}Se			17.4 s	I.T./		7/2+			0.1619(2)/52.
^{77}Se	7.63(16)	76.919915				1/2-	+0.53506		
^{78}Se	23.77(28)	77.917310				0+			
^{79m}Se			3.92 m	I.T./					0.09573(3)/9.5
^{79}Se		78.918500	1.1x10^6 y	β^-/0.151		7/2+	-1.018	+0.8	
^{80}Se	49.61(41)	79.916522				0+			
^{81m}Se			57.3 m	I.T./99/0.1031		7/2+			0.1031(3)/9.7
									0.2602(2)/0.06
									0.2760/0.06
^{81}Se		80.917993	18.5 m	β^-/1.585	1.6/98.	1/2-			0.2759/0.85
									0.2901/0.75
									0.8283/0.32
^{82}Se	8.73(22)	81.916700	≈1×10^{20} y	$\beta^-\beta^-$		0+			
^{83m}Se			1.17 m	β^-/3.96	2.88/	1/2-			0.35666(6)/17.
					3.92/				0.9879(1)/15.
									1.0305(1)/21.
									2.0514(2)/11.
									(0.19-3.1)
^{83}Se		82.919119	22.3 m	β^-/3.668	0.93/	9/2+			0.22516(6)/33.
					1.51/				0.35666(6)/69.
									0.51004(8)/45.
									(0.21-2.42)
^{84}Se		83.91847	3.3 m	β^-/1.83	1.41/100.	0+			0.4088(5)/100.
^{85}Se		84.92225	32. s	β^-/6.18	5.9/	5/2+			0.3450(1)/22.
									0.6094(1)/41.
^{86}Se		85.92428	15. s	β^-/5.10		5/2+			2.0124(1)/24.
									2.4433(8)/100.
									2.6619(1)/49.
^{87}Se		86.92853	5.4 s	β^-/7.28					0.468(1)/100.
				n/					1.4979(1)/23.
^{88}Se		87.93143	1.5 s	β^-,n/6.85					0.5346/
^{89}Se		88.9360	0.41s	β^-,n/9.0					
^{90}Se		89.9394	>0.15 µs						
^{91}Se		90.945	0.27 s	β^-,n/8.					

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^{92}Se		91.949	>0.15 µs						
^{93}Se			>0.15 µs						
^{94}Se			>0.15 µs						
$_{35}$Br		79.904(1)							
^{67}Br		66.9648							
^{68}Br		67.958	<1.2 µs						
^{69}Br		68.9502	<0.024 µs	β^+/9.6					
^{70}Br		69.9446	79. ms	β^+/10.0	/0.75				
^{71}Br		70.9392	21. s	β^+/6.9					
^{72}Br		71.9365	1.31 m	β^+/8.7		3	≈0.55		0.4547-1.3167
^{73}Br		72.9318	3.4 m	β^+/4.7	3.7/	3/2-			ann.rad
									0.065-0.700
^{74m}Br			46. m	β^+/	4.5/	4-	1.82		ann.rad
									0.6348
									0.7285
									(0.2 - 4.38)
^{74}Br		73.92989	25.4 m	β^+/6.91					ann.rad
									0.6341
									0.6348
									(0.2-4.7)
^{75}Br		74.92578	1.62 h	β^+/76/3.03		3/2-	+0.75		ann.rad
									0.28650
									(0.1-1.56)
^{76m}Br			1.4 s	I.T./5.05		4+			0.104548
									0.05711
^{76}Br		75.92454	16.0 h	β^+/57/4.96	1.9/	1-	0.54821	0.270	ann.rad
					3.68/				0.55911
									1.85368
									(0.4-4.6)
^{77m}Br			4.3 m	I.T./0.1059		9/2+			0.1059
^{77}Br		76.921380	2.376 d	EC/99/1.365		3/2-	0.973	+0.53	ann.rad.
									0.23898
									0.52069
									(0.08-1.2)
^{78}Br		77.921146	6.45 m	β^+/92/3.574	1.2/	1+	0.13		ann.rad.
				EC/8/	2.5/				0.61363
									(0.7-3.0)
^{79m}Br			4.86 s	I.T./0.207		9/2+			0.2072
^{79}Br	50.69(7)	78.918338				3/2-	+2.10640 0	+0.331	
^{80m}Br			4.42 h	I.T./0.04885		5-	+1.3177	+0.75	Br k x-ray
									0.03705/39.1
									0.04885/0.3
^{80}Br		79.918530	17.66 m	β^-/92/2.004	1.38 β^-/7.6	1+	0.5140	0.196	ann.rad.
				EC/5.7/1.8706	1.99 β^-/82				0.6169/6.7
				β^+/2.6/	0.85 β^+/2.8				(0.64-1.45)
^{81}Br	49.31(7)	80.916291				3/2-	+2.27056 2	+0.276	
^{82m}Br			6.1 m	I.T./98/0.046		2-			0.046/0.24
				β^-/2/3.139					(0.62-2.66)
^{82}Br		81.916805	1.471 d	β^-/3.093	0.444/	5-	+1.6270	0.751	0.5544/71
									0.61905/43
									0.77649/84
									(0.013-1.96)
^{83}Br		82.915181	2.40 h	β^-/0.972	0.395/1	3/2-			0.52964
					0.925/99				(0.12-0.68)
^{84m}Br			6.0 m	β^-/4.97	2.2/100	(6-)			0.4240/100

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									0.8817/98
									1.4637/101
^{84}Br		83.91651	31.8 m	β^-/4.65	2.70/11	2-	2.		0.8816/41
					3.81/20				1.8976/13
					4.63/34				(0.23-4.12)
^{85}Br		84.91561	2.87 m	β^-/2.87	2.57	3/2-			0.80241/2.56
									0.92463/1.6
									(0.09-2.4)
^{86}Br		85.91880	55.5 s	β^-/7.63	3.3	(2-)			1.56460/64
					7.4				2.75106/21
									(0.5-6.8)
^{87}Br		86.92072	55.6 s	β^-/6.85	6.1/	3/2-			1.41983
				n/					1.4762
									(0.2-6.1)
^{88m}Br			5.1 µs						
^{88}Br		87.92407	16.3 s	β^-/8.96		1-			0.7649
				n/					0.7753
									0.8021
									(0.1-6.99)
^{89}Br		88.92640	4.35 s	β^-/8.16		3/2-			0.7753
				n/					1.0978
^{90}Br		89.9306	1.91 s	β^-/10.4	8.3/	2-			0.6555
				n/	9.8/				0.7071
									1.3626
^{91}Br		90.9339	0.54 s	β^-/90/9.80					0.263
				β^- n/10/					0.803
^{92}Br		91.9392	0.31 s	β^-/12.20					0.740
				β^- n/					
^{93}Br		92.9431	0.10 s	β^- n/11.1					
^{94}Br		93.9487	0.07 s	β^- n/					
^{95}Br			>0.15 µs						
^{96}Br			>0.15 µs						
^{97}Br			>0.15 µs						
$_{36}$Kr		83.80(1)							
^{69}Kr		68.9653	0.03 s	β^+,(p)	4.07/				
^{70}Kr		69.9560	>1.2 µs						
^{71}Kr		70.9505	100. ms	β^+,EC/10.1					(0.198-0.207)
^{72}Kr		71.9419	17. s	β^+/5.0		0+			ann.rad
				EC/					0.3100/29
									0.4150/36
									(0.12-0.58)
^{73}Kr		72.9389	28. s	β^+/6.7		5/2-			ann.rad.
				EC/					0.1781/66
				β^+,p/	/0.25				(0.06-0.86)
^{74}Kr		73.9333	11.5 m	β^+/3.1		0+			ann.rad.
				EC/					0.08970/31
									0.2030/20
									(0.010-1.06)
^{75}Kr		74.93104	4.3 m	β^+/4.90	3.2/	5/2+	- 0.531	+ 1.1	ann.rad.
				EC/					0.1325/68
									0.1547/21
									(0.02-1.7)
^{76}Kr		75.92595	14.8 h	EC/1.31		0+			Br k x-ray
									0.270/21
									0.3158/39
									(0.03-1.07)
^{77}Kr		76.92467	1.24 h	β^+/80/3.06		5/2+	- 0.583	+ 0.9	ann.rad.
				EC/20/	1.55/				0.1297/80
					1.70/				0.1465/38

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					1.87/				(0.02-2.3)
^{78}Kr	0.35(1)	77.92039	>0.9×10^{20} y	$\beta^-\beta^-$		0+			
^{79m}Kr			53. s	I.T./0.1299		7/2+	- 0.786	+ 0.40	Kr x-ray
^{79}Kr		78.920083	1.455 d	β^+/7/1.626		1/2-	+ 0.536		ann.rad.
				EC/93/					0.2613/13
									0.39756/19
									0.6061/8
									(0.04-1.3)
^{80}Kr	2.28(6)	79.916379				0+			
^{81m}Kr			13.1 s	I.T./0.1904		1/2-	+ 0.586		0.1904
^{81}Kr		80.916593	2.1x10^5 y	EC/0.2807		7/2+	- 0.908	+ 0.63	Br k x-ray
									0.2760
^{82}Kr	11.58(14)	81.913485				0+			
^{83m}Kr			1.86 h	I.T./0.0416		1/2-	+ 0.591		Kr k x-ray
									0.00940
									0.03216
^{83}Kr	11.49(6)	82.914137				9/2+	-0.970699	+0.253	
^{84}Kr	57.00(4)	83.911508				0+			
^{85m}Kr			4.48 h	β^-/79/	0.83/79	1/2-	+ 0.633		0.30487
				I.T./21/0.305					0.15118
^{85}Kr		84.912530	10.73 y	β^-/0.687	0.15/0.4	9/2+	1.005	+0.43	0.51399
^{86}Kr	17.30(22)	85.910615				0+			
^{87}Kr		86.913359	1.27 h	β^-/3.887	1.33/8	5/2+	-1.023	- 0.30	0.40258/49.6
					3.49/43				2.5548/9.2
					3.89/30				(0.13-3.31)
^{88}Kr		87.91445	2.84 h	β^-/2.91		0+			0.19632/26.
									2.392/34.6
									(0.03-2.8)
^{89}Kr		88.91764	3.15 m	β^-/4.99	3.8/	5/2+	- 0.330	+ 0.16	0.19746
					4.6/				0.2209/19.9
					4.9/				0.5858/16.4
									1.4728/6.8
									(0.2-4.7)
^{90}Kr		89.91953	32.3 s	β^-/4.39	2.6/77	0+			0.12182/32.9
					2.8/6				0.5395/28.6
									1.1187/36.2
									(0.1 - 4.2)
^{91}Kr		90.9234	8.6 s	β^-/6.4	4.33/	5/2+	- 0.583	+ 0.30	0.10878/43.5
					4.59/				0.50658/19.
									(0.2-4.4)
^{92}Kr		91.92611	1.84 s	β^-/5.99					0.1424/66.
				n/					(0.14 - 3.7)
^{93}Kr		92.9312	1.29 s	β^-/8.6	7.1/	1/2+	- 0.413		0.1820
				n/					0.2534/42.
									0.32309/24.6
									(0.057-4.03)
^{94}Kr		93.9343	0.21 s	β^-/7.3					0.2196/67
									0.6293/100.
							- 0.410		(0.098-0.985)
^{95}Kr		94.9397	0.78 s	β^-/9.7					
^{96}Kr		95.9431	> 50 ms						
^{97}Kr		96.9486	< 0.1 s	β^-					
^{98}Kr			>0.15 μs						
^{99}Kr			>0.15 μs						
^{100}Kr			>0.15 μs						
$_{37}$Rb		85.4678(3)							
^{71}Rb		70.9653							
^{72}Rb		71.9591	<1.2 μs						

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{73}Rb		72.9504	<0.03 μs						
^{74}Rb		73.9445	65. ms	β^+/10.4					
^{75}Rb		74.93857	19. s	β^+/7.02	2.31/				ann. rad.
									0.179
^{76}Rb		75.93508	39. s	β^+/8.50	4.7/	1-	-0.372623	+0.4	ann.rad.
									0.4240/92.
									(0.064-1.68)
^{77}Rb		76.93041	3.8 m	β^+/5.34	3.86/	3/2-	+0.65446 8	+0.70	ann.rad.
									0.0665/59
									(0.04 - 2.82)
^{78m}Rb			5.7 m	I.T./0.1034		4-	+2.549	+0.81	ann.rad.
				β^+/	3.4				0.4553/81.
				EC/					(0.103-4.01)
^{78}Rb		77.92814	17.7 m	β^+/7.22		0+			ann.rad.
				EC/					0.4553/63.
									(0.42-5.57)
^{79}Rb		78.92400	23. m	β^+/84/3.65		5/2+	+0.3358	-0.10	ann.rad.
				EC/16/					0.68812/23.
									(0.017-3.02)
^{80}Rb		79.92252	34. s	β^+/5.72	4.1/22	1+	-0.0836	+0.35	ann.rad.
					4.7/74				0.6167/25.
^{81m}Rb			30.5 m	I.T./0.85	1.4	9/2+	+5.598	-0.74	ann.rad.
				β^+,EC/					(0.085-1.9)
^{81}Rb		80.91900	4.57 h	β^+/27/2.24	1.05/	3/2-	+2.060	+0.40	ann.rad./
				EC/73					0.19030/64.
									(0.05 - 1.9)
^{82m}Rb			6.47 h	β^+/26/	0.80/	5-	+1.5100	+1.0	ann.rad./
				EC/74/					0.5544/63.
									0.7765/85.
									(0.092 - 2.3)
^{82}Rb		81.91821	1.258 m	β^+/96/4.40	3.3/	1+	+0.55450 8	+0.19	ann.rad./
				EC/4/					0.7665/13.
									(0.47 - 3.96)
^{83}Rb		82.91511	86.2 d	EC/0.91		5/2-	+1.425	+0.20	Kr x-ray
									0.5205/46.
									(0.03-0.80)
^{84m}Rb			20.3 m	I.T./0.216		6-	+0.2129	+0.6	0.2163/34.
									0.2482/63.
									0.4645/32.
^{84}Rb		83.914387	32.9 d	β^+/22/2.681	0.780/11	2-	-1.32412	-0.015	ann.rad./
				EC/75/	1.658/11				0.8817/68.
				β^-/3/0.894	0.893/				(1.02-1.9)
^{85}Rb	72.17(2)	84.911792				5/2-	+1.353	+0.23	
^{86m}Rb			1.018 m	I.T./0.5560		6-	+1.815	+0.37	0.556/98.
^{86}Rb		85.911170	18.65 d	β^-/1.775	1.774/8.8	2-	-1.6920	+0.19	1.0768/8.8
^{87}Rb	27.83(2)	86.909186	4.88×10^{10} y	β^-/0.283	0.273/100	3/2-	+2.7512	+0.13	
^{88}Rb		87.911323	17.7 m	β^-/5.316	5.31	2-	0.508		0.8980/14.
									1.8360/21.
									(0.34-4.85)
^{89}Rb		88.91229	15.4 m	β^-/4.50	1.26/38	3/2-	+2.304	+0.14	1.032/58.
					1.9/5				1.248/42.
					2.2/34				2.1960/13
					4.49/18				(0.12-4.09)
^{90m}Rb			4.3 m	β^-/4.50	1.7/	4-	+1.616	+0.20	0.1069(IT)
					6.5/				0.8317/94
									(0.20-5.00)

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{90}Rb		89.91481	2.6 m	β^-/6.59	6.6	1-			0.8317/28.
									(0.31-5.60)
^{91}Rb		90.91649	58.0 s	β^-/5.861	5.9	3/2-	+2.182	+0.15	0.0936/34.
									(0.35-4.70)
^{92}Rb		91.91968	4.48 s	β^-/8.11	8.1/94	1-			0.8148/8.
									(0.1-6.1)
^{93}Rb		92.92195	5.85 s	β^-/7.46	7.4/	5/2	+1.410	+0.18	0.2134/4.8
				n/1					0.4326/12.5
									0.9861/4.9
									(0.16-5.41)
^{94}Rb		93.92643	2.71 s	β^-/10.31	9.5/	3	+1.498	+0.16	0.8369/87.
				n/10					1.5775/32.
									(0.12-6.35)
^{95}Rb		94.92929	0.377 s	β^-/9.30	8.6/	5/2	+1.334	+0.21	0.352/65.
				n/8					0.680/22.
									(0.20-2.27)
^{96m}Rb			1.7 μs						0.2999
									0.4612
									0.2400
									0.093-0.369
^{96}Rb		95.93427	0.199 s	β^-/11.76	10.8/	2+	+1.466	+0.25	0.815/76.
				n/13/					(0.20-5.42)
^{97}Rb		96.93733	0.169 s	β^-/10.42	10.0	3/2	+1.841	+0.58	0.167/100.
				n/27/					0.585/79.
									0.599/56.
									1.258/52.
									(0.14-2.08)
^{98}Rb		97.94174	0.107 s	β^-/12.34	0.144/				
				n/13					(0.07-3.68)
^{99}Rb		98.9453	59. ms	β^-/11.3					
^{100}Rb		99.9499	53. ms	β^-/13.5					
^{101}Rb		100.9532	0.03 s	β^-/11.8					
^{102}Rb		101.9592	0.09 s	β^-					
$_{36}$Sr		87.62(1)							
^{73}Sr		72.966	> 25 ms						
^{74}Sr		73.9563	>1.2 μs						
^{75}Sr		74.9499	≈ 0.07 s						
^{76}Sr		75.9416	8.9 s	β^+/6.1					
^{77}Sr		76.9378	9.0 s	β^+/6.9	5.6		-0.35	+1.4	0.147
^{78}Sr		77.93218	2.7 m	β^+/3.76					(0.047-0.793)
^{79}Sr		78.92971	2.1 m	β^+/5.32	4.1	3/2-	-0.474	+0.74	ann.rad./
									0.039/28.
									0.105/22.
									(0.135-0.612)
^{80}Sr		79.92453	1.77 h	β^+/1.87		0+			ann.rad./
									0.174/10.
									0.589/39.
									(0.24-0.55)
^{81}Sr		80.92322	22.3 m	β^+/87/3.93	2.43/	1/2-	+0.544		ann.rad./
				EC/13/	2.68/				0.148/31.
									0.1534/35
									(0.06-1.7)
^{82}Sr		81.91840	25.36 d	EC/0.18					Rb x-ray
^{83m}Sr			5.0 s	I.T./0.2591		1/2-	+0.582		0.2591/87.5
^{83}Sr		82.91756	1.350 d	β^+/24/2.28	0.465/	7/2+	-0.898	+0.79	ann.rad./
				EC/76/	0.803/				0.3816/12.
					1.227/				0.3816
									0.7627/30.
									(0.094-2.15)

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^{84}Sr	0.56(1)	83.913426				0+			
^{85m}Sr			1.127 h	I.T./87/0.2387		1/2-	+0.601		0.2318/84.
				EC/13					(0.15-0.24)
^{85}Sr		84.912936	64.85 d	EC/1.065		9/2+	-1.001	+0.30	0.51399/99.3
^{86}Sr	9.86(1)	85.909265				0+			
^{87m}Sr			2.81 h	I.T./0.3884		1/2-	+0.63		0.3884(IT)
^{87}Sr	7.00(1)	86.908882				9/2+	-1.09360	+0.34	
^{88}Sr	82.58(1)	87.905617				0+			
^{89}Sr		88.907455	50.52 d	β^-/1.497	1.492/100	5/2+	-1.149	-0.3	0.9092
^{90}Sr		89.907738	29.1 y	β^-/0.546	0.546/100	0+			
^{91}Sr		90.91020	9.5 h	β^-/2.70	0.61/7	5/2+	-0.887	+0.044	0.5556/61.
					1.09/33				0.7498/24.
					1.36/29				1.0243/33.
					2.66/26				(0.12-2.4)
^{92}Sr		91.91098	2.71 h	β^-/1.91	0.55/96	0+			1.3831/90.
					1.5/3				(0.24-1.1)
^{93}Sr		92.91394	7.4 m	β^-/4.08	2.2/10	5/2+	-0.794	+0.26	0.5903/
					2.6/25				0.7104
					3.2/65				0.87573
									0.8883/
									(0.17-3.97)
^{94}Sr		93.91537	1.25 m	β^-/3.511	2.1/	0+			0.6219
					3.3/				0.7043
									0.7241
									0.8064
									1.4283
^{95}Sr		94.91931	25.1 s	β^-/6.08		1/2+	-0.5379		0.6859
					6.1/50				0.8269
									2.7173
									2.9332
^{96}Sr		95.92165	1.06 s	β^-/5.37	4.2/	0+			0.1222
									0.5305
									0.8094
									0.9318
^{97}Sr		96.92615	0.42 s	β^-/7.47	5.3	(1/2+)	-0.500		0.2164
									0.3071
									0.6522
									0.9538
									1.2580
									1.9050
^{98}Sr		97.92845	0.65 s	β^-/5.83	5.1				0.0365
									0.1190
									0.4286
									0.4447
									0.5636
^{99}Sr		98.9333	0.27 s	β^-/8.0			-0.26	0.8	
^{100}Sr		99.9354	0.201 s	β^-/7.1					
^{101}Sr		100.9405	0.115 s	β^-/9.5					
^{102}Sr		101.9430	68. ms	β^-/8.8					
^{103}Sr		102.9490	>0.15 μs						
^{104}Sr		103.952	>0.15 μs						
^{105}Sr			>0.15 μs						
$_{39}$Y		88.90585(2)							
^{77}Y		76.9496	> 0.5 μs						
^{78m}Y			0.06 s						
^{78}Y		77.9435	5.8 s	β^+/10.5		(5+)			0.279/100
									0.504/90
									0.713/40
^{79}Y		78.9374	15. s	β^+/7.1					(0.152-1.106)

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^{80m}Y			4.7 s						0.2285
^{80}Y		79.9320	30. s	β^+/7.0	5.5	(4)			ann.rad./
					5.0/				0.3858/100
									0.5951/42
									0.756-1.396
^{81}Y		80.9291	1.21 m	β^+/5.5	3.7/				ann.rad./
					4.2/				0.428
									0.469
^{82}Y		81.9268	9.5 s	β^+/7.8	6.3/	1+			ann.rad./
									0.5736
									0.6017
									0.7375
^{83m}Y			2.85 m	β^+/95/4.6	2.9	1/2-			ann.rad./
				EC/5/					0.2591
									0.4218
									0.4945
^{83}Y		82.92235	7.1 m	β^+/4.47	3.3	9/2+			ann.rad./
				EC/					0.0355
									0.4899
									0.8821
									(0.03 - 3.4)
^{84m}Y			4.6 s	β^+/		1+			ann.rad./
				EC/					0.7930
^{84}Y		83.9203	40. m	β^+/6.4	1.64/47	5-			ann.rad./
				EC/	2.24/25				0.4628
					2.64/21				0.6606
					3.15/7				0.7931
									0.9744
									1.0398
									(0.2 - 3.3)
^{85m}Y			4.9 h	β^+/70/		9/2+	6.2		ann.rad./
				EC/30/					0.2317
									0.5356
									0.7673
									2.1238
									(0.1 - 3.1)
^{85}Y		84.91643	2.6 h	β^+/55/3.26	1.54/	1/2-			ann.rad./
				EC/45/					0.2317
									0.5045
									0.9140
									(0.07 - 1.4)
^{86m}Y			48. m	I.T./99/		8+	4.8		ann.rad./
				β^+/					0.0102(IT)
				EC/					0.2080
									(0.09 - 1.1)
^{86}Y		85.91489	14.74 h	β^+/5.24		4-	<0.6		ann.rad./
				EC/					0.3070
									0.6277
									1.0766
									1.1531
									1.9207
									(0.1 - 3.8)
^{87m}Y			13. h	I.T./98/		9/2+	6.1		0.3807
				β^+/0.7/	1.15/0.7				
				EC/					
^{87}Y		86.910880	3.35 d	EC/99+/1.862	0.78/	1/2-			0.3880
									0.4870
^{88}Y		87.909506	106.6 d	EC/99+/3.623	0.76/	4-			ann.rad./
				β^+/0.2/					0.89802

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									1.83601
									2.73404
									3.2190
^{89m}Y			15.7 s	I.T./0.909		9/2+			0.9092(IT)
^{89}Y	100.	88.905849				1/2-	-0.13742		
^{90m}Y			3.24 h	I.T./99+/0.68204		7+	5.1		0.2025
				β^-/0.002/					0.4794
									0.6820
^{90}Y		89.907152	2.67 d	β^-/2.282	2.28/	2-	-1.630	-0.155	
^{91m}Y			49.7 m	I.T./0.555		9/2+	5.96		0.5556(IT)
^{91}Y		90.907301	58.5 d	β^-/1.544	1.545/	1/2-	0.1641		1.208
^{92}Y		91.90893	3.54 h	β^-/3.63	3.64/	2-			0.4485
									0.5611
									0.9345
									1.4054
									(0.4 - 3.3)
^{93m}Y			0.82 s	I.T./0.759		9/2+			0.1686(IT)
									0.5902
^{93}Y		92.90956	10.2 h	β^-/2.87	2.88/90	1/2-			0.2669
									0.9471
									1.9178
^{94m}Y			1.4 µs						0.4322
									0.7699
									1.2024
^{94}Y		93.91160	18.7 m	β^-/4.919	4.92/	2-			0.3816
									0.9188
									1.1389
									(0.3 - 4.1)
^{95}Y		94.91279	10.3 m	β^-/4.42		1/2-			0.4324
									0.9542
									2.1760
									3.5770
^{96m}Y			9.6 s	β^-/		(3+)			0.1467
									0.6174
									0.9150
									1.1071
									1.7507
^{96}Y		95.91588	6.2 s	β^-/7.09	7.12/	0-			1.594
^{97m}Y			1.21 s	β^-/7.4	4.8/	9/2+			0.1614
					6.0/				0.9700
									1.1030
^{97}Y		96.91813	3.76 s	β^-/6.69	6.7	1/2-			0.2969
									1.9960
									3.2876
									3.4013
^{98m}Y			2.1 s	β^-/9.8	5.5/	(4-)			0.2415
									0.6205
									0.6473
									1.2228
									1.8016
^{98}Y		97.92224	0.59 s	β^-/8.83	8.7/	1+			0.2131
									1.2228
									1.5907
									2.9413
									4.4501
^{99m}Y			0.011 ms						
^{99}Y		98.92463	1.47 s	β^-/7.57		1/2-			0.1218/43.8
				n	/2.5/				0.5362
									0.7242

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									1.0130
^{100m}Y			0.94 s	β^-,n/		3+			
^{100}Y		99.9278	0.73 s	β^-,n/9.3	n/1.8/	1+			
^{101}Y		100.9303	0.43 s	β^-,n/8.6	n/1.5/	(5/2)			
^{102}Y		101.9336	0.36 s	β^-,n/9.9	n/4.0/				
^{103}Y		102.9369	0.23 s	β^-,n	n/8.3/				
^{104}Y		103.9414	0.18 s						
^{105}Y		104.9451	>0.15 μs						
^{106}Y		105.950	>0.15 μs						
^{107}Y			>0.15 μs						
^{108}Y			>0.15 μs						
$_{40}$Zr		91.224(2)							
^{79}Zr		78.949	0.06 s						
^{80}Zr		79.9406	4. s	β^+/8.0					0.290
									0.538
^{81}Zr		80.9368	5. s	β^+/7.2	6.1	(3/2-)			
^{82}Zr		81.9311	32. s	β^+ /4.0	3.				ann.rad./
^{83m}Zr			7. s	β^+ /7.0		(7/2+)			ann.rad./
^{83}Zr		82.9287	44. s	β^+ /5.9	4.8	(1/2-)			ann.rad./
				EC					0.0556
									0.1050
									0.2560
									0.474
									1.525
^{84}Zr		83.9233	26. m	β^+ /2.7		0+			ann.rad./
				EC/					0.0449
									0.1125
									0.3729
									0.667
^{85m}Zr			10.9 s	I.T./0.2922		1/2-			ann.rad./
				β^+ ,EC/					0.2922(IT)
									0.4165
^{85}Zr		84.9215	7.9 m	β^+ /4.7	3.1	7/2+			ann.rad./
				EC/					0.2663
									0.4163
									0.4543
^{86}Zr		85.91647	16.5 h	EC/1.47		0+			0.0280
									0.243
									0.612
^{87m}Zr			14.0 s	I.T./0.3362		1/2-			0.1352(IT)
									0.2010
^{87}Zr		86.91482	1.73 h	β^+ /3.67	2.26	9/2+			ann.rad./
				EC/					0.3811
									1.228
^{88}Zr		87.91023	83.4 d	EC/0.67		0+			0.3929
^{89m}Zr			4.18 m	I.T./94/0.5877		1/2-			ann.rad./
				β^+ /1.5/					0.5877(IT)
				EC/4.7/					1.507
^{89}Zr		88.908889	3.27 d	β^+ /23/2.832	0.9/	9/2+	-1.07		ann.rad./
				EC/77/					0.9092
^{90m}Zr			0.809 s	I.T./		5-	6.3		0.1326
									2.1862
									2.3189(IT)
^{90}Zr	51.45(40)	89.904702				0+			
^{91}Zr	11.22(5)	90.905643				5/2+	-1.30362	-0.21	
^{92}Zr	17.15(8)	91.905039				0+			
^{93}Zr		92.906474	1.5x10^{6}y	β^- /0.091		5/2+			0.0304
^{94}Zr	17.38(28)	93.906314	> 10^{17} y	$\beta^-\beta^-$		0+			
^{95}Zr		94.908041	64.02 d	β^- /1.125	0.366/55	5/2+	1.13	+0.29	0.7242

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
					0.400/44				0.7567
^{96}Zr	2.80(9)	95.908275	$>2\times10^{19}$ y	$\beta^-\beta^-$		0+			
^{97}Zr		96.910950	16.8 h	β^- /2.658	1.91/	1/2-			0.7434
^{98}Zr		97.91276	30.7 s	β^- /2.26	2.2/100	0+			
^{99}Zr		98.91651	2.2 s	β^- /4.56	3.9/	1/2+			0.4692/55.2
					3.5/				0.5459/48
									0.028-1.321
^{100}Zr		99.91776	7.1 s	β^- /3.34		0+			0.4006
									0.5043
^{101}Zr		100.92114	2.1 s	β^- /5.49	6.2/	3/2-			0.1194
									0.2057
									0.2089
^{102}Zr		101.92298	2.9 s	β^- /4.61					
^{103}Zr		102.9266	1.3 s	β^- /7.0					
^{104}Zr		103.9288	1.2 s	β^- /5.9					
^{105}Zr		104.9331	≈1. s	β^- /8.5					
^{106}Zr		105.9359	>0.24 µs						
^{107}Zr		106.941	>0.24 µs						
^{108}Zr		107.944	>0.15 µs						
^{109}Zr			>0.15 µs						
^{110}Zr			>0.15 µs						
$_{41}$Nb		92.90638(2)							
^{81}Nb		80.949	< 0.08 µs						
^{82}Nb		81.9431	50 ms	β^+/11.					
^{83}Nb		82.9367		β^+/7.5					
^{84}Nb		83.9336	12. s	β^+ ,EC/9.6		(3+)			
^{85}Nb		84.9279	2.3 m	β^+ /6.0					
^{86m}Nb			56. s	β^+					
^{86}Nb		85.9250	1.46 m	β^+ /8.0					ann.rad./
									0.751
									1.003
^{87m}Nb			3.7 m	β^+ /		1/2-			ann.rad./
				EC/					0.1352
									0.2010
^{87}Nb		86.92036	2.6 m	β^+ 5.2/		(9/2+)			ann.rad./
				EC/					0.2010
									0.4706
									0.6165
									1.0665
									1.8842
^{88m}Nb			7.7 m	β^+ /		4-			ann.rad./
				EC/					0.2625
									0.3996
									1.0569
									1.0825
^{88}Nb		87.9183	14.3 m	β^+ /7.6	3.2/	8+			ann.rad./
				EC/					1.0570
									1.0828
									(0.07 - 2.5)
^{89m}Nb			2.0 h	β^+ /	3.3/	9/2+			0.5880/10(D)
				EC/					(0.17 - 4.0)
^{89}Nb		88.91349	1.10 h	β^+ /74/4.29	2.8/	1/2-	+6.216		ann.rad./
				EC/26/					0.5074
									0.5880
									0.7696
									1.2775
^{90m}Nb			18.8 s	I.T./0.1246		4-			0.002
									0.1225
^{90}Nb		89.911263	14.6 h	β53/6.111	0.86/5	8+	4.961		ann.rad./

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/Energy Intensity (MeV/%)
				EC/47/	1.5/92				0.1412
									1.1292
									2.1862
									2.3189
									(0.1 - 3.3)
^{91m}Nb			62. d	I.T./97/		1/2-			0.1045(IT)
				EC/3/					1.2050
^{91}Nb		90.906989	7x10^{2}y	EC/1.253		9/2+			Mo k x-ray
^{92m}Nb			10.13 d	EC/99+/		2+	6.114		0.9126
									0.9345
									1.8475
^{92}Nb		91.907192	3.7x10^{7}y	EC/2.006		7+			0.5611
									0.9345
^{93m}Nb			16.1 y	I.T./0.0304		1/2-			Nb x-ray
									0.0304
^{93}Nb	100.	92.906376				9/2+	+6.1705	-0.32	
^{94m}Nb			6.26 m	I.T./99+/2.086		3+			Nb k x-ray
				β^- /0.5/					0.0409
									0.87109
^{94}Nb		93.907282	2.4x10^{4}y	β^- /2.045	0.47/	6+			0.70263
									0.87109
^{95m}Nb			3.61 d	I.T./97.5/	0.2357	1/2-			0.2040
				β^- /2.5/					0.2356
^{95}Nb		94.906834	34.97 d	β^- /0.926	0.160/	9/2+	6.141		0.76578
^{96}Nb		95.908099	23.4 h	β^- /3.187	0.5/10	6+	4.976		0.7782
					0.75/90				0.2191-1.498
^{97m}Nb			58.1 s	I.T./0.7434	0.734/98	1/2-			0.7434
^{97}Nb		96.908096	1.23 h	β^- /1.934	1.27/98	9/2+	6.15		0.4809
									0.6579
^{98m}Nb			51. m	β^- /4.67		5+			0.7874
									0.1726-1.89
^{98}Nb		97.91033	2.9 s	β^- /4.59	4.6/	1+			0.6451
									0.7874
									1.0243
^{99m}Nb			2.6 m	β^- /	3.2/	1/2-			0.0978/100
									(0.138-3.010)
^{99}Nb		98.91162	15.0 s	β^- /3.64	3.5/100	9/2+			0.0977
									0.1378/3.1
^{100m2}Nb			0.013 ms						
^{100m1}Nb			3.0 s	β^- /6.74	5.8				Nb k x-ray
									0.159
									0.6364
									1.0637
^{100}Nb		99.91418	1.5 s	β^- /6.25	6.2/				0.5354
					5.3/				0.6001-1.566
^{101}Nb		100.91525	7.1 s	β^- /4.57	4.3/				0.1105-0.810
^{102m}Nb			4.3 s	β^- /					
^{102}Nb		101.91804	1.3 s	β^- /7.21	7.2/				0.2960-2.184
^{103}Nb		102.91914	1.5 s	β^- /5.53	5.3/	5/2+			
^{104m}Nb			0.9 s	β^-,n/	n/0.06				
^{104}Nb		103.9225	4.8 s	β^-,n/8.1	n/0.05				
^{105}Nb		104.9239	3.0 s	β^-,n/6.5	n/1.7				
^{106}Nb		105.9282	1.0 s	β^-,n/9.3	n/4.5				
^{107}Nb		106.9303	0.30 s	β^-,n/7.9	n/6.0				
^{108}Nb		107.9350	0.19 s	β,n/	n/6.2				(0.193-0.590)
^{109}Nb		108.9376	0.19 s	β,n/	n/31				
^{110}Nb		109.943	0.17 s	β,n/	n/40				
^{111}Nb			>0.15 µs						
^{112}Nb			>0.15 µs						

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{113}Nb			>0.15 µs						
$_{42}$Mo		95.94(1)							
^{83}Mo		82.949							
^{84}Mo		83.9401	>0.15 µs	β^+/6.		(1/2-)			
^{85}Mo		84.9366	3.2 s	β^+/8.1					
^{86}Mo		85.9302	20. s	β^+/4.8					
^{87}Mo		86.9273	14. s	EC, β^+/6.5					(0.752-1.004)
^{88}Mo		87.92195	8.0 m	β^+ /3.4		0+	+0.5		ann.rad./
				EC					0.0800
									0.1399
									0.1707
^{89m}Mo			0.19 s	I.T./0.118		1/2-			0.118(IT)
									0.268
^{89}Mo		88.91948	2.2 m	β^+ /5.58		9/2+			ann.rad./
				EC/					0.659
									0.803
									1.155
									1.272
^{90}Mo		89.91394	5.7 h	β^+ /25/2.489 1.085/		0+			ann.rad./
				EC/75/					0.04274
									0.12237
									0.25734
^{91m}Mo			1.08 m	I.T./50/0.653		1/2-			ann.rad./
				β^+ ,EC/50/	2.5/				0.6529
					2.8/				1.2081
					4.0/				1.5080
									2.2407
^{91}Mo		90.91175	15.5 m	β^+ /94/4.43	3.44/94	9/2-			ann.rad./
				EC/6/					1.6373
									2.6321
									3.0286
									(0.1 - 4.2)
^{92}Mo	14.84(35)	91.906810				0+			
^{93m}Mo			6.9 h	I.T./99+/2.425		21/2+	+9.21		0.26306(IT)
									0.68461
									1.47711
^{93}Mo		92.906811	3.5x10^{3}y	EC/0.405		5/2+			0.0304
^{94}Mo	9.25(12)	93.905087				0+			
^{95}Mo	15.92(13)	94.905841				5/2+	-0.9142	-0.02	
^{96}Mo	16.68(2)	95.904678				0+			
^{97}Mo	9.55(8)	96.906020				5/2+	-0.9335	+0.26	
^{98}Mo	24.13(31)	97.905407				0+			
^{99}Mo		98.907711	2.7476 d	β^- /1.357	0.45/14	1/2+	0.375		0.144048
					0.84/2				0.18109
					1.21/84				0.36644
									0.73947
^{100}Mo	9.63(23)	99.90748	≈ 1×10^{19} y	$\beta^-\beta^-$		0+			
^{101}Mo		100.91035	14.6 m	β^- /2.82	2.23/	1/2+			0.0063
					0.7/				0.19193
									0.5909
									(0.0809-2.405)
^{102}Mo		101.91030	11.3 m	β^-/1.01	1.2/	0+			0.1493/89.
									0.2116/100.
									0.2243/32.
^{103}Mo		102.91320	1.13 m	β^-/3.8		3/2+			0.1028(2)/
									0.1440(2)
									0.2511(2)
^{104}Mo		103.91376	1.00 m	β^-/2.16		0+			0.0686(1)/100.

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.4239(4)/21.
^{105}Mo		104.9170	36. s	β^-/4.95		3/2+			0.0642/
									0.0856/
									0.2495/
^{106}Mo		105.91814	8.4 s	β^-/3.52		0+			0.1894(2)/22.
									0.3644(2)/6.
									0.3723(2)/12.
^{107}Mo		106.9217	3.5 s	β^-/6.2					
^{108}Mo		107.9236	1.1 s	β^-/5.1					(0.028-0.636)
^{109}Mo		108.9278	0.5 s	β^-/7.2					
^{110}Mo		109.9297	0.30 s	β^-/5.7					Tc k x-ray
									0.142
									(0.039-0.599)
^{111}Mo		110.9345	>0.15 µs						
^{112}Mo		111.937	>0.15 µs						
^{113}Mo		112.942	>0.15 µs						
^{114}Mo			>0.15 µs						
^{115}Mo			>0.15 µs						
^{116}Mo			>0.15 µs						
^{117}Mo			>0.15 µs						
$_{43}$Tc									
^{85}Tc		84.949	< 0.1 ms						
^{86}Tc		85.9430	0.05 s	β^+/11.9					
^{87}Tc		86.9365	>0.15 µs	β^+/8.6					
^{88}Tc		87.9328	5.8 s	β^+/10.1					
^{89m}Tc			13. s						
^{89}Tc		88.9275	13. s	β^+/7.5					
^{90m}Tc			49.2 s	β^+	5.3/	6+			ann.rad./
									0.9479/
									1.0542/
^{90}Tc		89.9235	8.3 s	β^+/8.9	7.0/15	1+			ann.rad./
					7.9/95.				0.9479/
^{91m}Tc			3.3 m	β^+		1/2+			ann.rad./170.
				EC					0.8110(5)/5.
									1.6052(1)/7.8
									1.6339(1)/9.1
									1.9023(1)/6.
									2.4509(1)/13.5
^{91}Tc		90.9184	3.14 m	β^+/6.2	5.2	9/2+			ann.rad./200.
^{92}Tc		91.91526	4.4 m	β^+/7.87	4.1	8+			ann.rad./200.
				EC					0.0850/
									0.1475
									0.3293
									0.7731
									1.5096
^{93m}Tc			43. m	I.T./13		1/2-			0.3924(IT)
				EC/20					0.9437
									2.6445
^{93}Tc		92.910248	2.73 h	β^+/13/3.201	0.81	9/2+	6.26		ann.rad./
				EC/87/					1.3629
									1.4771
									1.5203
									(0.1 - 3.0)
^{94m}Tc			52. m	β^+/72/4.33		2+			ann.rad./
				EC/28/					0.8710
									1.8686
^{94}Tc		93.909655	4.88 h	β^+/11/4.256		7+	5.08		ann.rad./
				EC/89/					0.4491
									0.7026

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.8496
									0.8710
^{95m}Tc			61. d	I.T./4/		1/2-			ann.rad./
				β^+/0.3	0.5/				0.0389(IT)
				EC/96	0.7/				0.2041
									0.5821
									0.5821
									0.8351
^{95}Tc		94.90766	20.0 h	EC/100/1.691		9/2+	5.89		0.7657
									1.0738
^{96m}Tc			52. m	I.T./90/		4+			0.0342(IT)
				β^+,EC/2/					0.7782
									1.2002
^{96}Tc		95.90787	4.3 d	EC/2.973		7+	+5.04		Mo k x-ray
									0.7782
									0.8125
									0.8498
									1.12168
^{97m}Tc			91. d	I.T./0.0965		1/2-			Tc k x-ray
				EC	/3.9				0.0965
^{97}Tc		96.906364	4.2x10^6 y	EC/100/0.320		9/2+			Mo k x-ray
^{98}Tc		97.907215	≈6.6x10^6 y	β^-/1.80	0.40/100	6+			0.65241
									0.74535
^{99m}Tc			6.01 h	I.T./100/0.142		1/2-			Tc k x-ray
									0.14049
									0.14261
^{99}Tc		98.906254	2.13x10^5 y	β^-/0.294	0.293/100	9/2+	+5.6847	-0.129	
^{100}Tc		99.907657	15.8 s	β^-/3.202	2.2/	1+			0.5396
				EC/1.8(10)$^{-3}$/0.17	2.9/				0.5908
					3.3				1.5122
									(0.3 - 2.6)
^{101}Tc		100.90731	14.2 m	β^-/1.61	1.32/	9/2+			0.1272
									0.1841
									0.3068
									0.5451
									(0.073-0.969)
^{102m}Tc			4.4 m	I.T./2/4.8	1.8/				0.4184
				β^-/98/					0.4752
									0.6281
									0.6302
									1.0464
									1.1033
									1.6163
									2.2447
^{102}Tc		101.90921	5.3 s	β^-/4.53	3.4/	1+			0.4686
					4.2				0.4751
					2.2/				1.1055
^{103}Tc		102.90918	54. s	β^-/2.66	2.0/	5/2+			0.1361
					2.2/				0.1743
									0.2104
									0.3464
									0.5629
									(0.13 - 1.0)
^{104m}Tc			0.005 ms						
^{104}Tc		103.91144	18.2 m	β^-/5.60	5.3/	(3+)			0.3483
									0.3580
									0.5305

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.5351
									0.8844
									0.8931
									1.6768
									(0.3 - 3.7)
^{105}Tc		104.91166	7.6 m	β^-/3.6	3.4/	5/2+			0.1079
									0.1432
									0.3215
^{106}Tc		105.91436	36. s	β^-/6.55		2+			0.2703
									0.5222
									1.9694
									2.2393
									2.7893
^{107}Tc		106.9151	21.2 s	β^-/4.8					0.1027
									0.1063
									0.1770
									0.4587
^{108}Tc		107.9185	5.1 s	β^-/7.72		(3)			0.2422
									0.4656
									0.7078
									0.7326
									1.5835
^{109}Tc		108.9200	1.4 s	β^-/6.3	p/0.08				
^{110}Tc		109.9234	0.83 s	β^-/8.8	p/0.04				0.2407
^{111}Tc		110.9250	0.30 s	β^-.n/7.0	n/0.85				0.150/92.7
									0.063-1.435
^{112}Tc		111.9292	0.26 s	β,n	n/2.6				
^{113}Tc		112.931	0.15 s	β^-,n/8.	/2.1				0.0985/100
									0.0658-1.520
^{114}Tc		113.936	0.15 s	β^-,n	/1.3				
^{115}Tc		114.938	>0.15 µs						
^{116}Tc			>0.15 µs						
^{117}Tc			>0.15 µs						
^{118}Tc			>0.15 µs						
$_{44}$Ru		101.07(2)							
^{87}Ru		86.949	>1.5 µs						
^{88}Ru		87.9404	>0.15 µs			0^+			
^{89}Ru		88.936	1.2 s	β^+.p/8.					
^{90}Ru		89.9298	11. s	β^+/5.9		0^+			ann.rad./
									0.155 - 1.551
^{91}Ru		90.9264	9. s	β^+,EC/7.4		9/2+			ann.rad./
^{92}Ru		91.9201	3.7 m	β^+/53/4.5		0+			ann.rad./
				EC/47/					0.1346
									0.2138
									0.2593
^{93m}Ru			10.8 s	I.T./21/		1/2-			ann.rad./
				β^+,EC/79/	5.3/				0.7344
									1.1112
									1.3962
									2.0931
^{93}Ru		92.9171	1.0 m	β^+/6.3		9/2+			ann.rad./
				EC/					0.6807
									1.4349
									(0.5- 4.2)weak
^{94}Ru		93.91137	52. m	EC/100/1.59		0^+			0.3672
									0.5247
									0.8922
^{95}Ru		94.91042	1.64 h	EC/85/2.57	1.20/	5/2+	0.86		ann.rad./
				β^+/15/	0.91/				0.2904

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.3364
									0.6268
^{96}Ru	5.52(20)	95.90760				0+			
^{97}Ru		96.90756	2.89 d	EC/1.12		5/2+	-0.78		Tc k x-ray
									0.2157
									0.3245
									0.4606
^{98}Ru	1.88(9)	97.90529				0+			
^{99}Ru	12.74(26)	98.905939				5/2+	-0.6413	+0.079	
^{100}Ru	12.60(19)	99.904219				0+			
^{101}Ru	17.05(7)	100.905582				5/2+	-0.7188	+0.46	
^{102}Ru	31.57(31)	101.904349				0+			
^{103}Ru		102.906323	39.27 d	β^-/0.763	0.223	3/2+	0.206	+0.62	0.05329
									0.29498
									0.4438
									0.49708
									0.55704
									0.61033
									(0.04 - 1.6)
^{104}Ru	18.66(44)	103.905430				0+			
^{105}Ru		104.907750	4.44 h	β^-/1.917	1.11/22	3/2+	-0.3		0.12968
					1.134/13				0.1491
					1.187/49				0.2629
									0.31664
									0.46943
									0.67634
									0.72420
									(0.1 - 1.8)
^{106}Ru		105.90733	1.020 y	β^-/0.0394	0.0394/100	0+			
^{107}Ru		106.9099	3.8 m	β^-/2.9	2.1/				0.1939
					3.2/				0.3741
									0.4625
									0.8488
^{108}Ru		107.9102	4.5 m	β^-/1.4	1.2/	0^+			0.0923
									0.1651
									0.4339
									0.4975
									0.6189
^{109}Ru		108.91320	34.5 s	β^-/4.2					0.1164
									0.3584
^{110}Ru		109.9140	15. s	β^-/2.81					0.1121
									0.3737
									0.4397
									0.7967
^{111}Ru		110.9176	1.5 s	β^-/5.5					
^{112}Ru		111.9188	4.5 s	β^-/4.5					
^{113}Ru		112.9225	2.7 s	β^-/7.					
^{114}Ru		113.9239	0.57 s	β^-/6.1					0.127/24
									(0.053-0.180)
^{115}Ru		114.928	≈0.74 s		β^-/8.				
^{116}Ru		115.930	>0.15 µs						
^{117}Ru		116.935	>0.15 µs						
^{118}Ru		117.937	>0.15 µs						
^{119}Ru			>0.15 µs						
^{120}Ru			>0.15 µs						
$_{45}$Rh		102.90550(2)							
^{89}Rh		88.9494	>0.15 µs						
^{90}Rh		89.9429	>0.15 µs						
^{91}Rh		90.9366	>0.15 µs						

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{92}Rh		91.9320	>0.15 µs	β^+/11.1					
^{93}Rh		92.9257	>0.15 µs	β^+/8.1					(0.138-1.493)
^{94m}Rh			25.8 s	β^+/		8+			ann.rad./
									0.1264
									0.3117
									0.7562
									1.0752
									1.4307
^{94}Rh		93.9217	1.18 m	β^+/9.6	6.4/	3+			ann.rad./
									0.1461
									0.3117
									0.7562
									1.4307
^{95m}Rh			1.96 m	I.T./88/		1/2+			ann.rad./
				β^+,EC/12/					0.5433(IT)
									0.7837
^{95}Rh		94.9159	5.0 m	β^+/5.1	3.2	9/2+			ann.rad./
									0.2293
									0.4103
									0.6610
									0.9416
									1.3520
									(0.2 - 3.8)
^{96m}Rh			1.51 m	I.T./60/0.052		2+			ann.rad./
				β^+,EC/40/	4.70/				Tc,Ru x-rays
									0.8326
									1.0985
									1.6921
									(0.4 - 3.3)
^{96}Rh		95.91452	9.6 m	β^+/6.45	3.3/	5+			ann.rad./
				EC/					0.4299
									0.6315
									0.6853
									0.7418
									0.8326
									(0.2 - 3.4)
^{97m}Rh			46.m	I.T./5/	2.6/	1/2-			ann.rad./
				β^+,EC/95/					0.1886
									0.4215
									2.2452
^{97}Rh		96.91134	31.0m	β^+/3.52	2.1/	9/2+			ann.rad./
									0.1886
									0.3892
									0.4515
									0.8398
									0.8788
									(0.2 - 3.5)
^{98m}Rh			3.5 m	β^+ /		5+			ann.rad./
									0.6154
									0.6524
									0.7452
^{98}Rh		97.91072	8.7 m	β^+/90/5.06	3.4/	2+			ann.rad./
									0.6524
									0.7623
^{99m}Rh			4.7 h	β^+/8/	.74/	9/2+	5.67		ann.rad./
				EC/92/					0.2766/
									0.3408
									0.6178
									1.2612

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{99}Rh		98.90820	16. d	β+/4/2.10	0.54/	1/2-			ann.rad./
				EC/97/	0.68/				0.0894/
									0.3530
									0.5277
									(0.1 - 2.0)
^{100m}Rh			4.7 m	I.T./99/		5+			ann.rad./
				β+ /0.4/					0.0748/
									0.2647(IT)
^{100}Rh		99.90812	20.8 h	β+ /3.63	2.62/	1-			0.4462
				EC/	2.07/				0.5396
									0.5882
									0.8225
									1.5534
									2.3761
^{101m}Rh			4.35 d	EC/92/		9/2+	+5.51		Rh k x-ray
				I.T./8/0.1573					0.1272/
									0.3069
									0.5451
^{101}Rh		100.90616	3.3 y	EC/0.54		1/2-			Ru k x-ray
									0.1272
									0.1980
									0.3252
^{102m}Rh			3.74 y	EC/2.323		6+	4.04		0.4751
				IT/0.0419					0.6313
									0.6975
									0.7668
									1.0466
									1.1032
^{102}Rh		101.906842	207. d	EC/62			0.5		ann.rad./
				β¯ /19/					0.4686
				β+ /14/					0.4751
									0.5566
									0.6280
									1.1032
									(0.4 - 1.6)
^{103m}Rh			56.12 m	IT		7/2+	4.54		
^{103}Rh	100.	102.905504				1/2-	-0.0884		
^{104m}Rh			4.36 m	I.T./99+/		5+			Rh k x-ray
				β¯	1.3/				0.0514
									0.0971
									0.5558
^{104}Rh		103.906655	42.3 s	β¯/99+/2.441	1.88/2	1+			0.3581
				EC/0.4/1.141	2.44/98				0.5558
									1.2370
									(0.35 - 1.8)
^{105m}Rh			43. s	I.T./1.296		1/2-			Rh k x-ray
									0.1296
^{105}Rh		104.905692	35.4 h	β¯ /0.567	0.247/30	7/2+	+4.45		0.2801
					0.567/70				0.3061
									0.3189
^{106m}Rh			2.18 h	β¯ /	0.92/	6+			0.2217
									0.4510
									0.5119
									0.6162
									0.7173
									0.7484
									1.0458
									1.5277
^{106}Rh		105.90729	29.9 s	β¯ /3.54	2.4/2	1+	+2.58		0.51186/

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
					3.0/12				0.61612
					3.54/79				0.62187
									(0.05 - 3.04)
^{107}Rh		106.90675	21.7 m	β^- /1.51	1.20/65	7/2+			0.2776
					1.5/17				0.3028
									0.3925
^{108m}Rh			6.0 m	β^- /	1.57/				0.4339
									0.4973
									0.6189
^{108}Rh		107.9087	17. s	β^- /4.5		1+			0.4046
									0.4339
									0.4973
									0.5811
									0.6146
									0.9014
									0.9471
^{109}Rh		108.90874	1.34 m	β^- /2.59	2.25/	7/2+			0.1134
									0.1780
									0.2914
									0.3254
									0.3268
									0.4261
									(0.1 - 1.6)
^{110m}Rh			29. s	β^- /	0.6/				0.3737
									0.4397
									0.7967
^{110}Rh		109.9110	3.1 s	β^- /5.4	5.5/	1+			0.3737
									0.4400
									0.5463
									0.6877
									0.8381
									0.9045
^{111}Rh		110.9117	11. s	β^- /3.7					0.275
^{112m}Rh			6.8 s	β^- /					
^{112}Rh		111.9140	3.5 s	β^- /6.2		1+			0.3489
^{113}Rh		112.9154	0.9 s	β^- /4.9					0.1285
^{114m}Rh			1.8 s	β^- /					
^{114}Rh		113.9173	1.8 s	β^- /6.5		1+			
^{115}Rh		114.9201	0.99 s	β^- /6.0					
^{116m}Rh			0.9 s	β^- /					0.3405
^{116}Rh		115.9228	0.7 s	β^- /8.0		1+			
^{117}Rh		116.925	0.44 s	β^-/7.					0.0346
									0.1317
^{118}Rh		117.929	>0.15 µs						
^{119}Rh		118.931	>0.15 µs						
^{120}Rh		119.936	>0.15 µs						
^{121}Rh		120.938	>0.15 µs						
^{122}Rh									
$_{46}$Pd		106.42(1)							
^{91}Pd		90.949	>1.5 µs						
^{92}Pd		91.9404	>0.15 µs						
^{93}Pd		92.9359	0.9 s	β^+,p					0.240/81
									0.382-0.864
^{94}Pd		93.9288	9. s	EC,β^+ /≈ 6.6					0.5582
									(0.0546-0.798)
^{95m}Pd		94.92684	13.4 s	EC,β^+ /10.2		21/2+			
^{95}Pd									
^{96}Pd		95.9182	2.03 m	EC,β^+ /3.5	1.15/				0.1248
									0.4995

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{97}Pd		96.9165	3.1 m	β^+ ,EC/4.8	3.5/	5/2+			ann.rad./
									0.2653
									0.4752
									0.7927
									(0.2 - 3.4)
^{98}Pd		97.91273	17.7 m	β^+ /1.87		0+			ann.rad./
				EC/					0.0677
									0.1125
									0.6630
									0.8379
^{99}Pd		98.91181	21.4 m	β^+ /49/3.37	2.18/	5/2+			ann.rad./
				EC/51/					0.1360
									0.2636
									0.6734
									(0.2 - 2.85)
^{100}Pd		99.90851	3.7 d	EC/0.36		0+			0.03271
									0.0748
									0.0840
^{101}Pd		100.90829	8.4 h	β^+ /5/1.980	0.776/	5/2+	-0.66		ann.rad./
				EC/95/					0.0244
									0.2963
									0.5904
^{102}Pd	1.02(1)	101.905607				0+			
^{103}Pd		102.906087	16.99 d	EC/0.543		5/2+			Rh k x-ray
									0.03975
									0.3575
									0.4971
^{104}Pd	11.14(8)	103.904034				0+			
^{105}Pd	22.33(8)	104.905083				5/2+	-0.642	+0.66	
^{106}Pd	27.33(3)	105.903484				0+			
^{107m}Pd			20.9 s	I.T./0.2149		11/2-			Pd k x-ray
									0.2149(IT)
^{107}Pd		106.90513	6.5x10^{6}y	β^- /0.033	0.03/	5/2+			
^{108}Pd	26.46(9)	107.903895				0+			
^{109m}Pd			4.75 m	I.T./0.1889		11/2-			Pd x-ray
									0.1889(IT)
^{109}Pd		108.905954	13.5 h	β^- /1.116	1.028	5/2+			0.0880
									(0.08 - 1.0)
^{110}Pd	11.72(9)	109.905153				0+			
^{111m}Pd			5.5 h	I.T./73/0.172		11/2-			0.0704
				β^- /27/	0.35				0.1722
					0.77				0.3912
									(0.1 - 1.97)
^{111}Pd		110.90764	23.4 m	β^- /2.19	2.2/95	5/2+			0.0598
									0.2454
									0.5800
									0.6504
									1.3885
									1.4590
^{112}Pd		111.90731	21.04 h	β^- /0.29	0.28/	0+			0.018
^{113m}Pd			1.48 m	β^- /		5/2+			0.0959
^{113}Pd		112.91015	1.64 m	β^- /3.34					0.0958
									0.4824
									0.6436
									0.7394
^{114}Pd		113.91037	2.48 m	β^- /1.45		0+			0.1266
									0.2320
									0.5582
									0.5760

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{115}Pd		114.9137	47. s	β^- /4.58					0.1255
									0.2554
									0.3428
^{116}Pd		115.9142	12.7 s	β^- /2.61					0.1015
									0.1147
									0.1778
^{117}Pd		116.9178	4.4 s	β^-/5.7					0.2473
									0.077-0.403
^{118}Pd		117.9189	2.4 s	β^-/4.1					0.1254
									0.028-0.596
^{119}Pd		118.9227	0.9 s	β^-/6.5					0.2566
									0.070-0.326
^{120}Pd		119.9240	0.5 s	β^-/5.0					0.1581
									0.053-0.595
^{121}Pd		120.9282	>0.24 μs						
^{122}Pd		121.9298	>0.24 μs						
^{123}Pd		122.934	>0.15 μs						
^{124}Pd									
$_{47}$Ag		107.8682(2)							
^{93}Ag									
^{94}Ag		93.9428	0.42 s	β^+, p/					
^{95}Ag		94.9355	2.0 s	β^+, p/					(0.539-2.025)
^{96}Ag		95.9307	5.1 s	β^+/11.6					ann.rad./
				EC/					0.1248
									0.4995
									(0.1066-1.416)
^{97}Ag		96.9240	19. s	β^+ /7.0					ann.rad./
				EC/					0.6862
									1.2941
									(0.352-3.294)
^{98}Ag		97.9218	47. s	β^+ /8.4		5+			ann.rad./
				EC/					0.5711
									0.6786
									0.8631
									(0.153-1.185)
^{99m}Ag			11. s	I.T./100/		1/2-			Ag k x-ray
									0.1636(IT)
									0.3426
^{99}Ag		98.9176	2.07 m	β^+ /87/5.4		9/2+			ann.rad./
				EC/13/					0.2199
									0.2645
									0.8056
									0.8323
									(0.2 - 3.5)
^{100m}Ag			2.3 m	β^+ /		2+			ann.rad./
				EC/					0.6657
									1.6941
^{100}Ag		99.9161	2.0m	β^+/7.1	4.7/	5+			ann.rad./
				EC/					0.2807
									0.4503
									0.6657
									0.7508
									0.7732
^{101m}Ag			3.1 s	I.T./0.23		1/2-			Ag k x-ray
									0.0981
									0.176(IT)
^{101}Ag		100.9128	11.1 m	β^+/69/4.2	2.7/	9/2+	5.7		ann.rad./
				EC/31/					0.2610
					2.18/				0.2747

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
					2.73/				0.3269
					3.38/				0.4392
									0.6673
									1.1739
									(0.2 - 3.1)
^{102m}Ag			7.8 m	β^+/38/	3.4	2+	+4.14		ann.rad./
				EC/13/					0.5567
				I.T./49/					0.9777
									1.8347
									2.0545
									2.1594
									3.2386
^{102}Ag		101.91197	13.0 m	β^+/78/5.92	2.26/	5+	4.6		ann.rad./
				EC/22/					0.5567
									0.7194
									0.8354
									1.2571
									1.5816
									1.7446
^{103m}Ag			5.7 s	I.T./0.134		1/2-			Ag k x-ray
									0.1344
^{103}Ag		102.90897	1.10 h	β^+/28/2.69	1.7	7/2+	+4.47		ann.rad./
				EC/72/	1.3				0.1187
									0.1482
^{104m}Ag			33. m	β^+/64/	2.71/	2+	+3.7		ann.rad./
				EC/36/					0.5558
				I.T./0.07/					0.7657
									(0.5 - 3.4)
^{104}Ag		103.90863	69. m	β^+/16/4.28	0.99/	5+	3.92		ann.rad./
				EC/84/					0.5558
									0.9259
									0.9416
									(0.18 - 2.27)
^{105m}Ag			7.2 m	I.T./98/0.0255		7/2+	+4.41		Ag x-ray
				EC/2/					0.3063
									0.3192
									(0.1 - 1.0)
^{105}Ag		104.90653	41.3 d	EC/1.35		1/2-	0.1014		0.0640
									0.2804
									0.3445
									0.4434
^{106m}Ag			8.4 d	EC/		6+	3.71	+1.1	Pd k x-ray
									0.4510
									0.5118
									0.7173
									1.0458
^{106}Ag		105.90667	24.0 m	β^+/59/2.965	/1.96	1+	+2.85		ann.rad./
				EC/41/					0.5119
^{107m}Ag			44.2 s	I.T./0.093		7/2+	+4.40	1.0	Ag x-ray
									0.0931
^{107}Ag	51.839(8)	106.905093				1/2-	-0.11357		
^{108m}Ag			418.y	EC/92/		6+	3.580	+1.3	Ag k x-ray
				I.T./8/0.079					Pd k x-ray
									0.43392
									0.61427
									0.72290
^{108}Ag		107.905954	2.39 m	β^-/97/1.65	1.02/1.7	1+	+2.6884		ann.rad./
				EC/2/	1.65/96				0.43392
				β^-/1/1.92	0.88/0.3				0.61885

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.63298
^{109m}Ag			39.8 s	I.T./0.088		7/2+	+4.40	+1.0	Ag k x-ray
									0.0880
^{109}Ag	48.161(8)	108.904756				1/2-	-0.13069		
^{110m}Ag			249.8 d	β^-/99/	0.087	6+	+3.60	+1.4	0.65774
				I.T./1/0.1164	0.530				0.76393
									0.88467
									0.93748
									1.38427
									(0.447-1.56)
^{110}Ag		109.906111	24.6 s	β^-/2.892	2.22/5	1+	+2.7271	0.2	0.65774
					2.89/95				0.8154
									1.1257
^{111m}Ag			1.08 m	IT/99/0.0598	7/2+				Ag k x-ray
				β^-/1/					0.0598
									0.2454
^{111}Ag		110.905295	7.47 d	β^-/1.037	1.035/	1/2-	-0.146		0.2454
									0.3421
^{112}Ag		111.90701	3.13 h	β^-/3.96	3.94/	2-	0.0547		0.6067
					3.4				0.6174
									1.3877
									(0.4 - 2.9)
^{113m}Ag			1.14 m	I.T./80/0.043	7/2+				0.1422
				β^-/20/	1.5				0.2983
									0.3161
									0.3923
^{113}Ag		112.90657	5.3 h	β^-/2.02	2.01/	1/2-	0.159		0.2588
									0.2986
^{114}Ag		113.90881	4.6 s	β^-/5.08	4.9/	1+			0.5582
									0.5760
									1.9946
^{115m}Ag			18.7 s	β^-/		7/2+			0.1134
									0.1315
									0.2288
									0.3887
^{115}Ag		114.90876	20. m	β^-/3.10		1/2-			0.1316
									0.2128
									0.2291
									0.4727
									(0.13 - 2.49)
^{116m}Ag			10.5 s	I.T./2/	3.2/	5+			0.1027
				β^-/98/	2.9				0.2549
									0.5134
									0.7055
									1.0289
^{116}Ag		115.91137	2.68 m	β^-/6.16	5.3	2-			0.5134
									0.6993
									2.4779
^{117m}Ag			5.3 s	β^-/	3.2/	7/2+			0.1354
									0.2981
									0.3868
^{117}Ag		116.91171	1.22 m	β^-/4.18	2.3	1/2-			0.1354
									0.1571
									0.3377
^{118m}Ag			2.8 s	β^-/59/					0.1277
				I.T./41/0.1277					0.4878
									0.6771
									0.7709
									1.0586

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{118}Ag		117.9145	4.0 s	β^-/7.1					0.4878
									0.6771
									3.2259
^{119}Ag		118.9157	2.1 s	β^-/5.35		7/2+			0.0674
									0.3662
									0.3991
									0.6264
^{120m}Ag			0.32 s	β^-/					0.2030
				I.T./					0.5059
									0.6978
									0.8300
									0.9258
^{120}Ag		119.9188	1.23 s	β^-/8.2					0.5059
									0.6978
									0.8171
									1.3231
^{121}Ag		120.9198	0.78 s	β^-/6.4					0.1150
									0.3148
									0.3537
									0.3696
									0.5007
									1.5105
									(0.11 - 2.5)
^{122m}Ag			1. s	β^-/					
^{122}Ag		121.9233	0.44 s	β^-/9.2					
^{123}Ag		122.9249	0.31 s	β^-/7.4					
^{124}Ag		123.9285	0.22 s	β^-/10.1					
^{125}Ag		124.9305	0.17 s	β^-					
^{126}Ag		125.9345	0.11 s	β^-					
^{127}Ag		126.9369	0.11 s	β^-					
^{128}Ag			58 ms	β^-					
^{129}Ag			0.05 s	β^-,n					
$_{48}$Cd		112.411(8)							
^{96}Cd		95.9398							
^{97}Cd		96.9349	3. s	β^+,(p)					
^{98}Cd		97.9276	9.2 s	β^+/5.4					
				(p)	/0.025				
^{99}Cd		98.9250	16. s	β^+,EC/6.9					ann.rad./
^{100}Cd		99.9203	1.1 m	β^+,EC/3.9					ann.rad./
									(0.090-1.043)
^{101}Cd		100.9187	1.2 m	β^+/83/5.5	4.5	5/2+			In k x-ray
				EC/17/					0.0985
									1.7225
									0.31 - 2.84)
^{102}Cd		101.91474	5.8 m	β^+/27/2.59		0+			ann.rad./
				EC/73					0.0974
									0.4810
									1.0366
									1.3598
^{103}Cd		102.91342	7.5 m	β^+/33/4.14		5/2+	-0.81	-0.8	ann.rad./
				EC/67/					Ag k x-ray
									1.0799
									1.4487
									1.4618
									(0.1 - 2.8)
^{104}Cd		103.90985	58. m	EC/1.14		0+			Ag k x-ray
									0.0835
									0.7093
^{105}Cd		104.90947	55.5 m	β^+/26/2.739	1.69/	5/2+	-0.7393	+0.43	Ag k x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				EC/74/					0.3469
									0.6072
									0.9618
									1.3025
									(0.25 - 2.4)
^{106}Cd	1.25(6)	105.90646	>2.6x10^{17} y	β^+,EC		0+			
^{107}Cd		106.90661	6.52 h	EC/99+/1.417		5/2+	-0.615055	+0.68	Ag k x-ray
				β^+/					0.0931
									0.8289
^{108}Cd	0.89(3)	107.90418				0+			
^{109}Cd		108.904985	462.0 d	EC/0.214		5/2+	-0.827846	+0.69	Ag k x-ray
									0.08804
^{110}Cd	12.49(18)	109.903006				0+			
^{111m}Cd			48.5 m	I.T./		11/2-			Cd k x-ray
									0.1508(IT)
									0.2454
^{111}Cd	12.80(12)	110.904182				1/2+	-0.594886		
^{112}Cd	24.13(21)	111.902758				0+			
^{113m}Cd			14.1 y	β^-/99.9/0.59	0.59/99.9	11/2-	-1.087	-0.71	0.2637
^{113}Cd	12.22(12)	112.904401	7.7x10^{15}y	β^-		1/2+	-0.622301		
^{114}Cd	28.73(42)	113.903359				0+			
^{115m}Cd			44.6 d	β^-/1.629	0.68/1.6	11/2-	-1.042	-0.54	0.48450
					1.62/97				0.93381
									1.29064
^{115}Cd		114.905431	2.228 d	β^-/1.446	0.593/42	1/2+	-0.648426		0.23141
					1.11/58				0.26085
									0.33624
									0.49227
									0.52780
^{116}Cd	7.49(18)	115.904756	2.3×10^{19} y	$\beta^-\beta^-$		0+			
^{117m}Cd			3.4 h	β^-/2.66	0.72/	11/2-			0.1586
									0.5529
									0.37 - 2.42
^{117}Cd		116.907219	2.49 h	β^-/2.52	0.67/51	1/2+			0.2209
					2.2/10				0.2733
									0.3445
									1.3033
^{118}Cd		117.90692	50.3 m	β^-/0.52		0+			
^{119m}Cd			2.20 m	β^-/		11/2-			0.1056
									0.7208
									1.0250
									2.0213
^{119}Cd		118.90992	2.69 m	β^-/3.8	≈ 3.5/	1/2+			0.1340
									0.2929
									0.3429
^{120}Cd		119.90985	50.8 s	β^-/1.76	1.5/	0+			
^{121m}Cd			8. s	β^-/		11/2-			0.1008
									0.9878
									1.0209
									1.1815
									2.0594
^{121}Cd		120.9131	13.5 s	β^-/4.9		(3/2+)			0.2102
									0.3242
									0.3492
									1.0403
^{122}Cd		121.9135	5.3 s	β^-/3.0		0+			
^{123m}Cd			1.9 s	β^-/					

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{123}Cd		122.91770	2.09 s	β^-/6.12		3+			
^{124}Cd		123.9177	1.24 s	β^-/4.17		0+			0.0365
									0.0628
									0.1799
^{125m}Cd			0.66 s	β^-/					
^{125}Cd		124.92129	0.68 s	β^-/7.16		3/+			
^{126}Cd		125.9224	0.52 s	β^-/5.49		0+			0.2601
^{127}Cd		126.9264	0.4 s	β^-/8.5		3/+			
^{128}Cd		127.9278	0.28 s	β^-/7.1		0+			0.247
^{129}Cd		128.9323	0.27 s	β^-/5.9					0.281
^{130}Cd		129.9340	0.20 s	β^-/		0+			
^{131}Cd			68 ms	p/	/3.5				
^{132}Cd			0.10 ms	p/	/60				
$_{49}$In		114.818(3)							
^{98}In		97.9422	>1.5 μs						
^{99}In		98.9346	>0.15 μs	β^+/8.9					
^{100}In		99.9316	6. s	β^+,(p)/10.5					
^{101}In		100.9266	15. s	β^+/7.3					
^{102}In		101.9243	22. s	EC/8.9		(5)			0.1566
									0.7767
									(0.397-0.923)
^{103m}In			34. s						
^{103}In		102.91991	1.1 m	β^+,EC/6.05	4.2	9/2+			ann.rad./
				EC	/45				0.1879
									(0.157-3.98)
^{104m}In			16. s	IT/0.0935					
^{104}In		103.9183	1.84 m	β^+,EC/7.9	4.8	5+	+4.44	+0.7	ann.rad./
									0.6580
									0.8341
									0.8781
^{105m}In			43. s	I.T.		1/2-			In k x-ray
									0.6740
^{105}In		104.91467	5.1 m	β^+,EC/4.85	3.7	9/2+	+5.675	+0.83	0.1310
									0.2600
									0.6038
^{106m}In			5.3 m	β^+/85/	4.90	3+			ann.rad./
				EC/15/					0.6326
									0.8611
									1.7164
^{106}In		105.91346	6.2 m	β^+/65/6.52	2.6	7+	+4.92	+0.97	ann.rad./
				EC/35/					0.2259
									0.6327
									0.8611
									0.9978
									1.0091
^{107m}In			51. s	I.T./0.6786		1/2-			In k x-ray
									0.6785
^{107}In		106.91029	32.4 m	β^+/35/3.43	2.20/	9/2+	+5.59	+0.81	ann.rad./
				E.C/65/					Cd k x-ray
									0.2050
									0.3209
									0.5055
									(0.2 - 2.99)
^{108m}In			57. m	β^+/53/	1.3	6+	+4.94	+0.47	ann.rad./
				EC/47/					Cd k x-ray
									0.6329
									1.9863
									3.4522
^{108}In		107.90971	40. m	β^+/33/5.15	3.49/	3+	+4.56	+1.01	ann.rad./

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				EC/67/					Cd k x-ray
									0.2429
									0.6331
									0.8756
^{109m}In			1.3 m	I.T./0.650		1/2-			In k x-ray
									0.6498
^{109}In		108.90715	4.2 h	β^+/8/2.02	0.79/	9/2+	+5.54	+0.84	ann.rad./
				EC/92/					Cd k x-ray
									0.2035
									0.6235
^{110m}In			4.9 h	EC/		7+	+4.72	+1.00	Cd k x-ray
									0.6577
									0.8847
									0.9375
									(0.1 - 1.98)
^{110}In		109.90717	1.15 h	β^+/62/3.88	2.22/	2+	+4.37	+0.35	ann.rad./
				EC/38/					Cd k x-ray
									0.6577
									(0.6 - 3.6)
^{111m}In			7.7 m	I.T./0.537		1/2-	+5.53		In k x-ray
									0.537
^{111}In		110.90511	2.8049 d	EC/0.866		9/2+	+5.50	+0.80	Cd k x-ray
									0.1712
									0.2453
^{112m}In			20.8 m	I.T./0.155		4+			In k x-ray
									0.1555
^{112}In		111.90553	14.4 m	β^+/22/2.586		1+	+2.82	+0.09	ann.rad./
				EC/34/					Cd k x-ray
				β^-/0.663					0.6171
^{113m}In			1.658 h	I.T./0.3917		1/2-	-0.210		In k x-ray
									0.3917
^{113}In	4.29(5)	112.904062				9/2+	+5.529	+0.80	
^{114m}In			49.51 d	I.T./97/0.190		5+	+4.65	+0.74	In k x-ray
				EC/3/					0.19027
^{114}In		113.904918	1.198 m	β^-/97/1.989					Cd k x-ray
				EC/3/1.453	1.984/	1+	+2.82		0.5584
									0.5727
									1.2998
^{115m}In			4.486 h	I.T./95/0.336		1/2-	-0.255		In k x-ray
				β^-/5/0.83					0.3362
									0.4974
^{115}In	95.71(5)	114.903879	4.4x10^{14} y	β^-/0.495		9/2+	+5.541	+0.81	
^{116m2}In			2.16 s	I.T./0.162		8-	+3.22	+0.31	In k x-ray
				EC	/0.023				0.1624
^{116m1}In			54.1 m	β^-/	1.0	5+	+4.43	+0.80	0.13792
									0.41688/27
									1.09723/58.5
									1.29349/85
^{116}In		115.905261	14.1 s	β^-/3.274	3.3/99	1+	2.788	0.11	0.46313
									1.2526
									1.29349
^{117m}In			1.94 h	β^-/53/1.769	1.77/	1/2-	-0.2517		In k x-ray
				I.T./47/					0.15855
									0.31531
									0.55294
^{117}In		116.90452	44. m	β^-/1.455	0.74/	9/2+	+5.52	+0.83	0.15855
									0.3966
									0.55294
^{118m2}In			8.5 s	I.T./98/		(8-)	+3.32	+0.44	In k x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				β^-/2/					0.1382
^{118m1}In			4.40 m	β^-/	1.3	5+	+4.23	+0.80	0.2086
					2.0				0.6833
									1.2295
^{118}In		117.90636	5.0 s	β^-/4.42	4.2/	1+			0.5282
									1.1734
									1.2295
									2.0432
^{119m}In			17.9 m	β^-/97/	2.7/	1/2-	-0.32		0.3114
				I.T./3/0.311					0.7631
^{119}In		118.90585	2.3 m	β^-/2.36	1.6/	9/2+	+5.52	+0.85	0.0239
									0.6495
									0.7631
									1.2149
^{120m2}In			47 s	β^-/6.1		8-	+3.692	+0.53	1.171
									1.023
^{120m1}In			46. s	β^-/5.8	2.2/	5+	+4.30	+0.81	1.171
									1.023
^{120}In		119.90796	3.1 s	β^-/5.37	5.6/	(1+)			0.4146
					3.1/				0.5924
									0.8637
									1.0232
									1.1714
									(0.4 - 2.7)
^{121m}In			3.8 m	β^-/99/	3.7/	1/2-	-0.36		0.0601
				I.T./1/0.313					0.3136
									0.9256
									1.0412
									1.1022
									1.1204
^{121}In		120.90785	23. s	β^-/3.36	2.5	9/2+	+5.50	+0.81	0.2620
									0.6573
									0.9256
^{122m}In			10. s	β^-/	4.4/	8-	+3.78	+0.59	1.0014
									1.1403
^{122}In		121.91028	1.5 s	β^-/6.37	5.3/	(1+)			0.2391
									1.0014
									1.1403
									1.164
									1.1903
^{123m}In			47. s	β^-/	4.6/	(1/2-)	-0.40		0.1258
									1.170
									3.234
^{123}In		122.91044	6.0 s	β^-/4.39	3.3/	(9/2+)	+5.49	+0.76	0.6188
									1.0197
									1.1305
^{124m}In			3.4 s	β^-		8-	+3.89	+0.66	0.1029
									0.9699
									1.0729
									1.1316
^{124}In		123.91318	3.18 s	β^-/7.36	5/	3+	+4.04	+0.61	0.7070
									0.9978
									1.1316
									3.2142
									(0.3 - 4.6)
^{125m}In			12.2 s	β^-/	5.5/	1/2-	-0.43		0.1876
^{125}In		124.91360	2.33 s	β^-/5.42	4.1/	9/2+	+5.50	+0.71	0.4260
									1.0318
									1.3350

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{126m}In			1.53 s		4.9/	3+	+4.03	+0.49	0.9086
									0.9696
									1.1411
^{126}In		125.91646	1.63 s	β^-/8.21	4.2/	8-	+4.06		0.1118
									0.9086
									1.1411
^{127m}In			3.73 s	β^-/	6.4/	(1/2-)			0.2523
									3.074
^{127}In		126.91734	1.14 s	β^-/6.51	4.9/	(9/2+)	+5.52	+0.59	0.4680
									0.6461
									0.8051
									1.5977
^{128m}In			0.7 s	β^-/	5.4/	(8-)			1.8670
									1.9739
									(0.1205-2.12)
^{128}In		127.92017	0.80 s	β^-/8.98	5.0/	3+			0.9352
									1.1688
									3.5198
									4.2970
^{129m}In			1.23 s	β^-/98/	≈ 7.5/	1/2-			0.3153
				n/2/					0.9067
									1.2220
^{129}In		128.9217	0.63 s	β^-/7.66	5.5/	9/2+			0.2853
									0.7693
									1.8650
									2.1180
^{130m2}In			0.53 s	β^-/	8.8/	5+			0.0892
									0.7744
									1.2212
^{130m1}In			0.51 s	β^-/	6.1/	10-			0.0892
									0.1298
									0.7744
									1.2212
									1.9052
^{130}In		129.92486	0.29 s	β^-/10.25	10.0/	1-			
^{131m2}In			0.3 s	β^-/		(21/ 2+)			
^{131m1}In			0.35 s	β^-/		(1/2-)			
^{131}In		130.9268	0.28 s	β^-/9.18	6.4/	(9/2+)			0.3328
									2.433
^{132}In		131.9323	0.20 s	β^-/13.6	6.0/	(7-)			0.1320
					8.8/				0.2992
									0.3747
									4.0406
^{133}In		132.9383	0.18 s	β^-,(n)					
^{134}In		133.9447	0.14 s						(0.354-2.005)
^{135}In									
$_{50}$Sn		118.710(7)							
^{100}Sn		99.9394	≈ 0.9 s	β^+/7.3	3.4/				
^{101}Sn		100.9361	3. s	β^+/9.					
^{102}Sn		101.9243	≈ 5 s	β^+/5.8					
^{103}Sn		102.9281	7. s	β^+/7.7					
^{104}Sn		103.9232	21. s	β^+, EC/4.5					
^{105}Sn		104.9214	28. s	β^+/6.3					In-x-ray
									(0.2879-3.819)
^{106}Sn		105.91688	2.0 m	β^+/20/3.18					ann.rad./
				EC/80/					In k x-ray
									0.3865
									0.4772

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{107}Sn		106.9157	2.92 m	EC/5.0	1.2/				0.4218
				β^+/					0.6105
									0.6785
									1.0013
									1.1290
									1.542
^{108}Sn		107.91196	10.3 m	β^+/1/2.09	0.36/	0+			In k x-ray
				EC/99/					0.2724
									0.3965
									(0.105-1.68)
^{109}Sn		108.91129	18.0 m	β^+/9/3.85	1.52/	7/2+	-1.08	+0.3	ann.rad./
				EC/91/					In k x-ray
									0.6498
									1.0992
^{110}Sn		109.90785	4.1 h	EC/0.64		0+			In k x-ray
									0.283
^{111}Sn		110.90774	35. m	β^+/31/2.45	1.5/	7/2+	+0.61	+0.2	In k x-ray
				EC/69/					0.7620
									1.1530
									1.9147
^{112}Sn	0.97(1)	111.904822				0+			
^{113m}Sn			21.4 m	I.T./92/0.077		7/2+			Sn k x-ray
				EC/8/					In x-ray
									0.0774
^{113}Sn		112.905174	115.1 d	EC/1.036		1/2+	-0.879		In k x-ray
									0.25511
									0.39169
^{114}Sn	0.65(1)	113.902783				0+			
^{115}Sn	0.34(1)	114.903347				1/2+	-0.9188		
^{116}Sn	14.54(9)	115.901745				0+			
^{117m}Sn			13.60 d	I.T./0.3146		11/2-	-1.396	-0.4	Sn k x-ray
									0.15856
^{117}Sn	7.68(7)	116.902955				1/2+	-1.0010		
^{118}Sn	24.22(9)	117.901608				0+			
^{119m}Sn			293. d	I.T./0.0896		11/2-	-1.4	0.21	Sn k x-ray
									0.02387
^{119}Sn	8.59(4)	118.903311				1/2+	-1.0473		
^{120}Sn	32.59(9)	119.902199				0+			
^{121m}Sn			≈ 55. y	I.T./78/0.006		11/2-	-1.388	-0.14	Sn k x-ray
				β^-/22/	0.354/				0.03715
^{121}Sn		120.904239	1.128 d	β^-/0.388	0.383/100	3/2+	0.698	-0.02	
^{122}Sn	4.63(3)	121.903441				0+			
^{123m}Sn			40.1 m	β^-/1.428	1.26/99	3/2+			0.1603
									0.3814
^{123}Sn		122.905723	129.2 d	β^-/1.404	1.42/99.4	11/2-	-1.370	+0.03	0.1603
									1.0302
									1.0886
^{124}Sn	5.79(5)	123.905275				0+			
^{125m}Sn			9.51 m	β^-/2.387	2.03/98	3/2+			0.3321
									1.4040
^{125}Sn		124.907785	9.63 d	β^-/2.364	2.35/82	11/2-	-1.35	+0.1	1.0671
									(0.2-2.3)
^{126}Sn		125.90765	2.34x10^{5}y	β^-/0.38	0.25/100	0+			0.0643
									0.0876
									0.4148
									0.6663
									0.6950
^{127m}Sn			4.15 m	β^-/3.21	2.72/	3/2+			0.4909
									1.3480

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/Energy Intensity (MeV/%)
									1.5640
^{127}Sn		126.91035	2.12 h	β^-/3.20	2.42/	11/2-			0.8231
					3.2/				1.0956
									(0.120-2.84)
^{128m}Sn			6.5 s	IT/0.091		(7-)			
^{128}Sn		127.91054	59.1 m	β^-/1.27	0.48/	0+			0.4823
					0.63/				0.5573
									0.6805
^{129m}Sn			6.9 m	β^-/		11/2-			1.1611
^{129}Sn		128.9134	2.4 m	β^-/4.0		3/2+			0.6456
^{130m}Sn			1.7 m	β^-/		(7-)			0.1449
									0.8992
^{130}Sn		129.91386	3.7 m	β^-/2.15	1.10/	0+			0.0700
									0.1925
									0.7798
^{131m}Sn			1.02m	β^-/	3.4/	11/2-			0.3043
									0.4500
									0.7985
									1.2260
									(0.08 - 3.21)
^{131}Sn		130.9169	39. s	β^-/4.69	3.8/	3/2+			see ^{131m} Sn
^{132}Sn		131.91775	40. s	β^-/3.12	1.8/				0.0855
									0.2467
									0.3402
									0.8985
^{133}Sn		132.9236	1.44 s	β^-/7.8	7.5/	7/2-			
^{134}Sn		133.9278	1.04 s	β^-/6.8					
^{135}Sn		134.9347	>0.15 μs						
^{136}Sn		135.9393	>0.15 μs						
^{137}Sn		136.946	>0.15 μs						
$_{51}$Sb		121.760(1)							
^{103}Sb		102.9401	>1.5 μs						
^{104}Sb		103.9363	0.5 s						
^{105}Sb		104.9315	1.1 s						
^{106}Sb		105.9288	0.6 s	β^+/10.5					
^{107}Sb		106.9242	≈ 4.6 s	β^+/7.9					(0.253-2.154)
^{108}Sb		107.9222	7.0 s	β^+/9.5					(0.151-1.280)
^{109}Sb		108.91814	17. s	β^+/6.38	4.42/	5/2+			0.6645/63
				EC/	4.67/				0.9254/100
					4.33/				1.0617/75
									0.247-1.495
^{110}Sb		109.9175	24. s	β^+/9.0	6.8/	3+			ann.rad./
				EC/					0.6365
									0.9847
									1.2117
									1.2433
^{111}Sb		110.91254	1.25 m	β^+/87/4.47	3.3/	5/2+			ann.rad./
				EC/13/					0.1002
									0.1545
									0.4891
									1.0326
^{112}Sb		111.91240	51.4 s	β^+/90/7.06	4.75/	3+			ann.rad./
				EC/10/					0.6700
									0.9909
									1.2571
									(0.3 - 3.6)
^{113}Sb		112.90937	6.7 m	β^+/65/3.91	2.42/	5/2+			ann.rad./
				EC/35/					Sn k x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.3324
									0.4980
^{114}Sb		113.9091	3.49 m	β^+/78/5.9	3.4/	3+	1.7		ann.rad./
				EC/22/					Sn k x-ray
									0.8876
									1.2999
^{115}Sb		114.90660	32.1 m	β^+/67/3.03	1.51/	5/2+	+3.46	-0.4	ann.rad./
				EC/33/					Sn k x-ray
									0.4973
^{116m}Sb			1.00 h	β^+/78/	1.16/	8-	2.6		ann.rad./
				EC/22/					Sn k x-ray
									0.4073
									0.5429
									0.9725
									1.2935
									(0.0998-1.501)
^{116}Sb		115.90680	16. m	β^+/50/4.707	1.3/	3+	2.72		ann.rad./
				EC/50/	2.3/				Sn k x-ray
									0.93180
									1.29354
									(0.138-3.903)
^{117}Sb		116.90484	2.80 h	β^+/2/1.76	0.57/	5/2+	+3.4		Sn k x-ray
				EC/98/					0.1586
^{118m}Sb			5.00 h	EC/99/		8-	2.3		Sn k x-ray
									0.25368
									1.05069
									1.22964
^{118}Sb		117.905533	3.6 m	β^+/74/3.657	2.65/	1+	2.5		ann.rad./
				EC/26/					Sn k x-ray
									1.22964
^{119}Sb		118.90395	38.1 h	EC/0.59		5/2+	+3.45	-0.4	Sn k x-ray
									0.0239
^{120m}Sb			5.76 d	EC/		8-	2.34		Sn k x-ray
									0.0898
									0.19730
									1.02301
									1.17121
^{120}Sb		119.90508	15.89 m	β^+/41/2.68	1.72/	1+	+2.3		ann.rad./
				EC/59/					Sn k x-ray
									0.7038
									1.17121
^{121}Sb	57.21(5)	120.903822				5/2+	+3.363	-0.4	
^{122m}Sb			4.19 m	I.T./0.162		8-			Sb x-ray
									0.0614
									0.0761
^{122}Sb		121.90518	2.72 d	β^-/98/1.979	1.414/65	2-	-1.90	+0.9	0.56409
				β^+/2/1.620	1.980/26				0.69277
									1.14050
									1.2569
^{123}Sb	42.79(5)	122.904216				7/2+	+2.550	-0.5	
^{124m2}Sb			20.3 m	I.T./0.035		8-			
^{124m1}Sb			1.6 m	I.T./80/	1.2/	5+			0.4984
				β^-/20/	1.7/				0.6027
									0.6458
									1.1010
^{124}Sb		123.905938	60.20 d	β^-/2.905	0.61/52	3-	1.2	+1.9	0.60271/97.8
					2.301/23				0.64583/7.4
									0.72277/10.5
									1.69094/48.2

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									(0.0274-2.808)
^{125}Sb		124.905247	2.758 y	β⁻/0.767	0.13/30	7/2+	+2.63		0.0355
					0.302/45				0.17632
					0.62/13				0.38044
									0.42786
									0.46336
									0.60060
									0.63595
^{126m2}Sb			11. s	I.T./		3-			L x-ray
									0.0227
^{126m1}Sb			19.0 m	β⁻/86/	1.9	5+			0.4148
				I.T./14/					0.6663
									0.6950
^{126}Sb		125.90725	12.4 d	β⁻/3.67	1.9	8-	1.3		0.2786
									0.4148/83.3
									0.6663/99.7
									0.6950/99
									0.7205
^{127}Sb		126.906914	3.84 d	β⁻/1.581	0.89/	7/2+	2.70		0.2524
					1.10/				0.2908
					1.50/				0.4121
									0.4370
									0.6857
									0.7837
^{128m}Sb			10.1 m	β⁻/96/	2.6/	5+			0.3140
				I.T./4/					0.5941
									0.7432
									0.7539
^{128}Sb		127.90917	9.1 h	β⁻/4.38	2.3/	8-	1.3		0.2148
									0.3141
									0.5265
									0.7433
									0.7540
^{129m}Sb			17.7 m	β⁻/					0.4338
									0.6578
									0.7598
^{129}Sb		128.90915	4.40 h	β⁻/2.38	0.65/	7/2-	2.82		0.0278
									0.1808
									0.3594
									0.4596
									0.5447
									0.8128
									0.9146
									1.0301
^{130m}Sb			6.5 m	β⁻/2.6	2.12/				0.1023
									0.7934
									0.8394
^{130}Sb		129.91155	38.4 m	β⁻/4.96	2.9/	8-			0.1823
									0.3309
									0.4680
									0.7394
									0.8394
^{131}Sb		130.9120	23.0 m	β⁻/3.20	1.31/	7/2+			0.6423
					3.0/				0.6579
									0.9331
									0.9434
^{132m}Sb			2.8 m	β⁻/	3.9/	4+			0.1034
									0.3538
									0.6968

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.9739
									0.9896
^{132}Sb		131.91420	4.2 m	β^-/5.49		8-			0.1034
									0.1506
									0.6968
									0.9739
^{133}Sb		132.9152	2.5 m	β^-/4.00	1.20/	7/2+	3.00		0.4235
									0.6318
									0.8165
									1.0764
^{134m}Sb			10.4 s	β^-/	6.1	7-			
^{134}Sb		133.9206	0.8 s	β^-/8.4	8.4	0-			0.1152
									0.2970
									0.7063
									1.2791
^{135}Sb		134.9252	1.71 s	β^-/8.12		7/2+			1.127
									1.279
^{136}Sb		135.9301	0.82 s	β^-/9.3					
^{137}Sb		136.9353	>0.15 μs						
^{138}Sb		137.9410	>0.15 μs						
^{139}Sb		138.946	>0.15 μs						
$_{52}$Te		127.60(3)							
^{106}Te		105.9377	0.06 ms	α/4.32					
^{107}Te		106.9350	3.1 ms	α/ 70/	3.86(1)/				
				β^+,EC/10.1					
^{108}Te		107.9295	2.1 s	α/68/	3.314(4)/	0+			
				β^+,EC/32/6.8					
^{109}Te		108.9275	4.6 s	β^+ EC/96/8.7					
				α/4/	3.107(4)/				
^{110}Te		109.9224	19. s	β^+,EC/4.5		0+			ann.rad./
									0.2191
									0.6059
^{111}Te		110.9211	19.3 s	β^+,EC/8.0		(7/2+)			ann.rad./
									0.267
									0.322
									0.341
^{112}Te		111.9171	2.0 m	β^+,EC/4.3		0+			ann.rad./
									0.2962
									0.3727
									0.4187
^{113}Te		112.9154	1.7 s	β^+/85/5.7	4.5/	(7/2+)			ann.rad./
				EC/15/					Sb k x-ray
									0.8144
									1.0181
									1.1812
^{114}Te		113.9125	15. m	β^+/40/3.2		0+			ann.rad./
				EC/60/					Sb k x-ray
									0.0838
									0.0903
^{115m}Te			6.7 m	β^+/45/		(1/2+)			ann.rad./
				EC/55/					Sb k x-ray
									0.7236
									0.7704
^{115}Te		114.9116	5.8 m	β^+/45/4.6	2.7/	7/2+			ann.rad./
				EC/55/					Sb k x-ray
									0.7236
									1.3268
									1.3806
									(0.22 - 2.7)

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^{116}Te		115.9084	2.49 h	EC/1.5		0+			Sb k x-ray
									0.0937
^{117}Te		116.90864	1.03 h	EC/75/3.54	1.78/	1/2+			ann.rad./
				β^+/25/					Sb k x-ray
									0.9197
									1.7164
									2.3000
^{118}Te		117.90583	6.00 d	EC/0.28		0+			Sb k x-ray
^{119m}Te			4.69 d	EC/		11/2-	0.89		Sb k x-ray
									0.15360
									0.2705
									1.21271
^{119}Te		118.90641	16.0 h	β^+/2/2.293	0.627/	1/2+	0.25		ann.rad.
				EC/98/					Sb k x-ray
									0.6440
									0.6998
^{120}Te	0.09(1)	119.90403				0+			
^{121m}Te			≈ 154. d	I.T.(89%)		11/2-	0.90		Te k x-ray
				EC(11%)					0.2122
^{121}Te		120.90494	16.8 d	EC/1.04		1/2+			Sb k x-ray
									0.5076
									0.5731
^{122}Te	2.55(12)	121.903056				0+			
^{123m}Te			119.7 d	I.T./0.247		11/2-	-0.93		Te k x-ray
									0.1590/84.1
^{123}Te	0.89(3)	122.904271	2.4x10^{19} y	EC/0.051		1/2+	-0.73695		
^{124}Te	4.74(14)	123.902819				0+			
^{125m}Te			58. d	I.T./0.145		11/2-	-0.99	-0.06	Te k x-ray
									0.0355
^{125}Te	7.07(15)	124.904424				1/2+	-0.8885		
^{126}Te	18.84(25)	125.903305				0+			
^{127m}Te			109. d	I.T./98/0.088		11/2-	-1.04		Te k x-ray
				β^-/2/0.77					0.0883
^{127}Te		126.905217	9.4 h	β^-/0.698	0.696/	3/2+	0.64		0.3603
^{128}Te	31.74(8)	127.904462	>0.6×10^{23} y	$\beta^-\beta^-$		0+			
^{129m}Te			33.6 d	I.T./63/0.105		11/2-	-1.09		Te k x-ray
				β^-/37/	1.60/				0.45984
									0.6959
^{129}Te		128.906596	1.16 h	β^-/1.498	0.99/9	3/2+	0.70	0.06	0.0278
					1.45/89				0.45984
									0.48728
^{130}Te	34.08(62)	129.906223	≈2×10^{21} y	$\beta^-\beta^-$		0+			
^{131m}Te			1.35 d	β^-/78/2.4	0.42/	11/2-	-1.04		0.0811
				I.T./22/0.18					0.1021
									0.14973
									0.77369
									0.79375
									0.85225
^{131}Te		130.908522	25.0 m	β^-/2.233	1.35/12	3/2+	0.70		0.14973
					1.69/22				0.45327
					2.14/60				0.49269
^{132}Te		131.90852	3.26 d	β^-/0.51	0.215	0+			0.049725
									0.11198
									0.22830
^{133m}Te			55.4 m	β^-/82/	2.4/30	11/2-			Te k x-ray
				I.T./18/0.334					0.0949
									0.1689
									0.3121

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.3341
^{133}Te		132.9109	12.4 m	β¯/2.94	2.25/25	3/2+			0.3121
					2.65				0.4079
									1.3334
^{134}Te		133.9116	42. m	β¯/1.51	0.6/	0+			0.7672/29
					0.7/				0.0794-0.9255
^{135}Te		134.9165	19.0 s	β¯/6.0	5.4/				0.267
					6.0				0.603
									0.870
^{136}Te		135.92010	17.5 s	β¯/5.1	2.5/	0+			2.0779/25
									0.0873-3.235
^{137}Te		136.9253	2.5 s	β¯/98/6.9	6.8	7/2-			0.2436
				n/2/					
^{138}Te		137.9292	1.4 s	β¯/6.4					
^{139}Te		138.9347	>0.15 µs						
^{140}Te		139.9387	>0.15 µs						
^{141}Te		140.9444	>0.15 µs						
^{142}Te		141.949	>0.15 µs						
$_{53}$I		126.90447(3)							
^{108}I		107.9436	0.04 s	α/91/4.	3.95				
^{109}I		108.9382	0.11 ms	p					0.593/100
									0.717/63
									0.496-1.057
^{110}I		109.9346	0.65 s	β⁺,EC/83/11.4					ann.rad./
				α/17/≈3.6	3.457(10)/				
				p/11/					
^{111}I		110.9303	2.5 s	β⁺,E../8.5					ann.rad./
									0.2665
									0.3215
									0.3412
^{112}I		111.9280	3.4 s	β⁺,EC/10.2					ann.rad./
									0.6889
									0.7869
^{113}I		112.9237	5.9 s	β⁺,EC/7.6					ann.rad./
									0.4625/100
									0.6224/74
									0.0550-1.422
^{114}I		113.9219	2.1 s	β⁺,EC/8.7					ann.rad./
									0.6826
									0.7088
^{115}I		114.9188	1.3 m	β⁺,EC/6.7		5/2+			ann.rad./
									0.275
									0.284
									0.460
									0.709
^{116}I		115.9167	2.9 s	β⁺/97/7.8	6.7/	1+			ann.rad./
				EC/3/					0.5402
									0.6789
^{117}I		116.9136	2.22 m	β⁺,EC/4.7	3.2/	(5/2+)	3.1		ann.rad./
									0.2744
									0.3259
^{118m}I			8.5 m	β⁺,EC/	4.9/	7-	4.2		ann.rad./
				I.T.					0.104
									0.5998
									0.6052
									0.6138
^{118}I		117.9134	14. m	β⁺,EC/7.0		2-	2.0		ann.rad./
									0.5448
									0.6052

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									1.3384
^{119}I		118.9102	19. m	β^+/54/3.5	2.4/	(5/2+)	+2.9		ann.rad./
				EC/46/					Te k x-ray
									0.2575
^{120m}I			53. m	β^+/80/	3.8		4.2		ann.rad.
				EC/20/					Te k x-ray
									0.4257
									0.5604
									0.6147
									1.3459
^{120}I		119.91005	1.35 h	β^+/56/5.62	4.03	2-	1.23		ann.rad./
				EC/	4.60				Te k x-ray
									0.5604
									0.6411
									1.5230
									(0.43 - 3.1)
^{121}I		120.90737	2.12 h	β^+/13/2.27	1.2/	5/2+	2.3		ann.rad./
				EC/87/					Te k x-ray
									0.2122
									(0.14 - 1.1)
^{122}I		121.90760	3.6 m	β^+/4.234	3.1/	1+	+0.94		ann.rad./
				EC/					Te k x-ray
									0.5641
^{123}I		122.905605	13.2 h	EC/1.242		5/2+	2.82		Te k x-ray
									0.1590
^{124}I		123.906211	4.18 d	β^+/23/3.160	1.54/	2-	1.44		ann.rad./
				EC/77/	2.14/				Te k x-ray
					0.75/				0.6027/62.9
									0.7228/10.3
									1.6910/11.2
									(0.31-1.73)
^{125}I		124.904624	59.4 d	EC/0.1861		5/2+	2.82	-0.89	Te k x-ray
									0.0355
^{126}I		125.905619	13.0 d	EC/		2-	1.44		ann.rad./
				β^+/2.155	1.13/				Te k x-ray
				β^-/1.258/47	0.87/				0.3887
					1.25/				0.6622
^{127}I	100.	126.904468				5/2+	+2.8133	-0.79	
^{128}I		127.905805	25.00 m	β^-/2.118	2.13/	1+			Te k x-ray
				EC/1.251					0.44287
									0.52658
^{129}I		128.904988	$1.7x10^7$ y	β^-/0.194	0.15/	7/2+	+2.621	-0.55	Xe k x-ray
									0.0396
^{130m}I			9.0 m	I.T./83/0.048		2+			I k x-ray
				β^-/17/					0.5361
^{130}I		129.906674	12.36 h	β^-/2.949	1.04/	5+	3.35		0.4180
					0.62				0.5361
									0.6685
									0.7395
^{131}I		130.906125	8.040 d	β^-/0.971	0.606/	7/2+	+2.742	-0.40	0.08017
									0.28431
									0.36446
									0.63699
^{132m}I			1.39 h	IT		8-			
^{132}I		131.90800	2.28 h	β^-/14/3.58	0.80/	4+	3.09	0.09	I k x-ray
				I.T./86/	1.03/				0.0980
					1.2/				0.5059
					1.6/				0.52264
					2.16/				0.63019

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.6506
									0.66768
									0.77260
									0.95457
^{133m}I			9. s	I.T./1.63		19/2-			I kx-ray
									0.0730
									0.6474
									0.9126
^{133}I		132.90781	20.8 h	β^-/1.77	1.24/85	7/2+	+2.86	-0.27	0.51056
									0.52989
									0.87537
^{134m}I			3.7 m	I.T./98/0.316		8-			I k x-ray
				β^-/2/					0.0444
									0.2719
^{134}I		133.9099	52.6 m	β^-/4.05	1.2/	4+			0.1354
									0.84702
									0.88409
^{135}I		134.91005	6.57 h	β^-/2.63	0.9/	7/2+	2.94		0.2884
					1.3/				0.41768
									0.52658
									1.13156
									1.26046
^{136m}I			47. s	β^-/	4.7/	6-			0.1973
					5.2/				0.3468
									0.3701
									0.3814
									1.3130
									(0.16 - 2.36)
^{136}I		135.91466	1.39 m	β^-/6.93	4.3/	2-			0.3447
					5.6/				1.3130
									1.3211
									2.2896
									(0.3 - 6.1)
^{137}I		136.91787	24.5 s	β^-/5.88	5.0/	(7/2+)			0.6010
									1.2180
									1.2201
									1.3026
									1.5343
									(0.25 - 4.4)
^{138}I		137.9224	6.5 s	β^-/7.8	6.9/	2-			0.4836
					7.4/				0.5888
									0.8752
									(0.4 - 5.3)
^{139}I		138.92609	2.30 s	β^-/6.81					0.192
				n/					0.198
									0.273
									0.382
									0.386
									0.468
									0.683
									1.313
^{140}I		139.9310	0.86 s	β^-/8.8		(3)			0.372
				n/					0.377
									0.457
^{141}I		140.9351	0.45 s	β^-/7.8					
^{142}I		141.9402	≈ 0.2 s	β^-					
^{143}I		142.9441	>0.15 µs						
^{144}I		143.9496	>0.15 µs						
$_{54}$Xe		131.293(6)							

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{110}Xe		109.9445	0.2 s	β^+/9.2					
^{111m}Xe			0.9 s	EC,β^+					
^{111}Xe		110.9416	0.7 s	EC,β^+/10.6					
				α/	3.58(1)/				
^{112}Xe		111.9357	3. s	EC,β^+/7.2 α/0.8/					
^{113}Xe		112.9334	2.8 s	EC,β^+/9.1					
^{114}Xe		113.9281	10.0 s	β^+,EC/5.9		0+			ann.rad./
									0.1031
									0.1616
									0.3085
									0.6826
									0.7088
^{115}Xe		114.9270	18. s	β^+,EC/7.6		(5/2+)			ann.rad./
^{116}Xe		115.9214	56. s	β^+,EC/4.3	3.3/	0+			ann.rad./
									0.1042
									0.1916
									0.2477
									0.3107
									0.4127
^{117}Xe		116.9206	1.02 m	β^+,EC/6.5		(5/2+)	-0.594	+1.16	ann.rad./
									0.2214
									0.5190
									0.6389
									0.6613
^{118}Xe		117.917	≈ 4. m	β^+,EC/3.	2.7/	0+			ann.rad./
									0.0535
									0.0600
									0.1199
^{119}Xe		118.9156	5.8 m	β^+,EC/5.0	3.5/	7/2+	-0.654	+1.31	0.0873
									0.1000
									0.2318
									0.4615
^{120}Xe		119.91216	40. m	β^+,EC/97/1.96		0+			I k x-ray
				β^+/3/					0.0251
									0.0726
									0.1781
									(0.1 - 1.03)
^{121}Xe		120.91138	39. m	β^+/44/3.73	2.8/	5/2+	-0.701	+1.33	ann.rad./
				EC/56/					I k x-ray
									0.1328
									0.2527
									0.4452
									(0.1 - 3.1)
^{122}Xe		121.9086	20.1 h	EC/0.9		0+			I k x-ray
									0.3501
^{123}Xe		122.90848	2.00 h	β^+/23/2.68	1.51/	1/2+	-0.150		ann.rad./
				EC/77/					I k x-ray
									0.1489
									0.1781
									(0.1 - 2.1)
^{124}Xe	0.09(1)	123.905895	> 10^{17} y	$\beta^-\beta^-$					
^{125m}Xe			57. s	I.T./0.252		(9/2-)	-0.745	+0.42	Xe k x-ray
									0.1111
									0.141
^{125}Xe		124.906398	17.1 h	EC/1.653	0.47/	1/2+	-0.269		I k x-ray
									0.1884
									0.2434
^{126}Xe	0.09(1)	125.90427				0+			
^{127m}Xe			1.15 m	I.T./0.297		(9/2-)	-0.884	+0.69	Xe k x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.1246
									0.1725
^{127}Xe		126.905179	36.4 d	EC/0.662		1/2+	-0.504		I k x-ray
									0.1721
									0.2029
									0.3750
^{128}Xe	1.92(3)	127.903531				0+			
^{129m}Xe			8.89 d	I.T./0.236		11/2-	-0.891	+0.64	Xe k x-ray
									0.0396
									0.1966
^{129}Xe	26.44(24)	128.904780				1/2+	-0.7780		
^{130}Xe	4.08(2)	129.903509				0+			
^{131m}Xe			11.9 d	I.T./0.164		11/2-	-0.9940	+0.73	Xe k x-ray
									0.16398
^{131}Xe	21.18(3)	130.905083				3/2+	+0.69186	-0.12	
^{132}Xe	26.89(6)	131.904155				0+			
^{133m}Xe			2.19 d	I.T./0.233		11/2-	-1.082	+0.77	Xe k x-ray
									0.23325
^{133}Xe		132.905906	5.243 d	β^-/0.427	0.346/99	3/2+	+0.813	+0.14	Cs k x-ray
									0.080998
									0.1606
^{134}Xe	10.44(10)	133.905395				0+			
^{135m}Xe			15.3 m	I.T./		11/2-	1.103	+0.62	Xe k x-ray
									0.52658
^{135}Xe		134.90721	9.10 h	β^-/1.15	0.91/	3/2+	0.903	+0.21	0.24975
									0.60807
^{136}Xe	8.87(16)	135.90722	>0.8×10^{21} y	$\beta^-\beta^-$		0+			
^{137}Xe		136.91156	3.82 m	β^-/4.17	4.1/	7/2-	-0.970	-0.49	0.45549
					3.6/				0.8489
									0.9822
									1.2732
									1.7834
									2.8498
^{138}Xe		137.91399	14.1 m	β^-/2.77	0.8/	0+			0.1538
					2.4/				0.2426
									0.2583
									0.4345
									1.76826
									2.0158
^{139}Xe		138.91879	39.7 s	β^-/5.06	4.5/		-0.304	+0.40	0.1750
					5.0/				0.2186
									0.2965
									(0.1 - 3.37)
^{140}Xe		139.9216	13.6 s	β^-/4.1	2.6	0+			0.0801
									0.6220
									0.8055
									1.4137
									(0.04 - 2.3)
^{141}Xe		140.9267	1.72 s	β^-/6.2	6.2/	5/2+	+0.010	-0.58	0.1187
									0.9095
									(0.05 - 2.55)
^{142}Xe		141.9297	1.22 s	β^-/5.0	3.7/	0+			0.0338
					4.2/				0.0729
									0.2038
									0.3091
									0.4145
									0.5382
									0.5718

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.6181
									0.6448
^{143m}Xe			0.96 s	β^-					
^{143}Xe		142.9352	0.30 s	β^-/7.3			-0.460	+0.93	
^{144}Xe		143.9385	1.2 s	β^-/6.1					
^{145}Xe		144.9437	0.9 s	β^-,(n)					
^{146}Xe		145.9473	>0.15 μs						
^{147}Xe		146.9530	>0.15 μs						
$_{55}$Cs		132.90545(2)							
^{112}Cs		111.9503	0.5 ms	p	0.81				
^{113}Cs		112.9445	17. μs	p	0.96				
^{114}Cs		113.9408	0.58 s	β^+,EC/11.8		1+			ann.rad./
									0.6826
									0.7088
^{115}Cs		114.9359	≈ 1.4 s	β^+,EC/8.4					ann.rad./
^{116m}Cs			0.7 s	β ,EC/					ann.rad./
									0.3935
^{116}Cs		115.9330	3.8 s	β^+,EC/10.8					ann.rad./
									0.3935
									0.5243
									0.6151
									0.6223
^{117m}Cs			6.5 s	β^+,EC/					
^{117}Cs		116.9286	≈ 8.4 s	β^+,EC/7.5					ann.rad./
^{118m}Cs			17. s	β^+,EC/			5.		
^{118}Cs		117.92654	14. s	β^+,EC/9.		2	+3.88	+1.4	ann.rad./
									0.3372
									0.4727
									0.5865
									0.5906
^{119m}Cs			28. s			3/2	+0.84	+0.9	
^{119}Cs		118.92234	38. s	β^+,EC/6.3		9/2+	+5.5	+2.8	ann.rad./
									0.169
									0.176
									0.224
									0.257
^{120m}Cs			60. s	β^+,EC/					
^{120}Cs		119.92066	64. s	β^+,EC/7.92		2+	+3.87	+1.45	ann.rad./
									0.3224
									0.4735
									0.5534
									(0.3 - 3.28)
^{121m}Cs			2.0 m	I.T./60/		(9/2+)	+5.41	+2.7	ann.rad./
				β^+/40/	4.4				0.1794
									0.1961
^{121}Cs		120.91718	2.3 m	β^+,EC/5.40	4.38/	3/2+	+0.77	+0.84	ann.rad./
									0.1537
									(0.08 - 0.56)
^{122m2}Cs			4.4 m	β^+,EC		8-	+4.77	+3.3	ann.rad./
^{122m1}Cs			0.36 s	IT					
									0.3311
									0.4971
									0.6385
									(0.27 - 2.22)
^{122}Cs		121.91614	21. s	β^+,EC/7.1	5.8/	(1+)	-0.133	-0.19	ann.rad./
									0.3311
									0.5120
									0.8179
^{123m}Cs			1.6 s	I.T./		11/2-			Cs k x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/Energy Intensity (MeV/%)
									0.0946
^{123}Cs		122.91299	5.87 m	β^+/75/4.20	3.0/	1/2+	+1.38		ann.rad./
				EC/25/					Xe k x-ray
									0.0974
									0.5964
^{124m}Cs			6.3 s	IT		7+			
^{124}Cs		123.91225	30. s	β^+/92/5.92	≈ 5.	1+	+0.673	-0.74	ann.rad./
				EC/8/					Xe k x-ray
									0.3539
									0.4925
									0.9418
^{125}Cs		124.90972	45. m	β^+/40/3.09	2.06/	1/2+	+1.41		ann.rad./
				EC/60/					Xe k x-ray
									0.112
									0.526
^{126}Cs		125.90945	1.64 m.	β^+/81/4.83	3.4	1+	+0.78	-0.68	ann.rad./
				EC/19/	3.7/				Xe k x-ray
									0.3886
									0.4912
									0.9252
^{127}Cs		126.90741	6.2 h	β^+/96/2.08	0.65/	1/2+	+1.46		Xe k x-ray
				EC/4/	1.06				0.1247
									0.4119
^{128}Cs		127.90775	3.62 m	β^+/68/3.930	2.44/	1+	+0.97	-0.57	ann.rad./
				EC/32/	2.88/				Xe k x-ray
									0.4429
^{129}Cs		128.90606	1.336 d	EC/1.195		1/2+	+1.49		Xe k x-ray
									0.3719
									0.4115
^{130m}Cs			3.5 m	IT,β^+,EC		5-	+0.629		+1.45
^{130}Cs		129.90671	29.21 m	β^+/55/2.98	1.98/	1+	+1.46	-0.06	ann.rad./
				EC/43/					Xe k x-ray
				β^-/1.6/0.37	0.44/1.6				0.5361
^{131}Cs		130.90546	9.69 d	EC/0.352		5/2+	+3.54	-0.58	Xe k x-ray
^{132}Cs		131.906430	6.48 d	EC/98/		2-	+2.22	+0.51	Xe k x-ray
				β^+/0.3/2.120					0.4646
				β^-/ /1.280					0.6302
									0.66769
^{133}Cs	100.	132.905447				7/2+	+2.582	-0.0037	
^{134m}Cs			2.91 h	I.T./0.139		8-	+1.098	+1.0	Cs k x-ray
									0.12749
^{134}Cs		133.906714	2.065 y	β^-/2.059	0.089/27	4+	+2.994	+0.39	0.56327
					0.658/70				0.56935
				EC/1.22					0.60473
									0.79584
^{135m}Cs			53. m	I.T./1.627		19/2-	+2.18	+0.9	0.7869
									0.8402
^{135}Cs		134.905972	$2.3x10^6$ y	β^-/0.269	0.205/100	7/2+	+2.732	+0.05	
^{136m}Cs			19. s	I.T./		8	+1.32	+0.7	
^{136}Cs		135.907307	13.16 d	β^-/2.548	0.341/	5+	+3.71	+0.2	0.06691
									0.34057
									0.81850
									1.04807
^{137}Cs		136.907085	30.2 y	β^-/1.176	0.514/95	7/2+	+2.84	+0.05	Ba k x-ray
									0.66164
^{138m}Cs			2.9 m	I.T./75/0.080		6-	+1.71	-0.40	Cs k x-ray
				β^-/25/	3.3				0.0799
									0.1917
									0.4628

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									1.43579
^{138}Cs		137.91101	32.2 m	β^-/5.37	2.9/	3-	+0.700	+0.12	0.1381
									0.46269
									1.00969
									1.43579
									2.21788
^{139}Cs		138.913359	9.3 m	β^-/4.213	4.21	7/2+	+2.70	-0.07	0.6272
									1.2832
									(0.4 - 3.66)
^{140}Cs		139.91727	1.06 m	β^-/6.22	5.7/	1-	+0.13390	-0.11	0.5283
					6.21/				0.6023
									0.9084
									(0.41 - 3.94)
^{141}Cs		140.92005	24.9 s	β^-/5.26	5.20/	7/2+	+2.44	-0.4	Ba k x-ray
									0.0485
									0.5616
									0.5887
									1.1940
									(0.05 - 3.33)
^{142}Cs		141.92430	1.8 s	β^-/7.31	6.9/				0.3596
					7.28				0.9668
									1.1759
									1.3265
^{143}Cs		142.92732	1.78 s	β^-/6.24	6.1	(3/2+)	+0.87	+0.47	0.1955
									0.2324
									0.3064
									(0.17 - 1.98)
^{144}Cs		143.93203	1.01 s	β^-/8.47	8.46/	1	-0.546	+0.30	0.1993
					7.9/				0.5598
									0.6392
									0.7587
^{145}Cs		144.93541	0.59 s	β^-/7.89	7.4/	3/2+	+0.784	+0.6	0.1126
					7.9/				0.1755
									0.1990
^{146}Cs		145.94024	0.322 s	β^-,(n)/9.38	≈ 9.0	2-	-0.515	+0.22	
^{147}Cs		146.9439	0.227 s	β^-,(n)/9.3					
^{148}Cs		147.9490	0.15 s	β^-,(n)/10.5					
^{149}Cs		148.9527	> 50 ms						
^{150}Cs		149.9580	> 50 ms						
^{151}Cs		150.9620	> 50 ms						
$_{56}$Ba		137.327(7)							
^{114}Ba		113.9509	0.43 s	β^+,(p)	p/20				
^{115}Ba		114.948	0.45 s	β^+,(p)	p/<15				
^{116}Ba		115.9417	1.3 s	β^+,(p)	p/3				
^{117}Ba		116.9377	1.8 s	β^+,(p),EC/8.4	p/13	(3/2-)			(0.0457-0.364)
^{118}Ba		117.9466	5.2 s	β^+,					(0.040-0.156)
^{119}Ba		118.931	5.4 s	β^+,EC/8.					
^{120}Ba		119.9260	24. s	β^+,EC/5.0		0+			ann.rad./
									0.140
									(0.075-0.146)
^{121}Ba		120.9245	30. s	β^+,EC/6.8		5/2	+0.660	+1.8	ann.rad./
^{122}Ba		121.9203	2.0 m	β^+,EC/3.8		0+			ann.rad./
^{123}Ba		122.9189	2.7 m	β^+,EC/5.5			-0.68	+1.5	ann.rad./
									0.0306
									0.0927
									0.1161
									0.1235
^{124}Ba		123.91509	12. m	β^+,EC/2.65					ann.rad./
									0.1695

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.1888
									1.2160
^{125m}Ba			8. m	β⁺,EC/	4.5		0.174		
^{125}Ba		124.9146	3.5 m	β⁺,EC/4.6	3.4	1/2+	+0.18		ann.rad./
									0.0550
									0.0776
									0.0854
									0.1409
^{126}Ba		125.91124	1.65 h	β⁺/2/1.67		0+			Cs k x-ray
				EC/98/					0.2179
									0.2336
									0.2576
^{127m}Ba			1.9 s	IT		7/2-	-0.723	1.6	
^{127}Ba		126.9111	12.9 m	β⁺/54/3.5		1/2+	+0.083		ann.rad./
				EC/46/					Cs k x-ray
									0.1148
									0.1808
									(0.07 - 2.5)
^{128}Ba		127.90831	2.43 d	EC/0.52		0+			Cs k x-ray
									0.27344
^{129m}Ba			2.17 h	EC/98/		7/2+	+0.93	+1.6	Cs k x-ray
				β⁺/2/					0.1769
									0.1823
									0.2023
									1.4593
^{129}Ba		128.90868	2.2 h	β⁺/20/2.43	1.42/	1/2+	-0.40		ann.rad./
				EC/80/					Cs k x-ray
									0.1291
									0.2143
									0.2208
^{130}Ba	0.106(1)	129.90631	>0.5×10^{15} y	β⁻β⁻		0+			
^{131m}Ba			14.6 m	I.T./0.187		9/2-	-0.87	+1.5	Ba k x-ray
									0.1085
^{131}Ba		130.90693	11.7 d	EC/1.37		1/2+	0.7081		Cs k x-ray
									0.12381/28.4
									0.21608/21.3
									0.49636/42.9
									(0.0549-1.171)
^{132}Ba	0.101(1)	131.905056				0+			
^{133m}Ba			1.621 d	I.T./0.288		11/2-	-0.91	+0.9	Ba k x-ray
									0.2761
^{133}Ba		132.906003	10.53 y	EC/0.517		1/2+	0.7717		Cs k x-ray
									0.08099
									0.35600
^{134}Ba	2.417(18)	133.904504				0+			
^{135m}Ba			1.20 d	I.T./0.2682		11/2-	-1.00	+1.0	Ba k x-ray
									0.2682
^{135}Ba	6.592(12)	134.905684				3/2+	+0.838	+0.16	
^{136m}Ba			0.308 s	I.T./2.0305		7-			Ba k x-ray
									0.8185
									1.0481
^{136}Ba	7.854(24)	135.904571				0+			
^{137m}Ba			2.552 m	I.T./0.6617		11/2-	-0.99	+0.8	Ba k x-ray
									0.66164
^{137}Ba	11.232(24)	136.905822				3/2+	+0.9374	+0.245	
^{138}Ba	71.698(42)	137.905242				0+			
^{139}Ba		138.908836	1.396 h	β⁻/2.317	2.14/27	7/2-	-0.97	-0.57	0.16585
					2.27/72				1.2544

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/Energy Intensity (MeV/%)
									1.42033
^{140}Ba		139.91060	12.75 d	β^-/1.05	0.48	0+			0.16268
					1.0/				0.30485
					1.02/				0.53727
^{141}Ba		140.91441	18.3 m	β^-/3.22	2.59/	3/2-	-0.34	+0.45	0.1903
					2.73/				0.2770
									0.3042
									(0.1 - 2.5)
^{142}Ba		141.91645	10.7 m	β^-/2.212	1.0/	0+			0.23152
					1.10/				0.25512
									0.3090
									1.2040
^{143}Ba		142.92061	14.3 s	β^-/4.24	4.2/	5/2+	+0.44	-0.88	0.1786
									0.21148
									0.7988
									(0.17 - 2.4)
^{144}Ba		143.92294	11.4 s	β^-/3.1	2.4/	0+			La k x-ray
					2.9/				0.10386
									0.1566
									0.1728
									0.3882
									0.43048
^{145}Ba		144.9269	4.0 s	β^-/4.9	4.9/	(5/2-)	-0.28	+1.22	La k x-ray
									0.0918
									0.09709
^{146}Ba		145.9302	2.20 s	β^-/4.12	3.9/	0+			0.0644
									0.2513
									0.3270
									0.3329
									0.3622
^{147}Ba		146.9340	0.892 s	β^-/5.75	5.5/				
^{148}Ba		147.9377	0.64 s	β^-,n/5.11					
^{149}Ba		148.9421	0.36 s	β^-,(n)/7.3					
^{150}Ba		149.9456	0.3 s						
^{151}Ba		150.9507	>0.15 µs						
^{152}Ba		151.9542							
^{153}Ba		151.9596							
$_{57}$La		138.9055(2)							
^{117}La		116.950							
^{118}La		117.946							
^{119}La		118.941							
^{120}La		119.938	2.8 s	EC,β^+/11.					
^{121}La		120.9330	5.3 s						
^{122}La		121.9307	9. s	EC,β^+/≈ 9.7					
^{123}La		122.9262	17. s	EC/7.					
^{124}La		123.9245	30. s	EC/≈ 8.8		(7+)			
^{125m}La			0.39 s						
^{125}La		124.9207	1.2 m	β^+,EC/5.6		11/2-			ann.rad./
									0.0436
									0.0676
^{126}La		125.9194	1.0 m	β^+,EC/7.6					ann.rad./
									0.2561
									0.340
									0.4555
									0.6214
^{127}La		126.9162	3.8 m	β^+,EC/4.7		3/2+			ann.rad./
									0.025
									0.0562
^{128}La		127.9155	5.0 m	β^+/80/6.7		(5-)			ann.rad./

TABLE OF ISOTOPES (CONTINUED)

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				EC/20/					Ba k x-ray
									0.2841/87
									0.4793/54
									(0.315-2.212)
^{129m}La			0.56 s	IT		(11/2-)			
^{129}La		128.91267	11.6 m	β^+/58/3.72	2.42/	3/2+			ann.rad./
				EC/42/					Ba k x-ray
									0.1105
									0.2786
									(0.1 - 1.8)
^{130}La		129.9123	8.7 m	β^+/78/5.6		3+			ann.rad./
				EC/22/					Ba k x-ray
									0.3573/81
									0.5506/27
									(0.1965-1.989)
^{131}La		130.9101	59. m	β^+/76/3.0	1.42/	3/2+			ann.rad./
				EC/24/	1.94/				Ba k x-ray
									0.1085
									0.3658
									0.5263
^{132m}La			24. m	I.T./76/		6-			La k x-ray
				β^+,EC/24/					0.1352
									0.4645
^{132}La		131.91011	4.8 h	β^+/40/4.71	2.6/	2-			ann.rad./
				EC/60/	3.2				Ba k x-ray
					3.7/				0.4645
									0.5671
^{133}La		132.9084	3.91 h	β^+/4/2.2	1.2/	5/2+			Ba k x-ray
				EC/96/					0.2788
									0.2901
									0.3024
^{134}La		133.90849	6.5 m	β^+/63/3.71	2.67/	1+			ann.rad./
				EC/37/					Ba k x-ray
									0.6047
									(0.5 - 1.9)
^{135}La		134.90697	19.5 h	EC/1.20		5/2+			Ba k x-ray
									0.4805
^{136}La		135.9077	9.87 m	β^+/36/2.9	1.8/	1+			ann.rad./
				EC/64/					Ba k x-ray
									0.8185
^{137}La		136.90647	6x10^4 y	EC/0.60		7/2+	+2.70	+0.2	0.2836
^{138}La	0.090(1)	137.907107	1.06x10^{11} y			5+	+3.7136	+0.4	1.4358/65
									0.7887/35
^{139}La	99.910(1)	138.906349				7/2+	+2.7830	+0.20	
^{140}La		139.909473	1.678 d	β^-/3.762	1.35	3-	+0.73	+0.09	
					1.24/				
					1.67/				
^{141}La		140.910958	3.90 h	β^-/2.502	2.43/	7/2+			
^{142}La		141.91408	1.54 h	β^-/4.505	2.11/	2-			
					2.98/				
					4.52/				
^{143}La		142.91606	14.1 m	β^-/3.43	3.3/	7/2-			
^{144}La		143.9196	40.7 s	β^-/5.5	4.1/				
^{145}La		144.9217	24. s	β^-/4.1	4.1/	3/2+			
^{146m}La			10.0 s	β^-/6.7	5.5/	(6)			
^{146}La		145.9258	6.3 s	β^-/6.6	6.2/	(2-)			
^{147}La		146.9278	4.02 s	β^-/5.0	4.6/				
^{148}La		147.9322	1.1 s	β^-/7.26		2-			

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{149}La		148.9342	1.10 s	β^-/5.5					
^{150}La		149.9386	0.51 s						x-ray
									(0.097-0.209)
^{151}La		150.9416	>0.15 μs						
^{152}La		151.946	>0.15 μs						
^{153}La		152.949	>0.15 μs						
^{154}La		153.954							
^{155}La		154.958							
$_{58}$Ce		140.116(1)							
^{119}Ce		118.953							
^{120}Ce		119.947							
^{121}Ce		120.944	1.1 s	β^+,p					
^{122}Ce		121.938							
^{123}Ce		122.936	3.8 s	β^+,EC/≈8.6					ann.rad./
^{124}Ce		123.931	6. s	EC/≈5.6					
^{125}Ce		124.929	9.6 s	β^+,EC/7.		(5/2+)			ann.rad./
^{126}Ce		125.9241	50. s	EC/4.					
^{127}Ce		126.9228	32. s	β^+,EC/6.1					ann.rad./
									(0.058-1.148)
^{128}Ce		127.9189	4.1 m	β^+,EC/3.2					ann.rad./
									(0.023-0.880)
^{129}Ce		128.9187	3.5 m	β^+,EC/5.6					ann.rad./
									(0.0675-1.015)
^{130}Ce		129.9147	26. m	β^+,EC/2.2		0+			ann.rad./
									La k x-ray
									(0.047-1.431)
^{131m}Ce			5. m	β^+,EC/					ann.rad./
									0.2304
									0.3955
									0.4213
^{131}Ce		130.9144	10. m	β^+,EC/4.0	2.8/				ann.rad./
									0.119
									0.169
									0.414
^{132}Ce		131.9115	3.5 h	EC/1.3		0+			La k x-ray
									0.1554
									0.1821
^{133m}Ce			1.6 h	β^+,EC/		1/2+			ann.rad./
									0.0769
									0.0973
									0.5577
^{133}Ce		132.9116	5.4 h	β^+/8/2.9	1.3/	9/2-			ann.rad./
				EC/92/					La k x-ray
									0.0584
									0.1308
									0.4722
									0.5104
^{134}Ce		133.9090	3.16 d	EC/0.5		0+			La k x-ray
									0.1304
									0.1623
									0.6047
^{135m}Ce			20. s	I.T./0.446		11/2-			Ce k x-ray
									0.0826
									0.1497
									0.2134
^{135}Ce		134.90915	17.7 h	β^+/1/2.026	0.8/	1/2+			La k x-ray
				EC/99/					0.0345
									0.2656
									0.3001

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.6068
^{136}Ce	0.19(1)	135.90714				0+			
^{137m}Ce			1.43 d	I.T./99/0.254		11/2-	1.0		Ce k x-ray
				EC/0.8/					0.1693
									0.2543
^{137}Ce		136.90778	9.0 h	β^+/1.222		3/2+	0.96		La k x-ray
									0.4472
^{138}Ce	0.25(1)	137.90599				0+			
^{139m}Ce			56.4 s	I.T./0.7542		11/2-			Ce k x-ray
									0.7542
^{139}Ce		138.90665	137.6 d	EC/0.28		3/2+	1.06		La k x-ray
									0.16585
^{140}Ce	88.48(10)	139.905435				0+			
^{141}Ce		140.908272	32.50 d	β^-/0.581	0.436/69	7/2-	1.1		Pr k x-ray
					0.581/31				0.14544/48.0
^{142}Ce	11.08(10)	141.909241				0+			
^{143}Ce		142.912382	1.38 d	β^-/1.462	1.404/	3/2-	≈ 1.		Pr k x-ray
					1.110/47				0.0574
									0.2933
^{144}Ce		143.913643	284.6 d	β^-/0.319	0.185/20	0+			Pr k x-ray
					0.318/				0.0801
									0.1335
^{145}Ce		144.91723	3.00 m	β^-/2.54	1.7/24	3/2-			Pr k x-ray
					1.3				0.0627
									0.7245
^{146}Ce		145.9187	13.5 m	β^-/1.04	0.7/90	0+			Pr k x-ray
									0.0986
									0.2182
									0.3167
^{147}Ce		146.9225	56. s	β^-/3.29	3.3/				0.0930
									0.2687
^{148}Ce		147.9244	56. s	β^-/2.1	1.66/	0+			0.0904
									0.0985
									0.1212
									0.2918
^{149}Ce		148.9283	5.2 s	β^-/4.2					0.0577
									0.0864
									0.3800
^{150}Ce		149.9302	4.4 s	β^-/3.0					0.1099
^{151}Ce		150.9340	1.0 s	β^-/5.3					0.0526
^{152}Ce		151.9366	1.4 s	β^-/4.4					Pr k x-ray
									0.098
									0.115
^{153}Ce		152.9406	>0.15 μs						
^{154}Ce		153.943	>0.15 μs						
^{155}Ce		154.947	>0.15 μs						
^{156}Ce		155.951							
^{157}Ce		156.956							
$_{59}$Pr		140.90765(2)							
^{121}Pr		120.955	0.6 s						
^{122}Pr		121.952							
^{123}Pr		122.946							
^{124}Pr		123.943	1.2 s	β^+,EC/12.					ann.rad./
^{125}Pr		124.9378	≈ 3.3 s	β^+					ann.rad./
									0.1358
^{126}Pr		125.9353	3.1 s	β^+,EC/≈10.4					ann.rad./
									(0.170-0.985)
^{127}Pr		126.9308	4.2 s	β^+/≈7.5					ann.rad./
									(0.028-0.8949)

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{128}Pr		127.9288	3.0 s	β⁺,EC/≈9.3					ann.rad./
									0.207/100
									0.400-1.373
^{129}Pr		128.9249	32 s	β⁺,EC/5.8					ann.rad./
									(0.0395-1.865)
^{130}Pr		129.9234	40. s	β⁺,EC/8.1					ann.rad./
^{131m}Pr			5.7 s						(0.06 - 0.16)
^{131}Pr		130.9201	1.7 m	β⁺,EC/5.3				≈5.5	ann.rad./
									(0.059-0.980)
^{132}Pr		131.9191	1.6 m	β⁺,EC/7.1					ann.rad./
									0.325
									0.496
									0.533
^{133}Pr		132.9162	6.5 m	β⁺,EC/4.3		5/2+			ann.rad./
									0.074
									0.1343
									0.2419
									0.3156
									0.3308
									0.4650
^{134m}Pr			≈ 11. m	β⁺,EC/					ann.rad./
									0.294
									0.460
									0.495
									0.632
^{134}Pr		133.9157	17. m	β⁺,EC/6.2		2+			ann.rad./
									0.294
									0.495
^{135}Pr		134.9131	24. m	β⁺,EC/3.7	2.5/	3/2+			ann.rad./
									0.0826
									0.2135
									0.2961
									0.5832
^{136}Pr		135.91265	13.1 m	β⁺/57/5.13	2.98/	2+			ann.rad./
				EC/43					Ce k x-ray
									0.5398
									0.5522
^{137}Pr		136.91068	1.28 h	β⁺/26/2.70	1.68/	5/2+			ann.rad./
				EC/74/					Ce k x-ray
									0.4339
									0.5140
									0.8367
									(0.16 - 1.8)
^{138m}Pr			2.1 h	β⁺/24/	1.65/	7-			ann.rad./
				EC/76/					Ce k x-ray
									0.3027
									0.7887
									1.0378
									(0.07 - 2.0)
^{138}Pr		137.91075	1.45 m	β⁺/75/4.44	3.42/	1+			ann.rad./
				EC/25/					Ce k x-ray
									0.7887
^{139}Pr		138.90893	4.41 h	β⁺/8/2.129	1.09/	5/2+			ann.rad./
				EC/92/					Ce k x-ray
									0.2551
									1.3473
									1.6307
^{140}Pr		139.90907	3.39 m	β⁺/51/3.39	2.37/	1+			ann.rad./
				EC/49/					Ce k x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.3069
									1.5965
^{141}Pr	100.	140.907648				5/2+	+4.275	-0.08	
^{142m}Pr			14.6 m	I.T./0.004	c.e./	5-	2.2		
^{142}Pr		141.910041	19.12 h	β^-/2.162	0.58/4	2-	+0.234	+0.030	0.5088
				EC/0.744	2.16/96				1.57580
^{143}Pr		142.910813	13.57 d	β^-/0.934	0.933/	7/2+	+2.70	+0.8	0.7420
^{144m}Pr			7.2 m	IT/99+/0.059		3-			Pr k x-ray
				β^-/					0.0590
									0.6965
									0.8142
^{144}Pr		143.913301	17.28 m	β^-/2.998	0.807/1	0-			0.69649
					2.30/				1.48912
					2.996/98				2.18562
^{145}Pr		144.91451	5.98 h	β^-/1.81	1.80/97	7/2+			0.0725
									0.6758
									0.7483
^{146}Pr		145.9176	24.2 m	β^-/4.2	2.2/30	2-			0.4539/48
					3.7/10				1.5247
					4.2/40				
^{147}Pr		146.91898	13.4 m	β^-/2.69	1.5/	3/2+			0.3146/24.
					2.1/				0.5779/16
									0.6413/19.
^{148m}Pr			2.0 m	β^-/	4.0/	(4)			0.3016
					3.8/				0.4506
									0.6975
^{148}Pr		147.9222	2.27 m	β^-/4.9	4.8/	1^-			0.3017
					4.5/				
^{149}Pr		148.92379	2.3 m	β^-/3.40	3.0	$(5/2^+)$			0.1085
									0.1385
									0.1651
^{150}Pr		149.9270	6.2 s	β^-/5.7		1^-			0.1302
					≈ 5.5				0.8044
									0.8527
^{151}Pr		150.9283	22.4 s	β^-/4.2					
^{152}Pr		151.9319	3.2 s	β^-/6.7		4^+			0.0726
									0.164
									0.285
^{153}Pr		152.9339	4.3 s	β^-/5.5					
^{154}Pr		153.9381	2.3 s	β^-/7.9					
^{155}Pr		154.9400							
^{156}Pr		155.944							
^{157}Pr		156.947							
^{158}Pr		157.952							
^{159}Pr		158.955							
$_{60}$Nd		144.24(3)							
^{125}Nd			0.6 s	β^+,p					
^{126}Nd		125.943							
^{127}Nd		126.941	1.8 s	β^+,EC/9.		(5/2)			ann.rad./
^{128}Nd		127.935	4. s	β^+,EC/6.					ann.rad./
^{129}Nd		128.933	4.9 s	β^+,EC/8.		5/2(-)			ann.rad./
									(0.091-0.875)
^{130}Nd		129.929	28. s	β^+,EC/5.					ann.rad./
^{131}Nd		130.9271	0.5 m	β^+,EC/6.6					ann.rad./
									(0.09-0.36)

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{132}Nd		131.9231	1.5 m	β^+,EC/3.7					ann.rad./
									(0.099-0.567)
^{133}Nd		132.9222	1.2 m	β^+,EC/5.6					ann.rad./
									(0.06-0.37)
^{134}Nd		133.9187	≈ 8.5 m	β^+/17/2.8		0+			ann.rad./
				EC/83/					Pr k x-ray
									0.1631/58
									(0.09-1.00)
^{135m}Nd			5.5 m	β^+/					
^{135}Nd		134.9182	12. m	β^+/65/4.8		9/2-	-0.78	+2.0	ann.rad./
				EC/35/					Pr k x-ray
									0.0415/23.
									0.204/51.
									(0.11-1.8)
^{136}Nd		135.9150	50.6 m	EC/94/2.21	1.04/	0+			Pr kx-ray
				β^+/6/					0.0401/21.
									0.1091/35.
									(0.10-0.97)
^{137m}Nd			1.6 s	I.T./0.5196		11/2-			Nd k x-ray
									0.1084
									0.1775
									0.2337
^{137}Nd		136.9146	38. m	β^+/40/3.69	1.7/20	1/2+	-0.63		ann.rad./
				EC/60/	2.40/20				Pr k x-ray
									0.0755
									0.5806
^{138}Nd		137.9119	5.1 h	EC/1.1		0+			Pr k x-ray
									0.1995
									0.3258
^{139m}Nd			5.5 h	I.T./12/0.231	1.17/	11/2-			Nd k x-ray
				β^+/88/					Pr k x-ray
									0.1139/34.
									0.7382/30.
^{139}Nd		138.91192	30. m	β^+/25/2.79	1.77/	3/2+	0.91	+0.3	ann.rad./
				EC/75/					Pr k x-ray
									0.4050
^{140}Nd		139.90931	3.37 d	EC/0.22		0+			Pr k x-ray
^{141m}Nd			1.04 m	IT/99+/0.756		11/2-			Nd k x-ray
									0.7565
^{141}Nd		140.909605	2.49 h	EC/98/1.823	0.802/	3/2+	1.01	+0.3	Pr k x-ray
				β^+/2/					(0.15-1.7)
^{142}Nd	27.13(12)	141.907719				0+			
^{143}Nd	12.18(6)	142.909810				7/2-	-1.07	-0.60	
^{144}Nd	23.80(12)	143.910083	2.1x10^{15} y			0+			
^{145}Nd	8.30(6)	144.912569				7/2-	-0.66	-0.31	
^{146}Nd	17.19(9)	145.913113				0+			
^{147}Nd		146.916096	10.98 d	β^-/0.896	0.805/	5/2-	0.58	0.9	Pr k x-ray
									0.53102
									0.09111-0.686
^{148}Nd	5.76(3)	147.916889				0+			
^{149}Nd		148.920145	1.73 h	β^-/1.691	1.03/25	5/2-	0.35	1.3	Pr k x-ray
					1.13/26				0.1143/19.
					1.42/				0.2113/27.
									(0.06 - 1.6)
^{150}Nd	5.64(3)	149.920887	≈1×10^{19} y	$\beta^-\beta^-$		0+			
^{151}Nd		150.923825	12.4 m	β^-/2.442	1.2/	(3/2+)			Pm k x-ray
									0.1168
									0.2557
									1.1806

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									(0.10 - 1.9)m
^{152}Nd		151.92468	11.4 m	β^-/1.1		0+			0.2785/29.
									0.2501/18.
									(0.016 - 0.66)
^{153}Nd		152.9280	28.9 s	β^-/3.6					0.418
^{154}Nd		153.9296	25.9 s	β^-/2.8					0.1519
									0.7998
^{155}Nd		154.9334	8.9 s	β^-/5.0					0.1807
^{156}Nd		155.9355	5.5 s	β^-/4.1					0.0848
^{157}Nd		156.9393							
^{158}Nd		157.942							
^{159}Nd		158.946							
^{160}Nd		159.949							
^{161}Nd		160.954							
$_{61}$Pm									
^{128}Pm		127.948	1.0 s	β^+,p					Ann.rad.
^{129}Pm		128.943							
^{130}Pm		129.940	2.5 s	β^+,EC/11.					0.1589
									0.326-1.062
^{131}Pm		130.936	≈ 6.3 s	β^+					0.185
									0.220
									0.146
^{132}Pm		131.934	6. s	β^+,EC/10.					ann.rad./
^{133}Pm		132.930	12. s	β^+,EC/≈ 7.0					ann.rad./
^{134}Pm		133.9282	24. s	β^+,EC/≈ 8.9		(5+)			ann.rad./
									0.294
									0.495
^{135}Pm		134.9247	0.8 m	β^+,EC/6.0		11/2-			(0.13-0.47)
^{136}Pm		135.9235	1.8 m	β^+/89/7.9		(3+)			ann.rad./
				EC/11/					Nd k x-ray
									0.3735
									0.6027
^{137}Pm		136.9206	2.4 m	β^+,EC/5.6		(11/2-)			ann.rad./
									0.1086
									0.1775
^{138m}Pm			3.2 m	β^+/50/≈ 7.0	3.9/	3+	3.		ann.rad./
				EC/50/					Nd k x-ray
									0.5209
									0.7290
^{138}Pm		137.9193	10. s	β^+/6.9	6.1/	1+			ann.rad./
^{139m}Pm			0.18 s	IT/		(11/2-)			0.1887
^{139}Pm		138.91678	4.14 m	β^+/68/4.52	3.52/	(5/2+)			ann.rad./
				EC/32/					Nd k x-ray
									0.4028
									(0.27 - 2.4)
^{140m}Pm			5.87 m	β^+/70/	3.2	7/2-			ann.rad./
				EC/30/					Nd k x-ray
									0.4199
									0.7738
									1.0283
^{140}Pm		139.91585	9.2 s	β^+/89/6.09	5.07/74	1+			ann.rad./
				EC/11/					Nd k x-ray
									0.7738
									1.4898
^{141}Pm		140.91359	20.9 m	β^+/52/3.72	2.71	5/2+			ann.rad./
				EC/48/					Nd k x-ray
									0.8862
									1.2233
^{142}Pm		141.91295	40.5 s	β^+/86/4.87	3.8/	1+			ann.rad./

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				EC/20/					Nd k x-ray
									0.6414
									1.5758
^{143}Pm		142.910928	265. d	EC/1.041		5/2+	3.8		Nd k x-ray
				β^+/<6 x 10^{-6}/					0.7420
^{144}Pm		143.912586	360. d	EC/2.332		5-	1.7		Nd k x-ray
				β^+/7x10^{-6}/					0.6180
									0.6965
^{145}Pm		144.912745	17.7 y	EC/0.163		5/2+	+3.8	+0.2	Nd k x-ray
									0.0723
^{146}Pm		145.914693	5.53 y	EC/63/1.472		3-			Nd k x-ray
				β^-/37/1.542	0.795/				0.4538
									0.7362
									0.7474
^{147}Pm		146.915134	2.623 y	β^-/0.224	0.224/	7/2+	+2.6	+0.7	0.1213
									0.1974
^{148m}Pm			41.3 d	β^-/95/2.6	0.4/60	6-	1.8		0.5503/94.
				I.T./5/0.137	0.5/17				0.6300/89.
					0.7/21				0.7257/33
^{148}Pm		147.91747	5.37 d	β^-/2.47	1.02/	1-	+2.0	+0.2	0.5503
					2.47/				0.9149
									1.4651
^{149}Pm		148.918330	2.212 d	β^-/1.071	0.78/9	7/2+	3.3		0.2859
					1.072/90				0.5909
									0.8594
^{150}Pm		149.92098	2.68 h	β^-/3.45	1.6/	(1-)			0.3339/69.
					2.3/				1.1658/16.
					1.8/				1.3245/17.
									(0.25 - 2.9)
^{151}Pm		150.92120	1.183 d	β^-/1.187	0.84/	5/2+	+1.8	1.9	0.1677/8
									0.2751/7
									0.3401/22
^{152m2}Pm			15. m	β^-,I.T./		(>6)			(0.14-1.4)
^{152m1}Pm			7.5 m	β^-/		(4-)			0.1218
									0.2447
									0.3404
									1.0971
									1.4375
^{152}Pm		151.9235	4.1 m	β^-/3.5	3.5/20	1+			0.1218
					3.50/60				(0.12 - 2.1)
^{153}Pm		152.92414	5.4 m	β^-/1.90	1.7/	(5/2-)			0.0910
									0.1198
									0.1273
^{154m}Pm			2.7 m	β^-/	2.0/				0.0820
									0.1848
									1.4403
^{154}Pm		153.9266	1.7 m	β^-/4.1	1.9/				0.0820
									0.8396
									1.3940
									2.0589
									(0.08 - 2.8)
^{155}Pm		154.9280	48. s	β^-/3.2		(5/2-)			(0.05-0.78)
^{156}Pm		155.93106	26.7 s	β^-/5.16					
^{157}Pm		156.9332	10.9 s	β^-/4.6					
^{158}Pm		157.9367	5. s	β^-/6.3					
^{159}Pm		158.939	2 s						
^{160}Pm		159.943							
^{161}Pm		160.946							
^{162}Pm		161.950							

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{163}Pm		162.954							
$_{62}$Sm		150.36(3)							
^{129}Sm			≈ 0.55 s	β$^+$,p					
^{130}Sm		129.949							
^{131}Sm		130.946	1.2 s	β$^+$,EC/					ann.rad./
^{132}Sm		131.941	4.0 s	β$^+$					
^{133}Sm		132.939	2.9 s	β$^+$,EC/≈8.4		5/2+			ann.rad./
^{134}Sm		133.934	11. s	β$^+$,EC/5.		0+			ann.rad./
^{135}Sm		134.932	10. s	β$^+$,EC/7.		7/2+			ann.rad./
^{136}Sm		135.9283	42. s	β$^+$,EC/4.5		0+			ann.rad./
^{137}Sm		136.9271	45. s	β$^+$,EC/6.1					ann.rad./
^{138}Sm		137.9235	3.0 m	β$^+$,EC/3.9		0+			ann.rad./
									0.0536
									0.0747
^{139m}Sm			10. s	I.T./94/0.457		(11/2-)	1.1		Sm k x-ray
				β$^+$/6/	4.7				0.1118
									0.1553
									0.1901
									0.2673
^{139}Sm		138.9226	2.6 m	β$^+$/75/5.5	4.1/	1/2+	-0.53		Pm k x-ray
				EC/25/					0.3678
									0.4028
									(0.27 - 2.4)
^{140}Sm		139.9195	14.8 m	β$^+$,EC/3.4	1.9/	0+			ann.rad./
									Pm k x-ray
									0.1396
									0.2255
									(0.07 - 1.7)
^{141m}Sm			22.6 m	β$^+$/32/	1.6/	11/2-	-0.83	+1.6	ann.rad./
				EC/68/	2.19/				Pm k x-ray
				I.T./0.3/0.1758					0.1966
									0.4318
									0.7774
^{141}Sm		140.91847	10.2 m	β$^+$/52/4.54	3.2/	1/2+	-0.74		ann.rad./
				EC/48/					Pm k x-ray
									0.4382
^{142}Sm		141.91520	1.208 h	β$^+$/6/2.10	1.0/	0+			ann.rad./
				EC/94/					Pm k x-ray
^{143m}Sm			1.10 m	IT/99/0.7540		11/2-			Sm k x-ray
									0.7540
^{143}Sm		142.914624	8.83 m	β$^+$/46/3.443	2.47/	3/2+	+1.01	+0.4	ann.rad./
				EC/54/					Pm k x-ray
									1.0565
^{144}Sm	3.1(1)	143.911996				0+			
^{145}Sm		144.913407	340. d	EC/0.617		7/2-	-1.12	-0.60	Pm k x-ray
									0.0613
									0.4924
^{146}Sm		145.913038	1.03x10^{8} y	α/	2.50/	0+			
^{147}Sm	15.0(2)	146.914894	1.06x10^{11} y	α/	2.23/	7/2-	-0.815	-0.26	
^{148}Sm	11.3(1)	147.914818	7x10^{15} y	α/	1.96/	0+			
^{149}Sm	13.8(1)	148.917180	10^{16} y	α/		7/2-	-0.672	+0.075	
^{150}Sm	7.4(1)	149.917272				0+			
^{151}Sm		150.919929	90. y	β$^-$/0.0768	0.076/	5/2-	-0.363	+0.7	0.02154
^{152}Sm	26.7(2)	151.919729				0+			
^{153}Sm		152.922094	1.929 d	β$^-$/0.808	0.64/	3/2+	-0.0216	+1.3	Eu k x-ray
					0.69/				0.0697/4.7
									0.10318/29

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.075-0.714
^{154}Sm	22.7(2)	153.922206				0+			
^{155}Sm		154.924636	22.2 m	β^-/1.627	1.52	3/2-		1.1	Eu k x-ray
									0.1043/75.
^{156}Sm		155.92553	9.4 h	β^-/0.72	0.43/	0+			0.0872
					0.71/				0.1657
									0.2038
^{157}Sm		156.9283	8.0 m	β^-/2.7	2.4/	3/2-			Eu k x-ray
									0.1964
									0.1978
									0.3942
^{158}Sm		157.9299	5.5 m	β^-/2.0		0+			0.1894/100.
									0.3636/82.
^{159}Sm		158.9332	11.3 s	β^-/3.8					0.1898
^{160}Sm		159.9353	9.6 s	β^-/3.6		0+			0.110
^{161}Sm		160.9388	≈4.8 s						0.264
^{162}Sm		161.941							
^{163}Sm		162.945							
^{164}Sm		163.948							
^{165}Sm		164.953							
$_{63}$Eu		151.964(1)							
^{131}Eu			≈26. ms	β^+,p	p/0.95				
^{132}Eu		131.954							
^{133}Eu		132.949							
^{134}Eu		133.946	0.5 s	EC,β^+					ann.rad./
^{135}Eu		134.942	1.5 s	EC,β^+/≈8.7					ann.rad./
^{136m}Eu			≈ 3.2 s			7+			0.255
^{136}Eu		135.940	≈ 3.9 s	EC,β^+/10.		1+			ann.rad./
^{137}Eu		136.935	11. s	EC/≈7.5		11/2-			ann.rad./
^{138}Eu		137.9335	12. s	EC,β^+/≈ 9.2		7+	5		ann.rad./
^{139}Eu		138.9298	18. s	EC,β^+/6.7			6		ann.rad./
^{140m}Eu			0.125 s	EC,β^+					ann.rad./
^{140}Eu		139.9285	1.51 s	EC,β^+/8.4		1-			ann.rad./
^{141m}Eu			3.0 s	β^+/58/		11/2-			ann.rad./
				EC/9/					Eu k x-ray
				I.T./33/0.0964					(0.09 - 1.6)
^{141}Eu		140.9244	40. s	β^+/81/5.6		5/2+	+3.49	+0.85	ann.rad./
				EC/15/					Sm k x-ray
									0.3845
									0.3940
^{142m}Eu			1.22 m	β^+/83/	4.8/	8-	+2.98	+1.4	ann.rad./
				EC/17/					Sm k x-ray
									0.5566
									0.7680
									1.0233
^{142}Eu		141.9231	2.4 s	β^-/94/7.4	7.0/	1+	+1.54	+0.12	ann.rad./
				EC/6/					0.7680
^{143}Eu		142.92017	2.62 m	β^+/72/5.17	4.1/	5/2+	+3.67	+0.51	ann.rad./
				EC/28/	5.1/				Sm k x-ray
									0.1107/7
									1.5368/3.
									1.9127/2.
^{144}Eu		143.91879	10.2 s	β^+/86/6.33	5.31/	1+	+1.89	+0.10	ann.rad./
				EC/13/					Sm k x-ray
									1.6601
^{145}Eu		144.916263	5.93 d	β^+/2/2.660	0.79/	5/2+	+4.00	+0.29	ann.rad./
				EC/98/1.71					Sm k x-ray
									0.6535
									0.8937

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									1.6587
^{146}Eu		145.91720	4.57 d	β^+/5/3.88	1.47/	4-	+1.42	-0.18	ann.rad./
				EC/95/					Sm k x-ray
									0.6336
									0.6341
									0.7470
									(0.27 - 2.64)
^{147}Eu		146.916742	24.4 d	EC/99./1.722		5/2+	+3.72	+0.53	Sm k x-ray
				β^+/0.4/					0.12113
									0.19725
									0.6776
^{148}Eu		147.91815	54.5 d	EC/3.11	0.92	5-	+2.34	+0.35	Sm k x-ray
									0.5503/99.
									0.6299/71.
									(0.067-2.17)
^{149}Eu		148.91792	93.1 d	EC/0.692		5/2+	+3.57	+0.75	Sm k x-ray
									0.2770
									0.3275
^{150}Eu		149.91970	36. y	EC/2.26		5-	+2.71	+1.13	Sm k x-ray
									0.3340
									0.4394
									0.5843
									(0.25 - 1.8)
^{150m}Eu			12.8 h	β^-/92/	1.013/	0-			Sm k x-ray
				β^+/0.4/	1.24/				0.3339
				EC/8/					0.4065
^{151}Eu	47.8(15)	150.919846				5/2+	+3.472	+0.90	
^{152m2}Eu			1.60 h	I.T./0.1478		8-			Eu k x-ray
									0.0898
^{152m1}Eu			9.30 h	β^-/72/	1.85/	0-			Sm k x-ray
				EC/28/	0.89/				0.12178
									0.84153
									0.96334
^{152}Eu		151.921741	13.5 y	EC/72/1.874	0.69/	3-	-1.941	+2.71	Sm k x-ray
				β^-/28/1.818	1.47/				Gd k x-ray
									0.12178
									0.34427
									1.40802
									(0.252-1.528)
^{153}Eu	52.2(15)	152.921227				5/2+	+1.533	+2.41	
^{154m}Eu			46.1 m	I.T./≈ 0.16		8-			Eu k x-ray
									0.0682
									0.1009
^{154}Eu		153.922976	8.59 y	β^-/99.9/1.969	0.27/29	3-	-2.01	+2.8	Gd k x-ray
				EC/0.02/0.717	0.58/38				0.12299/40.
					0.84/17				0.72331/20.
					0.98/4				1.2745/36
					1.87/11				(0.059-1.90)
^{155}Eu		154.922890	4.76 y	β^-/0.252	0.15/	5/2+	+1.52	+2.4	Gd k x-ray
									0.0865/30
									0.1053/20
^{156}Eu		155.92475	15.2 d	β^-/2.451	0.30/11	1+	≈ 1.1		0.08899/9.
					0.49/30				0.64623/7.
					1.2/12				0.723441/6.
					2.45/31				0.8118/10.
^{157}Eu		156.92542	15.13 h	β^-/1.36	0.98/	(5/2+)	+1.50	+2.6	Gd k x-ray
					1.30/41				0.0639/100.
									0.3705/48.
									0.4107/76.

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{158}Eu		157.9278	45.9 m	β^-/3.5	2.5/	(1-)	+1.44	+0.7	0.0795
									0.8976
									0.9442
									0.9771
^{159}Eu		158.92909	18.1 m	β^-/2.51	2.4/	(5/2+)	+1.38	+2.7	0.0678
					2.57/				0.0786
									0.0957
^{160}Eu		159.9315	38. s	β^-/4.1	2.7/	(0-)			0.0753
					4.1/				0.1735
									0.4131
									0.5155
									0.8217
									0.9110
									0.9246
^{161}Eu		160.9337	27. s	β^-/3.7					0.0719
^{162}Eu		161.9370	11. s	β^-/5.6					
^{163}Eu		162.9392							
^{164}Eu		163.943							
^{165}Eu		164.946							
^{166}Eu		165.950							
^{167}Eu		166.953							
$_{64}$Gd		157.25(3)							
^{135}Gd			1.1 s	β^+					(0.163-0.360)
^{136}Gd		135.947							
^{137}Gd		136.945	7. s	EC,β^+/≈8.8					ann.rad./
^{138}Gd		137.9400	≈4.7 s	EC,β^+					0.0647
^{139m}Gd			≈4.8 s						0.1216
^{139}Gd		138.9381	5. s	EC,β^+/≈7.7					0.104-0.323
^{140}Gd		139.934	16. s	EC/4.8		0+			0.1748
^{141m}Gd			25. s	EC,β^+/		11/2-			ann.rad./
^{141}Gd		140.9322	21. s	β^+/7.3		0+			ann.rad./
^{142}Gd		141.9276	1.17 m	EC,β^+/4.2		1/2+			ann.rad./
^{143m}Gd			1.84 m	β^+/67/		11/2-			ann.rad./
				EC/33/					Eu k x-ray
				I.T./					0.1176
									0.2719
									0.5880
									0.6681
									0.7999
^{143}Gd		142.9266	39. s	β^+/82/6.0		1/2+			ann.rad./
				EC/18/					Eu k x-ray
									0.2048
									0.2588
^{144}Gd		143.9234	4.5 m	β^+/45/4.3	3.3/	0+			ann.rad./
				EC/55/					Eu k x-ray
									0.3332
^{145m}Gd			1.44 m	I.T./95/0.749		11/2-			0.0273
				β^+/4/5.7					0.3295
									0.3866
									0.7214
^{145}Gd		144.92169	23.4 m	β^+/33/5.05	2.5/	1/2+			ann.rad./
				EC/67/					Eu k x-ray
									1.7579
									1.8806
									(0.32 - 3.69)
^{146}Gd		145.91831	48.3 d	EC/99.9/1.03	0.35/	0+			Eu k x-ray
				β^+/0.2					0.1147
									0.1155
									0.1546

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{147}Gd		146.919090	1.588 d	EC/99.8/2.188	0.93/	7/2-	1.0		Eu k x-ray
				EC/0.2/					0.2293
									0.3699
									0.3960
									0.9289
									(0.1 - 1.8)
^{148}Gd		147.918111	75. y	α/3.27	3.1828/	0+			
^{149}Gd		148.919339	9.3 d	EC/1.32		7/2-	0.9		Eu k x-ray
									0.1496
									0.2985
									0.3465
^{150}Gd		149.91866	1.8x10^{6} y	α/2.80	2.73/	0+			
^{151}Gd		150.920345	124. d	EC/0.464		7/2-	0.8		Eu k x-ray
									0.1536
									0.2432
^{152}Gd	0.20(1)	151.919789				0+			
^{153}Gd		152.921747	241.6 d	EC/0.485		3/2-	0.4		Eu k x-ray
									0.09743
									0.10318
^{154}Gd	2.18(3)	153.920862				0+			
^{155}Gd	14.80(5)	154.922619				3/2-	-2.59	+1.30	
^{156}Gd	20.47(4)	155.922120				0+			
^{157}Gd	15.65(3)	156.923957				3/2-	-3.40	+1.36	
^{158}Gd	24.84(12)	157.924101				0+			
^{159}Gd		158.926385	18.6 h	β^- 0.971	0.60/11	3/2-	-0.44		Tb k x-ray
					0.89/26				0.36351
					0.96/63				0.058-0.855
^{160}Gd	21.86(4)	159.927051				0+			
^{161}Gd		160.929666	3.66 m	β^-/1.956	1.56/85	5/2-			Tb k x-ray
									0.1023
									0.3149
									0.3609
^{162}Gd		161.930981	8.4 m	β^-/1.39	1.0/	0+			0.4030
									0.4421
^{163}Gd		162.9340	1.13 m	β^-/3.1					0.2868
									0.214
									1.685
^{164}Gd		163.9359	45. s	β^-/2.3					
^{165}Gd		164.9394	10 s	β^-					
^{166}Gd		165.942							
^{167}Gd		166.946							
^{168}Gd		167.948							
^{169}Gd		168.953							
$_{65}$Tb		158.92534(2)							
^{138}Tb									
^{139}Tb		138.948	1.6 s						0.109
									0.120
^{140}Tb		139.946	2.4 s	β^+,EC/11					0.329
									0.355-0.740
^{141}Tb		140.941	3.5 s	β^+,EC/≈ 8.3					
^{142m}Tb			0.30 s	β^+,EC/		4-			
^{142}Tb		141.939	0.60 s	β^+,EC/10.		0+			
^{143}Tb		142.9346	12. s	β^+,EC/7.4		11/2-			
^{144m}Tb			4.1 s	IT		5-			
^{144}Tb		143.9324	< 1.5 s	β^+,EC/8.4		1+			
^{145m}Tb			30. s	β^+,EC/≈ 6.6		11/2-			ann.rad./
									0.2577
									0.5370
									0.9876

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{145}Tb		144.9287		β⁺,EC/6.5		1/2+			
^{146m}Tb			23. s	β⁺/76/		(5-)			ann.rad./
				EC/24/					Gd k x-ray
									1.0789
									1.5795
^{146}Tb		145.9270	≈ 8. s	β⁺/8.1		1+			
^{147m}Tb			1.8 m	β⁺/35/		11/2-			ann.rad./
				EC/65/					Gd k x-ray
									1.3977
									1.7978
^{147}Tb		146.92404	1.6 h	β⁺/42/4.61		5/2+	+1.70		ann.rad./
				EC/58/					Gd k x-ray
									0.6944
									1.1522
									(0.120-3.318)
^{148m}Tb			2.3 m	β⁺/25/		9+			ann.rad./
				EC/75/					Gd k x-ray
									0.3945
									0.6319
									0.7845
									0.8824
^{148}Tb		147.92422	1.00 h	β⁺,EC/5.69		2-	-1.75	-0.3	ann.rad./
									Gd k x-ray
									0.4888
									0.7845
									(0.14 - 3.8)
^{149m}Tb			4.16 m	EC/88/		11/2-			ann.rad./
				β⁺/12/					Gd k x-ray
									0.1650
									0.7960
^{149}Tb		148.923243	4.13 h	β⁺/4/3.636	1.8/	1/2+	+1.35		Gd k x-ray
				α/16/	3.97/				0.1650
									0.3522
									0.3886
									(0.1 - 3.2)
^{150m}Tb			6.0 m	β⁺/17/					ann.rad./
				EC/83/					Gd k x-ray
									0.4384
									0.6380
									0.6504
									0.8275
^{150}Tb		149.92366	3.3 h	β⁺,EC/4.66		2-	-0.90		ann.rad./
									0.4963
									0.6380
									(0.3 - 4.29)
^{151m}Tb			25. s	I.T./95/		11/2-			0.0229
				β⁺,EC/7/					0.0495
									0.3797
									0.8305
^{151}Tb		150.923099	17.61 h	β⁺/1/2.565	0.70/	1/2+	+0.92		Gd k x-ray
				EC/99/					0.1083
									0.2517
									0.2870
									(0.1 - 1.8)
^{152m}Tb			4.3 m	I.T./79/0.5018		(8+)			Tb k x-ray
				EC/21/4.35					Gd k x-ray
									0.2833
									0.3443
									0.4111

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{152}Tb		151.92407	17.5 h	β^+/20/3.99	2.5/	2-	-0.58	+0.3	ann.rad./
				EC/80/	2.8/				Gd k x-ray
									0.3443
									(0.2 - 2.88)
^{153}Tb		152.923433	2.34 d	EC/1.570		5/2+	+3.44	+1.1	Gd k x-ray
									0.2119
									(0.05 - 1.1)
^{154m2}Tb			23.1 h	EC/98/		(7-)	0.9		Gd k x-ray
				I.T./2/					0.1231
									0.2479
									0.3467
									1.4199
^{154m1}Tb			9. h	β^+/78/		(3-)	1.7	+3.	Gd k x-ray
				I.T./22/					0.1231
									0.2479
									0.5401
									(0.12 - 2.57)
^{154}Tb		153.92469	21.5 h	EC/99/3.56	1.86/	0-			Gd k x-ray
				β^+/1/	2.45				0.1231
									1.2744
									2.1872
									(0.12 - 3.14)
^{155}Tb		154.92350	5.3 d	EC/0.82		3/2+	+2.01	+1.41	Gd k x-ray
									0.08654
									0.10530
^{156m2}Tb			1.02 d	I.T./		(7-)			Tb k x-ray
									0.0496
^{156m1}Tb			5.3 h	I.T./0.0884		(0+)			Tb k x-ray
									0.0884
^{156}Tb		155.924744	5.3 d	EC/2.444		3-	≈1.7	+2.	Gd k x-ray
									0.08896
									0.19921
									0.53435
									1.22245
^{157}Tb		156.924021	1.1x10^2 y	EC/0.0601		3/2+	+2.01	+1.4	Gd k x-ray
									0.0545
^{158m}Tb			10.5 s	I.T./0.11		0-			Gd k x-ray
									0.0110
^{158}Tb		157.925410	1.8x10^2 y	EC/80/1.220		3-	+1.76	+2.7	Gd k x-ray
				β^-/20/0.937					0.0795
									0.9442
									0.9621
^{159}Tb	100.	158.925343				3/2+	+2.014	+1.43	
^{160}Tb		159.927164	72.3 d	β^-/1.835	0.57/47	3-	+1.79	3.8	Dy k x-ray
					0.86/27				0.08678
									0.29857
									0.87936
									0.96615
^{161}Tb		160.927566	6.91 d	β^-/0.593	0.46/23	3/2+	2.2	+1.2	Dy k x-ray
					0.52/66				0.02565
					0.6/10				0.04892
									0.07458
^{162}Tb		161.92948	7.6 m	β^-/2.51	1.4	(1/2-)			Dy k x-ray
									0.2600
									0.8075
									0.8882
^{163}Tb		162.930644	19.5 m	β^-/1.785	0.80/	3/2+			Dy k x-ray
									0.3511
									0.3897

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.4945
^{164}Tb		163.9334	3.0 m	β^-/3.9	1.7/	(5+)			Dy k x-ray
									0.1689
									0.2157
									0.6110
									0.6885
									0.7548
^{165}Tb		164.9349	2.1 m	β^-/3.0		3/2+			0.5389
									1.1785
									1.2920
									1.6648
^{166}Tb		165.9380	≈ 21 s	β^-/					
^{167}Tb		166.9401	19 s						0.057
									0.070
^{168}Tb		167.9436	8 s						0.075-0.227
^{169}Tb		168.946							
^{170}Tb		169.950							
^{171}Tb		170.953							
$_{66}$Dy		162.50(3)							
^{139}Dy			0.6 s	β^+,p					
^{140}Dy		139.954							
^{141}Dy		140.951	0.9 s	EC,β^+/9.					
^{142}Dy		141.946	2.3 s	EC,β^+/7.1					
^{143}Dy		142.9440	3.9 s	EC,β^+/≈ 8.8					
^{144}Dy		143.9391	9.1 s	EC,β^+/≈ 6.2					
^{145m}Dy		144.9365	14. s	EC,β^+		11/2-			
^{146m}Dy			0.15 s	I.T.		10+			
^{146}Dy		145.9325	30. s	EC,β^+/5.2					
^{147m}Dy			56. s	I.T./40/		(11/2-)	-0.66	+0.7	Dy k x-ray
				β^+,EC/60/					0.072
									0.6787
^{147}Dy		146.9309	75. s	EC,β^+/6.37		1/2+	-0.92		ann.rad./
									0.1007
									0.2534
									0.3653
^{148}Dy		147.92710	3.1 m	β^+/4/2.68	1.2/	0+			ann.rad./
				EC/96/					Tb k x-ray
									0.6202
^{149}Dy		148.92734	4.2 m	β^+,EC/3.81		(7/2-)	-0.12	-0.62	ann.rad./
									0.1008
									0.1063
									0.2534
									0.6536
									0.7894
									1.7765
									1.8062
^{150}Dy		149.92558	7.18 m	β^+,EC/67/1.79		0+			Tb k x-ray
				α/33/	4.233/				0.3967
^{151}Dy		150.926181	17. m	β^+/5/2.871		7/2-	-0.95	-0.30	Tb k x-ray
				EC/89/					0.1764
				α/6/	4.067/				0.3030
									0.3861
									0.5463
									(0.16 - 2.09)
^{152}Dy		151.92472	2.37 h	EC/0.60		0+			Tb k x-ray
				α/	3.63/				0.2569
^{153}Dy		152.925763	6.3 h	β^+/1/2.171	0.89/	(7/2-)	-0.78	≈-0.15	Tb k x-ray
				EC/99/					0.0807
				α/0.01/	3.46/				0.0997

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.2137
									(0.08 - 1.66)
^{154}Dy		153.92442	3.x10^{6} y	α/2.95	2.87/	0+			
^{155}Dy		154.92575	9.9 h	β$^+$/2/2.095	0.845/	3/2-	-0.385	+1.04	Tb k x-ray
				EC/98/					0.0655
									0.2269
^{156}Dy	0.06(1)	155.92428				0+			
^{157}Dy		156.92546	8.1 h	EC/1.34		3/2-	-0.301	+1.30	Tb k x-ray
									(0.0609-1.319)
^{158}Dy	0.10(1)	157.924405				0+			
^{159}Dy		158.925736	144. d	EC/0.366		3/2-	-0.354	+1.37	Tb k x-ray
									0.3262
^{160}Dy	2.34(6)	159.925194				0+			
^{161}Dy	18.9(2)	160.926930				5/2+	-0.480	+2.51	
^{162}Dy	25.5(2)	161.926795				0+			
^{163}Dy	24.9(2)	162.928728				5/2-	+0.673	+2.65	
^{164}Dy	28.2(2)	163.929171				0+			
^{165m}Dy			1.26 m	I.T./98/0.108		1/2-			Dy k x-ray
				β$^-$/2/					0.1082
									0.5155
^{165}Dy		164.931700	2.33 h	β$^-$/1.286	1.29/	7/2+	-0.52	-3.5	Ho k x-ray
									0.09468
^{166}Dy		165.932803	3.400 d	β$^-$/0.486	0.40/	0+			Ho k x-ray
									0.0282
									0.0825
^{167}Dy		166.9357	6.2 m	β$^-$/≈ 2.35	1.78	(1/2-)			Ho k x-ray
									0.2593
									0.3103
									0.5697
									(0.06 - 1.4)
^{168}Dy		167.9372	8.5 m	β$^-$/1.6		0+			Ho k x-ray
									0.1925
									0.4867
^{169}Dy		168.9403	≈ 39. s	β$^-$/3.2					
^{170}Dy		169.9427							
^{171}Dy		170.9465							
^{172}Dy		171.949							
^{173}Dy		172.953							
$_{67}$Ho		164.93032(2)							
^{140}Ho			6 ms	p/	p/1.09				
^{141m}Ho			8 μs	p/	p/1.23				
^{141}Ho			4.2 ms	β$^+$,p	p/1.71				
^{142}Ho		141.960							
^{143}Ho		142.955							
^{144}Ho		143.952	0.7 s	β$^+$,EC/12					
^{145}Ho		144.947	2.4 s	β$^+$					
^{146}Ho		145.9440	3.3 s	β$^+$,EC/10.7		(10+)			ann.rad./
^{147}Ho		146.9396	5.8 s	β$^+$,EC/8.2		11/2-			ann.rad./
^{148m}Ho			9. s	β$^+$,EC/		4-			ann.rad./
^{148}Ho		147.9372	2. s	β$^+$,EC/9.4		1+			ann.rad./
									0.6615
									1.6883
^{149m}Ho			21. s	β$^+$,EC/		11/2-			ann.rad./
									1.0733
									1.0911
^{149}Ho		148.93379	> 30. s	β$^+$,EC/6.01		1/2+			
^{150m}Ho			25. s	β$^+$,EC/		(9+)			ann.rad./
									0.3939
									0.5511

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.6534
									0.8034
^{150}Ho		149.9326	1.3 m	β^+,EC/6.6					ann.rad./
									0.5913
									0.6534
									0.8034
^{151m}Ho			47. s	β^+,EC/87/					ann.rad./
				α/13	4.605/				0.2102
									0.4889
									0.6948
									0.7762
^{151}Ho		150.93169	35.2 s	β^+,EC/80/5.13					ann.rad./
				α/20/	4.519/				0.3522
									0.5274
									0.9676
									1.0471
^{152m}Ho			50. s	β^+,EC/90/		(9+)	+5.9	-1.	ann.rad./
				α/10/	4.453/				0.4929
									0.6138
									0.6474
									0.6835
^{152}Ho		151.93166	2.4 m	β^+,EC/88/6.47		(3+)	-1.02	+0.1	ann.rad./
				α/12/	4.387/				0.6140
									0.6476
^{153m}Ho			9.3 m	β^+,EC/99+/4.12		5/2	+1.19		ann.rad./
				α/	4.01/				0.0905
									0.1089
									0.1618
									0.2302
									0.2707
									0.3659
									0.4565
^{153}Ho		152.93020	2.0 m	β^+,EC/99+/4.13		11/2-	+6.8	-1.1	ann.rad./
				α/	3.91/				0.2958
									0.3346
									0.4381
									0.6383
^{154m}Ho			3.3 m	β^+,EC/		(8+)	5.7	-1.0	ann.rad./
									0.3346
									0.4124
									0.4771
^{154}Ho		153.93060	12. m	β^+,EC/5.75		1-	-0.64	+0.2	ann.rad./
									Dy k x-ray
									0.3346
									0.5700
									0.8734
^{155}Ho		154.92908	48. m	β^+/6/3.10		(5/2+)	+3.51	+1.5	ann.rad./
				EC/94/					Dy k x-ray
									0.0474
									0.1363
									0.3254
									(0.06 - 2.24)
^{156m}Ho			5.8 m	I.T./0.0352			+2.99	+2.3	ann.rad./
				β^+/25/	1.8/				Dy k x-ray
				EC/75/	2.9/				0.1378
									0.2666
									(0.28 - 2.9)
^{156}Ho		155.9290	56. m	β^+,EC/4.4		(5+)			ann.rad./
									0.1378

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.2665
^{157}Ho		156.92819	12.6 m	β+/5/2.54	1.18/	7/2-	+4.35	+3.0	ann.rad./
				EC/95/					Dy k x-ray
									0.2800
									0.3411
^{158m2}Ho			28. m	I.T./44/		2-	+2.44	+1.6	ann.rad./
				EC/56/					Dy k x-ray
									0.0989
									0.2182
^{158m1}Ho			21. m	β+,EC/		(9+)			ann.rad./
									0.0981
									0.1664
									0.2182
									0.3205
									0.4062
									0.9774
									1.0532
									0.4846
^{158}Ho		157.92895	11.3 m	β+/8/4.24	1.30/	5+	+3.77	+4.1	ann.rad./
				EC/92/					Dy k x-ray
									0.0989
									0.2182
									0.9488
^{159m}Ho			8.3 s	IT/0.206		1/2+			Ho k x-ray
									0.1660
									0.2059
^{159}Ho		158.927708	33.0 m	EC/1.838		7/2-	+4.28	+3.2	Dy k x-ray
									0.1210
									0.1320
									0.2529
									0.3096
									(0.06 - 1.2)
^{160m2}Ho			3. s			1+			
^{160m}Ho			5.0 h	IT/67/0.060		2-	+2.52	+1.8	0.0868
				EC/33/3.35					0.1970
									0.6464
									0.7281
									0.8791
									0.9619
									0.9658
^{160}Ho		159.92873	25.6 m	β+,EC/3.29	0.57/	5+	+3.71	+4.0	See Ho[166m]
									0.7282
									0.8794
^{161m}Ho			6.8 s	IT/0.211					Ho k x-ray
									0.2112
^{161}Ho		160.927852	2.48 h	EC/0.859		7/2-	+4.25	+3.2	Dy k x-ray
									0.0256
									0.0592
									0.0774
									0.1031
^{162m}Ho			1.12 h	IT/61/		6-	+3.60	+4.	Dy k x-ray
				EC/39/					Ho k x-ray
									0.0807
									0.1850
									0.2828
									0.9372
									1.2200
^{162}Ho		161.929092	15. m	EC/96/0.295		1+			Dy k x-ray
				β+/4/					0.0807

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									1.3196
									1.3728
^{163m}Ho			1.09 s	I.T./0.298		(1/2+)			Ho k x-ray
									0.2798
^{163}Ho		162.928730	4.57x10^3 y	EC/0.00258		7/2-	+4.23	+3.6	Dy M x-rays
^{164m}Ho			38. m	I.T./0.140		(6-)			Ho k x-ray
									0.0373
									0.0566
									0.0940
^{164}Ho		163.930231	29. m	EC/58/0.987		1+			Dy k x-ray
				β^-/42/0.963					0.0734
									0.0914
^{165}Ho	100.	164.930319				7/2-	+4.17	+3.49	
^{166m}Ho			1.2x10^3 y	β^-/		7-	3.6	-3.	Er k x-ray
									0.18407
									0.71169
									0.81031
^{166}Ho		165.932281	1.117 d	β^-/1.855	1.776/48	0-			Er k x-ray
					1.855/51				0.08057
									1.37943
^{167}Ho		166.933127	3.1 h	β^-/1.007	0.31/43	(7/2-)			Er k x-ray
					0.61/21				0.0793
					0.96/15				0.0835
					0.97/15				0.2379
									0.3213
									0.3465
^{168m}Ho			2.2 m	I.T./					
^{168}Ho		167.93550	3.0 m	β^-/2.91	2.0/	3+			Er k x-ray
									0.7413
									0.8159
									0.8211
									(0.08 - 2.34)
^{169}Ho		168.93687	4.7 m	β^-/2.12	1.2/	(7/2-)			
					2.0/				0.1496
									0.7610
									0.7784
									0.7884
									0.8529
^{170m}Ho			43. s	β^-/		1+			0.0787
									0.8123
									1.8940
									1.9726
^{170}Ho		169.93962	2.8 m	β^-/3.87		6+			Er k x-ray
									0.1816
									0.2582
									0.8902
									0.9321
									0.9414
									1.1387
^{171}Ho		170.941	53 s	β^-/					
^{172}Ho		171.9448	25. s	β^-/					Er k x-ray
									(0.077-1.186)
^{173}Ho		172.947							
^{174}Ho		173.951							
^{175}Ho		174.954							
$_{68}$Er		167.259(3)							
^{144}Er		143.961							
^{145}Er		144.957	0.9 s	β^+					

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^{146}Er		145.952	≈ 1.7 s	β^+					
^{147}Er		146.9494	2.5 s	E.C,β^+/≈ 9.1					
^{148}Er		147.9444	4.5 s	β^+,EC/6.8					
^{149m}Er			10. s	IT		11/2-			
^{149}Er		148.9425	10.7 s	ECβ^+/8.1		1/2+			
^{150}Er		149.9370	18. s	β^+/36/4.11		0+			ann.rad./
				EC/64/					Ho k x-ray
									0.4758
^{151}Er		150.9373	23. s	β^+,EC/5.2		7/2-			ann.rad./
^{152}Er		151.93500	10.2 s	β^+,EC/10/3.11		0+			ann.rad./
				α/90/	4.804/				
^{153}Er		152.93509	37.1 s	α/	4.674		-0.934	-0.42	0.351
				β^+,EC/47/4.56	4.35/				(0.0945-1.700)
^{154}Er		153.93278	3.7 m	β^+,EC/99+/2.03		0+			ann.rad./
				α/0.5/	4.166/				
^{155}Er		154.93321	5.3 m	β^+,EC/47/3.84		(7/2-)	-0.669	-0.27	ann.rad./
				EC/53/					Ho k x-ray
									0.1101
									0.2415
^{156}Er		155.9308	20. m	β^+,EC/1.7		0+			ann.rad./
									0.0298
									0.0352
									0.0522
									0.1336
^{157}Er		156.9319	25. m	β^+,EC/3.5		3/2-	-0.412	+0.92	ann.rad./
									0.117
									0.385
									1.320
									1.660
									1.820
									2.000
^{158}Er		157.93087	2.2 h	EC/99.5/1.78	0.74/	0+			Ho k x-ray
				β^+/0.5/					0.0719
									0.2486
									0.3868
^{159}Er		158.930681	36. m	β^+/7/2.769		3/2-	-0.304	+1.17	ann.rad./
				EC/93/					Ho k x-ray
									0.6245
									0.6493
									(0.07 - 2.5)
^{160}Er		159.92908	1.191 d	EC/0.33		0+			Ho k x-ray
									(0.05 - 0.96)
^{161}Er		160.93000	3.21 h	EC/2.00		3/2-	-0.37	+1.36	Ho k x-ray
									0.8265
									(0.07 - 1.74)
^{162}Er	0.14(1)	161.928775				0+			
^{163}Er		162.93003	1.25 h	EC/1.210		5/2-	+0.557	+2.55	Ho k x-ray
									0.4361
									0.4399
									1.1135
^{164}Er	1.61(2)	163.929197				0+			
^{165}Er		164.930723	10.36 h	EC/0.376		5/2-	+0.643	+2.71	Ho k x-ray
^{166}Er	33.6(2)	165.930290				0+			
^{167m}Er			2.27 s	I.T./0.208		1/2-			Er k x-ray
									0.2078
^{167}Er	22.95(15)	166.932046				7/2+	-0.5639	+3.57	
^{168}Er	26.8(2)	167.932368				0+			
^{169}Er		168.934588	9.40 d	β^-/0.351	0.35/≈ 100	1/2-	+0.485		Tm k x-ray
									0.1098

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									0.1182
^{170}Er	14.9(2)	169.935461				0+			
^{171}Er		170.938026	7.52 h	β^-/1.491		5/2-	0.66	2.9	Tm k x-ray
									0.11160
									0.29591
									0.30832
									(0.08 - 1.4)
^{172}Er		171.939352	2.05 d	β^-/0.891	0.28/48				Tm k x-ray
					0.36/46				0.0597
									0.4073
									0.6101
^{173}Er		172.9424	1.4 m	β^-/2.6		(7/2-)			Tm k x-ray
									0.1928
									0.1992
									0.8952
^{174}Er		173.9441	3.1 m	β^-/1.8					Tm k x-ray
									(0.100-0.152)
^{175}Er		174.9479	1.2 m	β^-					(0.0765-1.168)
^{176}Er		175.9503							
^{177}Er		176.954							
$_{69}$Tm		168.93421(2)							
^{145}Tm			≈3.5 µs						
^{146m}Tm			0.21 s	β^+,p	p/1.118				
^{146}Tm		145.967	0.06 s	β^+/14.					
				p	1.119/				
					1.189/				
^{147m}Tm			0.4 ms	β^+,p	p/1.115				
^{147}Tm		146.961	0.56 s	EC, β^+/85/≈10.7					
				p/15/	1.052/				
^{148m}Tm		147.9573	0.7 s	β^+,EC/12.					ann.rad./
^{148}Tm									
^{149}Tm		148.9524	0.9 s	β^+,EC/≈9.2		11/2-			
^{150}Tm		149.9494	2.3 s	β^+,EC/≈11.5		6-			(0.1007-2.177)
^{151}Tm		150.9454	4. s	β^+,EC/7.5					ann.rad./
^{152m}Tm			8. s	β^+,EC/		9+			
^{152}Tm		151.9443	5. s	β^+,EC/8.8					ann.rad./
^{153}Tm		152.94203	1.6 s	β^+,EC/10/6.46					ann.rad./
				α/90/	5.109/				
^{154m}Tm			3.3 s	β^+,EC/15/	α/5.031/100				ann.rad./
				α/	4.84/0.24				0.4605-0.7960
^{154}Tm		153.9407	8.1 s	β^+,EC/56/7.4	α/4.956/100				ann.rad./
				α/44/	4.83/0.45				
^{155}Tm		154.93919	30. s	β^+,EC/5.58					0.0315
				α/	4.46/				0.0638
									0.0881
									0.2268
									0.5320
									0.6067
^{156m}Tm			19. s	α/	4.46/				
^{156}Tm		155.9389	1.40 m	β^+,EC/7.6		2-	+0.40	-0.5	ann.rad./
				α/	4.23/				0.3446
									0.4529
									0.5860
^{157}Tm		156.9367	3.6 m	β^+,EC/4.5	2.6	1/2	+0.48		ann.rad./
				α/	3.97/				0.1104
									0.3484
									0.3855
									0.4550
									(0.1 - 1.58)

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^{158}Tm		157.9379	4.0 m	β^+,EC/74/6.5		(2-)	+0.04	+0.7	ann.rad./
				EC/26/					Er k x-ray
									0.1921
									0.3351
									0.6280
									1.1498
									(0.18 - 2.81)
^{159}Tm		158.9348	9.1 m	β^+/23/3.9		5/2+	+3.42	+1.9	ann.rad./
				EC/77/					Er k x-ray
									0.0591
									0.0848
									0.2713
									(0.05 - 1.27)
^{160m}Tm			1.24 m	IT		(5)			
^{160}Tm		159.9354	9.4 m	β^+/15/5.9		1-	+0.16	+0.58	ann.rad./
				EC/85/					Er k x-ray
									0.1264
									0.2642
									0.7285
									0.8544
									0.8614
									1.3685
^{161}Tm		160.9334	31. m	β^+,EC/3.2		7/2+	+2.40	+2.9	ann.rad./
									Er k x-ray
									0.0595
									0.0844
									1.6481
									(0.04 - 2.15)
^{162m}Tm			24. s	I.T./90/		5+			Tm k x-ray
				β^+,EC/10/					Er k x-ray
									0.0669
									0.8115
									0.9003
^{162}Tm		161.93394	21.7 m	β^+/8/4.81		1-	+0.07	+0.69	ann.rad./
				EC/92/					Er k x-ray
									0.1020
									0.7987
									(0.1 - 3.75)m
^{163}Tm		162.93265	1.81 h	EC/98/2.439		1/2+	-0.082		Er k x-ray
				β^+/1/					0.0692
									0.1043
									0.2414
^{164m}Tm			5.1 m	I.T./80/		6-			0.0914
				β^+,EC/20/					0.1394
									0.2081
									0.2405
									0.3149
^{164}Tm		163.93345	2.0 m	β^+/36/3.96	2.94/	1+	+2.38	+0.71	ann.rad./
				EC/64/					Er k x-ray
									0.0914
^{165}Tm		164.932433	1.253 d	EC/1.593		1/2+	-0.139		Er k x-ray
									0.0472
									0.0544
									0.29728
									0.80636
^{166}Tm		165.93355	7.70 h	EC/98/3.04		2+	+0.092	+2.14	Er k x-ray
				β^+/2/					0.0806
									0.1844
									0.7789

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									1.2734
									2.0524
^{167}Tm		166.932849	9.24 d	EC/0.748		1/2+	-0.197		Er k x-ray
									0.0571
									0.20778
^{168}Tm		167.934171	93.1 d	EC/1.679		3+	+0.23	+3.2	Er k x-ray
									0.19825
									0.4475
									0.81595
^{169}Tm	100	168.934211				1/2+	-0.232	-1.2	
^{170}Tm		169.935798	128.6 d	β^-/99.8/0.968	0.883/24	1-	+0.247	+0.74	Yb k x-ray
				EC/0.2/0.314	0.968/76				0.08425
^{171}Tm		170.936426	1.92 y	β^-/0.096	0.03/2	1/2+	-0.230		0.06674
					0.096/98				
^{172}Tm		171.93840	2.65 d	β^-/1.88	1.79/36	2-			Yb k x-ray
					1.88/29				0.07879
									1.38722
									1.46601
									1.52982
									1.60861
^{173}Tm		172.93960	8.2 h	β^-/1.298	0.80/21	1/2+			Yb k x-ray
					0.86/71				0.3988
									0.4613
^{174}Tm		173.94216	5.4 m	β^-/3.08	0.70/14	(4-)			Yb k x-ray
					1.20/83				0.07664
									0.17669
									0.27332
									0.3666
									0.99205
									(0.08 - 1.6)
^{175}Tm		174.94383	15.2 m	β^-/2.39	0.9/36	(1/2+)			Yb k x-ray
					1.9/23				0.36396
									0.51487
									0.94125
									0.98247
^{176}Tm		175.9471	1.9 m	β^-/4.2	2.0/	(4+)			Yb k x-ray
					1.2/				0.1898
									0.3819
									1.0691
^{177}Tm		176.9490	1.4 m	β^-					
^{178}Tm		177.9526							
^{179}Tm		178.9553							
$_{70}$Yb		173.04(3)							
^{148}Yb		147.967							
^{149}Yb		148.963							
^{150}Yb		149.958							
^{151}Yb		150.9545	1.6 s	β^+/8.5					
^{152}Yb		151.9502	3.2 s	β^+ EC/5.5					
^{153}Yb		152.9492	4. s	β^+ EC/6.7					
^{154}Yb		153.9455	0.40 s	β^+ EC/7/4.49					ann.rad./
				α/93/	5.32/				
^{155}Yb		154.9456	1.7 s	β^+,EC/16/6.0			-0.8	-1.	ann.rad./
				α/84/	5.19/				
^{156}Yb		155.94277	26. s	β^+,EC/21/3.57		0+			ann.rad./
				α/79/	4.69/				
^{157}Yb		156.9427	39. s	β^+,EC/99+/5.5			-0.64		ann.rad./
				α/0.5/	4.69/				0.231
									(0.035-0.670)
^{158}Yb		157.93986	1.5 m	β^+,EC/1.9		0+			ann.rad./

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.0741
									0.2526
^{159}Yb		158.9402	1.4 m	EC,β^+/5.1			-0.37	-.022	Tm k x-ray
									0.1661
									0.1772
									0.3297
									0.3903
^{160}Yb		159.9376	4.8 m	β^+,EC/2.0		0+			ann.rad./
									0.1404
									0.1737
									0.2158
^{161}Yb		160.9375	4.2 m	β^+,EC/3.9		3/2-	-0.33	+1.03	ann.rad./
									Tm k x-ray
									0.0782
									0.5999
									0.6315
^{162}Yb		161.9358	18.9 m	β^+,EC/1.7		0+			ann.rad./
									Tm k x-ray
									0.1188
									0.1635
^{163}Yb		162.9363	11.1 m	β^+/26/3.4	1.4/	3/2-	-0.37	+1.24	ann.rad./
									Tm k x-ray
									0.0636
									0.8603
									(0.06 - 1.9)
^{164}Yb		163.9345	1.26 h	EC/1.0		0+			Tm k x-ray
									0.0914
									0.6752
^{165}Yb		164.93540	9.9 m	β^+/10/2.76	1.58/	(5/2-)	+0.48	+2.48	ann.rad./
				EC/90/					Tm k x-ray
									0.0801
									1.0903
^{166}Yb		165.93388	2.363 d	EC/0.30		0+			Tm k x-ray
									0.0828
									0.1844
									0.7789
									1.2734
									2.0524
^{167}Yb		166.934947	17.5 m	β^+/0.5/1.954	0.639/	5/2-	+0.62	+2.70	Tm k x-ray
				EC/99.5/					0.06296
									0.10616
									0.11337
									0.17633
^{168}Yb	0.13(1)	167.933895				0+			
^{169m}Yb			46. s	I.T./0.0242		1/2-			Yb L x-ray
									0.0242
^{169}Yb		168.935187	32.03 d	EC/0.909		7/2+	-0.63	+3.5	Tm k x-ray
									0.1979/35.9
									0.0498-0.3078
^{170}Yb	3.05(6)	169.934759				0+			
^{171}Yb	14.3(2)	170.936323				1/2-	+0.49367		
^{172}Yb	21.9(3)	171.936378				0+			
^{173}Yb	16.12(21)	172.938207				5/2-	-0.67989	+2.80	
^{174}Yb	31.8(4)	173.938858				0+			
^{175}Yb		174.941273	4.19 d	β^-/0.470	0.466/73	7/2-	0.77		Lu k x-ray
					0.071/21				0.3963/13
					0.353/6.2				(0.114 - 0.28)
^{176m}Yb			11.4 s	I.T./1.051		(8-)			Yb k x-ray
									0.0961

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.1901
									0.2929
									0.3897
^{176}Yb	12.7(2)	175.942569	10^{26} y	$\beta^-\beta^-$		0+			
^{177m}Yb			6.41 s	I.T./0.3315		1/2-			Yb k x-ray
									0.1131
									0.2084
^{177}Yb		176.945257	1.9 h	β^-/1.399	1.40	9/2+			Lu k x-ray
									0.1504
^{178}Yb		177.94664	1.23 h	β^-/0.65	0.25/	0+			0.1415
									0.3246
									0.3516
									0.3815
									0.6125
^{179}Yb		178.9499	8. m	β^-/2.4					
^{180}Yb		179.9523	2. m	β^-					0.1028-0.4423
^{181}Yb		180.9561							
$_{70}$Lu		174.967(1)							
^{150m}Lu			≈0.03 ms	p/1.295					
^{150}Lu		149.973	49. ms	p					
^{151m}Lu			16 μs	p/1.31					
^{151}Lu		150.967	0.08 s	p/1.231					
^{152}Lu		151.963	0.7 s						
^{153}Lu		152.959							
^{154}Lu		153.9571	1.0 s	β^+,EC/10.8					
^{155m}Lu			2.6 ms	α/7.41					
^{155}Lu		154.9542	0.07 s	EC/8.0					
				α/	5.66/90				
^{156m}Lu			0.20 s	α/	5.57/				
^{156}Lu		155.9529	≈ 0.5 s	β^+,EC/9.5					ann.rad./
				α/	5.45/				
^{157m}Lu			≈9.6 s	α	4.925/				
^{157}Lu		156.95010	4.8 s	β^+,EC/94/6.93					ann.rad./
				α/	5.00/				
^{158}Lu		157.94984	10.4 s	β^+,EC/99/8.0					ann.rad./
				α/	4.67/				0.3682
									0.4770
^{159}Lu		158.9467	12.3 s	β^+,EC/6.0					ann.rad./
									0.1505
									0.1875
									0.3693
^{160}Lu		159.94654	36.1 s	β^+,EC/7.3					ann.rad./
									0.2434
									0.3957
									0.5773
^{161}Lu		160.9432	1.2 m	β^+,EC/5.3					ann.rad./
									0.0437
									0.0671
									0.1003
									0.1108
									0.1562
									0.2562
^{162m}Lu			≈ 1.5 m	EC/		4-			
^{162}Lu		161.9432	1.37 m	β^+,EC/6.9		1-			ann.rad./
									0.1666
									0.6314
^{163}Lu		162.9412	4.1 m	β^+,EC/4.6					ann.rad./
									0.0539
									0.0581

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.1504
									0.1631
									0.3717
^{164}Lu		163.9412	3.14 m	β$^+$,EC/6.3	1.6/				0.1238
					3.8/				0.2621
									0.7404
									0.8639
									0.8804
^{165}Lu		164.9396	10.7 m	β$^+$,EC/3.9	2.06/	1/2+			ann.rad./
									0.1206
									0.1324
									0.1742
									0.2036
									(0.04 - 2.0)
^{166m2}Lu			2.1 m	β$^+$/35/		(0-)			ann.rad./
				EC/65/					Yb k x-ray
									1.0673
									1.2566
									2.0986
^{166m1}Lu			1.4 m	β$^+$,EC/58/		(3-)			ann.rad./
				I.T./42/0.0344					0.1024
									0.2281
									0.2861
									0.8119
									0.8301
^{166}Lu		165.9398	2.8 m	β$^+$/25/5.5		(6-)			ann.rad./
				EC/75/					Yb k x-ray
									0.1024
									0.2281
									0.3375
									0.3679
^{167}Lu		166.9383	52. m	β$^+$/2/3.1	2.1/	7/2+			Yb k x-ray
				EC/98/					0.0297
									0.2392
									(0.03 - 2.0)
^{168m}Lu			6.7 m	β$^+$/12/		3+			ann.rad./
				EC/88/					Yb k x-ray
				IT/<0.8					0.1988/190
									0.8960/100
									0.9792/128
									0.018-2.65
^{168}Lu		167.9387	5.5 m	β$^+$/6/4.5	1.2/	(6-)			ann.rad./
				EC/94/					Yb k x-ray
									0.1114
									0.1124
									0.2286
									0.3483
									1.4836
^{169m}Lu			2.7 m	I.T./0.0290		1/2-			Lu L x-ray
									0.0290
^{169}Lu		168.93765	1.419 d	EC/2.293	1.271/	7/2+	2.30	3.5	Yb k x-ray
									0.19121
									0.9606
									(0.08 - 2.1)
^{170m}Lu			0.7 s	I.T./0.0929		4-			Lu L x-ray
									0.04449
									0.0484
^{170}Lu		169.93847	2.01 d	EC/3.46	2.44/	0+			Yb k x-ray
									0.58711

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.5908
									1.28029
									(0.1 - 3.38)
^{171m}Lu			1.31 m	I.T./0.0711		1/2-			Lu k x-ray
									0.07119
^{171}Lu		170.937910	8.24 d	EC/1.479	0.362/	7/2+	2.30	3.42	Yb k x-ray
									0.01939
									0.66744
									(0.02 - 1.3)
^{172m}Lu			3.7 m	I.T./0.0419		1-			Lu L x-rays
									0.04186
^{172}Lu		171.939082	6.70 d	EC/2.519		4-	2.90	3.80	Yb k x-ray
									0.18156
									1.09367
									(0.07 - 2.2)
^{173}Lu		172.938927	1.37 y	EC/0.671		7/2+	2.28	3.63	Yb k x-ray
									0.07860
									0.27198
^{174m}Lu			142. d	IT/99.3/	0.17086	6-	1.50		Lu k x-ray
				EC/0.7/					0.067055
^{174}Lu		173.940334	3.3 y	EC/1.374		1-	1.9		Yb k x-ray
									0.07664
									1.2419
^{175}Lu	97.41(2)	174.940768				7/2+	+2.2327	+3.49	
^{176m}Lu			3.66 h	β^-/1.315	1.229/	1-	+0.318	-1.47	Hf k x-ray
					1.317/				0.088372
^{176}Lu	2.59(2)	175.942683	3.8x10^{10} y	β^-/1.192		7-	+3.169	+4.92	Hf k x-ray
									0.20187
									0.30691
^{177m}Lu			160.7 d	IT/22/0.9702		23/2-	2.33	5.4	Lu k x-ray
				β^-/78					Hf k x-ray
									0.11295
									0.20836
									0.37850
									0.41853
^{177}Lu		176.943755	6.75 d	β^-/0.498	0.497/	7/2+	+2.239	+3.39	0.11295
									0.20836
^{178m}Lu			23.1 m	β^-/		(9-)			0.2166
									0.3317
^{178}Lu		177.945952	28.5 m	β^-/2.099	2.03/	1+			Hf k x-ray
									0.0932
									1.3099
									1.3408
									(0.09 - 1.7)
^{179}Lu		178.94732	4.6 h	β^-/1.405	1.35/	7/2+			0.2143
									0.3377
^{180}Lu		179.9499	5.7 m	β^-/3.1	1.49/				0.40795/50.
									(0.07-1.9)
^{181}Lu		180.9518	3.5 m	β^-/2.5		(7/2+)			0.0458
									0.2059
									0.5749
^{182}Lu		181.9552	2.0 m	β^-/≈ 4.1					0.0978
									0.7208
									0.8182
^{183}Lu		182.9576	58. s	β^-/		7/2+			
^{184}Lu		183.9612	20 s	β^-					
$_{72}$Hf		178.49(2)							
^{154}Hf		153.964	2. s	EC,β^+/≈ 6.7					
^{155}Hf		154.963	0.9 s	EC,β^+/8.					

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{156}Hf		155.9593	25. ms	α/					
^{157}Hf		156.9581	0.11 s	α/					
^{158}Hf		157.9539	2.9 s	EC/54/5.1		0+			
				α/46/	5.27/				
^{159}Hf		158.9538	5.6 s	β^+,EC/88/6.9					ann.rad./
				α/12/	5.09/				
^{160}Hf		159.95063	≈ 12. s	β^+,EC/97/4.9		0+			ann.rad./
				α/4.78					
^{161}Hf		160.9503	17. s	α/	4.60/				
^{162}Hf		161.94720	38. s	β^+,EC/3.7		0+			ann.rad./
									0.1739
									0.1963
									0.4101
^{163}Hf		162.9471	40. s	β^+,EC/5.5					ann.rad./
									0.0454
									0.0621
									0.0710
									0.6882
^{164}Hf		163.9536	2.8 m	EC,β^+/3.0					
^{165}Hf		164.9445	1.32 m	EC/4.6		11/2-			
^{166}Hf		165.9423	6.8 m	EC/93/2.3					ann.rad./
				β^+/7/					Lu k x-ray
									0.0788
^{167}Hf		166.9426	2.0 m	β^+/40/4.0		(5/2-)			ann.rad./
				EC/60/					Lu k x-ray
									0.1754
									0.3152
^{168}Hf		167.9406	25.9 m	β^+,EC/1.8		0+			ann.rad./
									(0.0144-1.311)
^{169}Hf		168.9412	3.25 m	EC/85/3.3		(5/2-)			ann.rad./
				β^+/15/					Lu k x-ray
									0.3695
									0.4929
^{170}Hf		169.9397	16.0 h	EC/1.1		0+			Lu k x-ray
									0.0985
									0.1202
									0.1647
									0.5729
									0.6207
^{171m}Hf			30. s			(1/2-)	+0.53		
^{171}Hf		170.9405	12.2 h	EC,β^+/2.4		7/2+	-0.67	+3.46	ann.rad./
									Lu k x-ray
									0.1221
									0.6620
									1.0714
^{172}Hf		171.93946	1.87 y	EC/0.35		0+			Lu k x-ray
									0.02399
									0.12582
									(0.0818-0.123)
^{173}Hf		172.9407	23.6 h	EC/1.6		1/2-			Lu k x-ray
									0.12367
									0.13963
									0.29697
									0.31124
									(0.1 - 2.1)
^{174}Hf	0.162(3)	173.940042	$2.0x10^{15}$ y			0+			
^{175}Hf		174.941504	70. d	EC/0.686		5/2-	-0.60	+2.7	Lu k x-ray
									0.08936
									0.34340

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{176}Hf	5.206(5)	175.941403				0+			
^{177m2}Hf			51.4 m	I.T./2.740		37/2-			Hf k x-ray
									0.2140
									0.2951
									0.3115
									0.3267
^{177m1}Hf			1.1 s	I.T./		23/2+			Hf k x-ray
									0.20836
									0.22847
									0.37851
^{177}Hf	18.606(4)	176.943220				7/2-	+0.7935	+0.337	
^{178m2}Hf			31. y	I.T./		16+	+8.2	+6.0	Hf k x-ray
									0.32555
									0.42635
									(0.0889-0.5742)
^{178m1}Hf			4.0 s	I.T./		8-			Hf k x-ray
									0.21342
									0.32555
									0.42635
^{178}Hf	27.297(4)	177.943698				0+			
^{179m2}Hf			25.1 d	I.T./1.1057		25/2-	7.4		Hf k x-ray
									0.1227
									0.1461
									0.3626
									0.4537
^{179m1}Hf			18.7 s	I.T./0.375		1/2-			Hf k x-ray
									0.1607
									0.2141
^{179}Hf	13.629(6)	178.945815				9/2+	-0.641	+3.79	
^{180m}Hf			5.52 h	I.T./1.1416		8-	+9.	+4.6	Hf k x-ray
									0.2152
									0.3323
									0.4432
^{180}Hf	35.100(7)	179.946549				0+			
^{181}Hf		180.949099	42.4 d	β^-/1.027	0.408/	1/2-			Ta k x-ray
									0.13294
									0.48200
^{182m}Hf			62. m	β^-/54/1.60	0.49/43	8-			Hf k x-ray
				IT/46/1.173	0.95/10				0.0509
									0.2244
									0.3441
									0.4558
									0.5066
									0.9428
^{182}Hf		181.95055	9.x10^{6} y	β^-/0.37		0+			Ta k x-ray
									0.2704
^{183}Hf		182.95353	1.07 h	β^-/2.01	1.18/68	3/2-			Ta k x-ray
					1.54/25				0.0732
									0.4591
									0.7837
^{184}Hf		183.95545	4.1 h	β^-/1.34	0.74/38	0+			Ta k x-ray
					0.85/16				0.0414
					1.10/46				0.1391
									0.3449
^{185}Hf		184.9588	≈3.5m	β^-/					0.165
^{186}Hf		185.9609	≈2.1 m						0.738
$_{73}$Ta		180.9479(1)							
^{155}Ta			12 µs	p/1.77					
^{156}Ta		155.972	0.11 s	β^+/≈11.6					

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				p/	1.02/≈100				
^{157}Ta		156.968	10 ms	α/	6.117				
				p/	0.927/3.4				
^{158}Ta		157.9664	37. ms	α/	6.05/100				
					5.97/100				
^{159}Ta		158.9629	0.6 s	$β^+$,EC/20/8.5	α/5.52/34				ann.rad./
				α/80/	5.60/55				
^{160}Ta		159.9615	1.4 s	$β^+$,EC/10.1					ann.rad./
				α	5.41/				
^{161}Ta		160.9584	2.9 s	$β^+$,EC/7.5					ann.rad./
				α/	5.15				
^{162}Ta		161.9564	4. s	EC/8.6					
^{163}Ta		162.9544	10.6 s	EC/6.8					
^{164}Ta		163.9536	14.2 s	$β^+$/8.5		3+			ann.rad./
				α/	4.62/				0.2110
									0.3768
^{165}Ta		164.9508	31. s	EC$β^+$/5.9					
^{166}Ta		165.9505	34. s	$β^+$/82/7.7					ann.rad./
				EC/18/					Hf k x-ray
									0.1587
									0.3117
									0.8101
^{167}Ta		166.9486	1.4 m	$β^+$,EC/5.6					ann.rad./
^{168}Ta		167.9478	2.4 m	$β^+$/77/6.7		3+			ann.rad./
				EC/23/					Hf k x-ray
									0.1239
									0.2615
									0.7502
^{169}Ta		168.9459	4.9 m	$β^+$,EC/4.4					ann.rad./
									0.0288
									0.1535
									0.1924
^{170}Ta		169.9461	6.8 m	$β^+$/70/6.0		(3+)			ann.rad./
				EC/35/					Hf k x-ray
									0.1008
									0.2212
^{171}Ta		170.9445	23.3 m	$β^+$,EC/3.7		(5/2-)			0.0496
									0.5018
									0.5064
									(0.05 - 1.02)
^{172}Ta		171.9447	36.8 m	$β^+$/25/4.9		(3-)			ann.rad./
				EC/75/					Hf k x-ray
									0.21396
									1.10923
									(0.09 - 3.8)
^{173}Ta		172.9446	3.6 h	$β^+$/24/3.7		(5/2-)	1.70	-1.9	ann.rad./
				EC/76/					Hf k x-ray
									0.06972
									0.17219
									(0.06 - 2.7)
^{174}Ta		173.9442	1.12 h	$β^+$/27/3.8		(3+)			ann.rad./
				EC/73/					Hf k x-ray
									0.09089
									0.20638
									(0.09 - 3.64)
^{175}Ta		174.9437	10.5 h	EC/2.0		7/2+	2.27	+3.7	Hf k x-ray
									0.2077
									0.2671
									0.3487

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{176}Ta		175.9447	8.1 h	EC/3.1		1-			Hf k x-ray
									0.08837
									1.15735
^{177}Ta		176.944472	2.356 d	EC/1.166		7/2+	2.25		Hf k x-ray
									0.11295
									(0.07 - 1.06)
^{178m}Ta			2.4 h	EC/		(7-)			Hf k x-ray
									0.08886
									0.21342
									0.32555
									0.42635
^{178}Ta		177.9458	9.29 m	EC/99/1.9		1+	+2.74	+0.65	ann.rad./
				β^+/1/					Hf k x-ray
									0.09316
^{179}Ta		178.94593	1.8 y	EC/0.110		7/2+	2.29	3.37	Hf k x-ray
^{180m}Ta	0.012(2)		>1.2x10^{15} y			(9-)	4.82		
^{180}Ta		179.947466	8.15 h	EC/87/0.854		1+			Hf k x-ray
				β^-/13/0.708	0.61/3				W k x-ray
					0.71/10				0.09333
									0.10340
^{181}Ta	99.988(2)	180.947996				7/2+	+2.370	+3.3	
^{182m}Ta			15.8 m	I.T./0.5198		10-			Ta k x-ray
									0.14678
									0.17157
^{182}Ta		181.950152	114.43 d	β^-/1.814	0.25/30	3-	+3.02	+2.6	W k x-ray
					0.44/20				1.12127/100
					0.52/40				1.22138/79
									0.085-1.289
^{183}Ta		182.951373	5.1 d	β^-/1.070	0.45/5	7/2+	+2.36		W k x-ray
					0.62/91				0.0847
									0.0991
									0.1079
									0.2461
									0.3540
^{184}Ta		183.95401	8.7 h	β^-/2.87	1.11/15	(5-)			W k x-ray
					1.17/81				0.2528/44.
									0.4140/74.
									(0.09-1.4)
^{185}Ta		184.95556	49. m	β^-/1.99	1.21/5	(7/2+)			W k x-ray
					1.77/81				0.0697
									0.1739
									0.1776
^{186}Ta		185.9586	10.5 m	β^-/3.9	2.2/	(3-)			W k x-ray
									0.1979
									0.2149
									0.5106
									(0.09 - 1.5)
^{187}Ta		186.9604							
^{188}Ta		187.9637							
$_{74}$W		183.84(1)							
^{158m}W			0.14 ms	α	8.28(3)/				
^{158}W		157.974	1.3 ms	α/	6.433/96				
^{159}W		158.972	7. ms	α/					
^{160}W		159.9684	0.08 s	α/	5.92/	0+			
^{161}W		160.9671	0.41 s	β^+,EC/18/8.1					
				α/82/	5.78/				
^{162}W		161.9626	1.39 s	β^+,EC/54/5.8		0+			
				α/46/	5.54/				

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{163}W		162.9624	2.8 s	β$^+$,EC/59/7.5					
				α/41/	5.38/				
^{164}W		163.95890	6. s	β$^+$,EC/97/5.0		0+			ann.rad./
				α/3/	5.15/				
^{165}W		164.9583	5.1 s	β$^+$,EC/99/7.0					ann.rad./
				α/1/	4.91/				
^{166}W		165.95502	16. s	β$^+$,EC/99/4.2		0+			ann.rad./
				α/1/	4.74/				
^{167}W		166.9547	20. s	EC/5.6					
^{168}W		167.9519	53. s	EC/3.8					ann.rad./
				α/10^{-5}/	4.40(1)				Ta k x-ray
									0.1755
									(0.037-0.573)
^{169}W		168.9518	1.3 m	EC/5.4					ann.rad./
									Ta k x-ray
									0.123
									(0.097-0.699)
^{170}W		169.9485	2.4 m	EC/2.2					ann.rad./
									Ta k x-ray
									0.3162
									(0.060-0.144)
^{171}W		170.9494	2.4 m	EC/4.6					ann.rad./
									Ta k x-ray
									0.1842
									(0.052-0.479)
^{172}W		171.9474	6.6 m	β$^+$,EC/2.5					ann.rad./
									Ta k x-ray
									0.0389
									(0.034-0.674)
^{173}W		172.9489	6.3 m	EC/4.0					ann.rad./
									Ta k x-ray
									0.4576
									(0.035-0.623)
^{174}W		173.9462	35. m	EC/1.9		0+			ann.rad./
									Ta k x-ray
									0.3287
									0.4288
									(0.056-0.429)
^{175}W		174.9468	35. m	EC/2.9		1/2-			(0.015-0.27)
^{176}W		175.9456	2.5 h	β$^+$,EC/0.8		0+			0.03358
									0.06129
									0.09487
									0.10020
^{177}W		176.9466	2.21 h	EC/2.0		(1/2-)			Ta k x-ray
									0.15505
									0.18569
									0.42694
^{178}W		177.9459	21.6 d	EC/0.091		0+			Ta k x-ray
^{179m}W			6.4 m	IT/99.7/0.222		(1/2-)			W k x-ray
				EC/0.3/					0.2220
^{179}W		178.94707	38. m	EC/1.06		(7/2-)			Ta k x-ray
									0.0307
^{180}W	0.120(1)	179.946706	7.4x10^{16} y	α/		0+			
^{181}W		180.94820	121.2 d	EC/0.188		9/2+			Ta k x-ray
									0.13617
									0.15221
^{182}W	26.498(29)	181.948205	8.3x10^{18} y	α/		0+			
^{183m}W			5.15 s	I.T./		(11/2+)			W k x-ray
									0.0465

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.0526
									0.0991
									0.1605
^{183}W	14.314(4)	182.950224	1.9x10^{18} y	α/		1/2-	+0.117784 8		
^{184}W	30.642(8)	183.950932	4.0x10^{18} y	α/		0+			
^{185m}W			1.6 m	I.T./0.1974		11/2+			W k x-ray
									0.0659
									0.1315
									0.1737
^{185}W		184.953420	74.8 d	β^-/0.433	0.433/99.9	3/2-			0.12536
^{186}W	28.426(37)	185.954362	6.5x10^{18} y	α/		0+			
^{187}W		186.957158	23.9 h	β^-/1.311	0.624/66	3/2-	0.62		Re k x-ray
					1.315/16				0.68572/33
					0.081-1.18				0.134-0.773
^{188}W		187.958487	69.4 d	β^-/0.349	0.349/99	0+			0.0636
									0.2271
									0.2907
^{189}W		188.9619	11.5 m	β^-/2.5	1.4/	(3/2-)			(0.1262-1.466)
					2.5/				
^{190m}W			0.3 ms						
^{190}W		189.9632	30. m	β^-/1.3	0.95/	0+			Re k x-ray
									0.1576
									0.1621
$_{75}$Re		186.207(1)							
^{160}Re		159.981	0.7 ms	p/	1.261(6)/91				
				α/	6.54/				
^{161}Re		160.978	14 ms	α/	6.24				
				p	1.35				
^{162}Re		161.9757	0.10 s	α/	6.12/94				
					6.09/94				
^{163}Re		162.9721	0.26 s	β^+,EC/9.0	α/5.87/32				
				α/	5.92/66				
^{164}Re		163.9704	0.9 s	β^+,EC/10.7					
				α/	5.78/				
^{165}Re		164.9671	2. s	β^+,EC/87/8.1					
				α/	5.51/				
^{166}Re		165.9651	2.5 s	β^+,EC/9.4					
				α/	5.50/				
^{167m}Re			6.2 s	α, EC/					
^{167}Re		166.9626	3.4 s	β^+,EC/7.4					
				α/	5.015/				
^{168}Re		167.9616	4.4 s	β^+,EC/9.1					
				α/	4.833/				0.1117
^{169m}Re			8.1 s	α	4.70/				
					4.87/				
^{169}Re		168.9588	16. s						
^{170}Re		169.9582	9.2 s	β^+, EC/9.0					0.1560
									0.3055
									0.4125
^{171}Re		170.9555	15.2 s	EC/≈ 5.7					
^{172m}Re			55. s	β^+,EC/		(2)			ann.rad./
									0.1234
									0.2537
									0.3504
^{172}Re		171.9553	15. s	β^+,EC/7.3					ann.rad./
									0.1234
									0.2537
^{173}Re		172.9531	2.0 m	EC/≈3.9					ann.rad./

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{174}Re		173.9521	2.4 m	β^+,EC/5.6					ann.rad./
									0.1119
									0.2430
^{175}Re		174.9514	5.8 m	β^+,EC/4.3					ann.rad./
^{176}Re		175.9516	5.3 m	β^+,EC/5.6		(3+)			ann.rad./
									0.1089
									0.2406
^{177}Re		176.9503	14. m	EC/78/3.4		(5/2-)			ann.rad./
				β^+/22/					W k x-ray
									0.0797
									0.0843
									0.1968
^{178}Re		177.9509	13.2 m	β^+/11/4.7	3.3/	(3)			ann.rad./
				EC/89/					W k x-ray
									0.1059
									0.2373
									0.9391
^{179}Re		178.9500	19.7 m	EC/99/2.71	0.95/	(5/2+)	2.8		W k x-ray
				β^+/1/					0.1199
									0.2900
									0.4154
									0.4302
									1.6803
^{180}Re		179.95079	2.45 m	EC/92/3.80	1.76/	1-	1.6		ann.rad./
				β^+/8/					W k x-ray
									0.1036
									0.9028
									(0.07 - 2.2)
^{181}Re		180.95006	20. h	EC/1.74		5/2+	3.19		W k x-ray
									0.3607
									0.3655
									0.6390
^{182m}Re			12.7 h	EC/	0.55/	2+	3.3	+1.8	W k x-ray
					1.74/				0.0677
									1.1214
									1.2215
									(0.06 - 2.2)
^{182}Re		181.9512	2.67 d	EC/2.8		(7+)	2.8	+4.1	W k x-ray
									0.0678
									0.2293
									1.1213
									1.2214
^{183}Re		182.95082	70. d	EC/0.56		(5/2+)	+3.17	+2.3	W k x-ray
									0.16232
^{184m}Re			165. d	I.T./75/0.188		8+	+2.9		Re k x-ray
				EC/25/					0.1047
									0.2165
									0.92093
									(0.10 - 1.1)
^{184}Re		183.95252	38. d	EC/1.48		3-	+2.53	+2.8	W k x-ray
									0.79207
									0.90328
									(0.1 - 1.4)
^{185}Re	37.40(2)	184.952955				5/2+	+3.1871	+2.18	
^{186m}Re			2.0x10^5 y	I.T./0.150		8+			Re k x-ray
									0.0590
^{186}Re		185.954986	3.718 d	β^-/92/1.070	0.973/21	1-	+1.739	+0.62	W k x-ray
				EC/8/0.582	1.07/71				0.1227/0.6
									0.1372/9.5

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									(0.63-0.77)
^{187}Re	62.60(2)	186.955751	4.4x10^{10} y	β$^-$/0.00266	0.0025/	5/2+	+3.2197		+2.07
^{188m}Re			18.6 m	I.T./0.172		(6-)			Re k x-ray
									0.0925
									0.1059
^{188}Re		187.958112	16.94 h	β$^-$/2.120	1.962/20	1-	+1.788	+0.57	Os k x-ray
					2.118/79				0.15502
									0.309-2.022
^{189}Re		188.959228	24. h	β$^-$/1.01	1.01/	(5/2+)			0.1471
									0.2167
									0.2194
									0.2451
^{190m}Re			3.0 h	β$^-$/51/		(6-)			Re k x-ray
				I.T./49/					0.1191
									0.2238
									0.6731
									(0.1 - 1.79)
^{190}Re		189.9618	3.0 m	β$^-$/3.2	1.8/	(2-)			Os k x-ray
									0.1867
									0.5580
									0.6051
^{191}Re		190.96312	9.7 m	β$^-$/2.05	1.8/				
^{192}Re		191.9660	16. s	β$^-$/4.2	≈ 2.5/				(0.2-0.75)
$_{76}$Os		190.23(3)							
^{162}Os		161.984	1.8 ms	α/	6.60				
^{163}Os		162.982	5.5 ms	α/	6.51				
^{164}Os		163.9779	0.04 s	α					
^{165}Os		164.9765	0.07 s	α					
^{166}Os		165.9718	0.18 s	β$^+$,EC/28/6.3	6.27/	0+			ann. rad./
				α/72/	5.98/				
^{167}Os		166.9714	0.7 s	β$^+$,EC/76/8.2					ann.rad./
				α/24/	5.84/				
^{168}Os		167.96775	2.2 s	β$^+$,EC/51/5.7		0+			ann. rad./
				α/49/					
^{169}Os		168.9671	3.3 s	β$^+$,EC/89/7.7	5.57/80				ann.rad./
				α/13/	5.51/12				
					5.54/8				
^{170}Os		169.96357	7.1 s	β$^+$,EC/5.0		0+			ann.rad./
				α/	5.40/				(0.162-0.216)
^{171}Os		170.9630	8.4 s	β$^+$,EC/98/7.1	α/5.24/93.5				ann.rad./
				α/19/	5.17/6.5				0.190-0.705
^{172}Os		171.9601	19. s	β$^+$,EC/99/4.5		0+			ann.rad./
				α/1.1/	5.10/				(0.063-1.120)
^{173}Os		172.9598	16. s	β$^+$,EC/6.3					ann.rad./
				α/0.4/	4.94/				0.142-0.299
^{174}Os		173.9563	44. s	β$^+$,EC/3.9		0+			0.118
				α/0.02/	4.76/				0.138/ 0.001
									0.158
									0.325
^{175}Os		174.9570	1.4 m	β$^+$,EC/5.3					0.125
									0.181
									0.248
^{176}Os		175.9550	3.6 m	β$^+$,EC/3.2		0+			0.8155
									0.7758
									0.8573
									1.2093
									1.2909
^{177}Os		176.9551	2.8 m	β$^+$,EC/4.5		(1/2-)			0.0848
									0.1958

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									0.3002
									1.2686
^{178}Os		177.9534	5.0 m	β^+,EC/2.3		0+			ann.rad./
									0.5946
									0.6850
									0.9687
									1.3311
^{179}Os		178.9539	7. m	β^+,EC/3.7					ann.rad./
									0.0654
									0.2186
									0.5938
^{180}Os		179.9524	21.5 m	β^+,EC/1.5		0+			Re k x-ray
									0.0202-0.7174
^{181m}Os			1.75 h	EC/		(1/2-)			ann.rad./
									0.0489
^{181}Os		180.9532	2.7 m	EC/2.9		(7/2-)			ann.rad./
									0.11794
									0.23868
									0.8267
									(0.07 - 2.64)
^{182}Os		181.95219	21.5 h	EC/0.9		0+			Re k x-ray
									0.1802
									0.5100
^{183m}Os			9.9 h	EC/84/		1/2-			Os k x-ray
				I.T./16/					Re k x-ray
									1.1020
									1.1080
^{183}Os		182.9531	13. h	EC/2.1		9/2+	-0.79	+3.1	Re k x-ray
									0.1144
									0.3818
^{184}Os	0.020(3)	183.952491				0+			
^{185}Os		184.954043	93.6 d	EC/1.013		1/2-			Re k x-ray
									0.6461
									0.8748
									0.8805
^{186}Os	1.58(10)	185.953838	2.x10^{15} y	α/	≈ 2.75/	0+			
^{187}Os	1.6(1)	186.955748				1/2-	+0.06465 19		
^{188}Os	13.3(2)	187.955836				0+			
^{189m}Os			5.8 h	I.T./0.0308		9/2-			Os L x-ray
									0.0308
^{189}Os	16.1(3)	188.958145				3/2+	+0.65993	+0.86	
^{190m}Os			9.9 m	I.T./1.705		10-	-0.6		Os k x-ray
									0.1867
									0.3611
									0.5026
									0.6161
^{190}Os	26.4(4)	189.958445				0+			
^{191m}Os			13.1 h	I.T./0.0744		3/2-			Os k x-ray
									0.0744
^{191}Os		190.960928	15.4 d	β^-/0.314	0.140/100	9/2-		+2.5	Ir k x-ray
									0.1294
^{192m}Os			6.0 s	I.T./2.0154		(10-)			Os k x-ray
									0.2058/65.9
									0.5692/70
									(0.201-1.000)
^{192}Os	41.0(3)	191.961479				0+			
^{193}Os		192.964148	30.5 h	β^-/1.141	1.04/20	3/2-	+0.730	+0.47	Ir k x-ray
									0.1389

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.4605
^{194}Os		193.965179	6.0 y	β^-/0.097	0.054/33	0+			Ir L x-ray
					0.096/67				0.0429
^{195}Os		194.9681	6.5 m	β^-/2.0	2.0/				
^{196}Os		195.96962	34.9 m	β^-/1.16	0.84/	0+			0.1262/5
									0.4079/5.9
$_{77}$Ir		192.217(3)							
^{164}Ir									
^{165}Ir		164.9876	0.3 ms	p/87	1.71				
				α/13	6.72				
^{166m}Ir			15 ms	α/98.2	6.56				
				p/1.8	1.32				
^{166}Ir		165.9855	≈ 11 ms	α/93	6.56				
				p/6.9	1.15				
^{167m}Ir			30 ms	α/48,β^+	6.41/80				
				p/32	1.24/0.4				
^{167}Ir		166.9817	35. ms	α/80,β^+	6.35/48				
				p/0.4	1.04/32				
^{168}Ir		167.9799	0.16 s	α/82					
^{169m}Ir			0.3 s	α/	6.11/84				
^{169}Ir		168.9764	0.6 s	α/	6.00/50				
^{170}Ir		169.9743	1.0 s	α/	6.03/				
^{171}Ir		170.9718	1.5 s	α/	5.91/				
^{172}Ir		171.9706	2.1 s	α/	5.811/				0.228
									(0.379-0.475)
^{173}Ir		172.9677	3.0 s	α/	5.665/				0.0493
									(0.092-0.296)
^{174}Ir		173.9668	4. s	α/	5.478/				0.1587
									(0.276-1.33)
^{175}Ir		174.9641	≈ 4.5 s	α/	5.393/				0.1056
^{176}Ir		175.9635	8. s	EC, β^+/80					0.260
				α/3.2/	5.118/				(0.135-0.415)
^{177}Ir		176.9612	30. s	EC, β^+/5.7					0.184
				α/0.06/	5.011/				(0.062-0.194)
^{178}Ir		177.9601	12. s	β^+,EC/6.3					
									0.1320
									0.2667
									0.3633
^{179}Ir		178.9592	4. m	EC/4.9					0.0975
									(0.045-0.220)
^{180}Ir		179.9593	1.5 m	EC/6.4					0.2765
									((0.132-1.106)
^{181}Ir		180.9576	4.9 m	β^+,EC/4.1		(7/2+)			ann.rad./
									0.1076
									(0.0196-1.715)
^{182}Ir		181.9582	15. m	β^+/44/5.6					ann.rad./
				EC/56/					Os k x-ray
									0.1273
									0.2370
^{183}Ir		182.9568	57. m	β^+,EC/3.5					ann.rad./
									0.0877
									0.2285
									0.2824
^{184}Ir		183.9574	3.0 h	β^+/12/4.6	2.3/	5-	0.70	+2.41	ann.rad./
				EC/88/	2.9/				Os k x-ray
									0.11968
									0.2640
									0.3904
^{185}Ir		184.9566	14. h	β^+/3/2.4		(5/2-)	2.60	-2.1	ann.rad./

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				EC/97/					Os k x-ray
									0.2543
									1.8288
^{186m}Ir			1.7 h	EC/		(2-)	0.64	+1.46	Os k x-ray
									0.1371
									0.7675
^{186}Ir		185.95795	15.7 h	EC/98/3.83		(5+)	3.9	-2.55	Os k x-ray
				β^+/2/					0.1372
									0.2968
									0.4348
									(0.13 - 3.0)
^{187}Ir		186.95736	10.5 h	EC/1.50		3/2+		+0.94	Os k x-ray
									0.0743
									0.4009
									0.4271
									0.6109
									0.9128
^{188}Ir		187.95885	1.72 d	β^+/2.81	1.13/	(2-)	0.30	+0.48	Os k x-ray
				EC/99+/	1.64/				0.1550
									0.4780
									0.6330
									2.2146
^{189}Ir		188.95872	13.2 d	EC/0.53		3/2+	0.13	+0.88	Os k x-ray
									0.2449
^{190m2}Ir			3.09 h	β^+,EC/95/		(11-)			0.376
				I.T./5/					
^{190m1}Ir			1.12 h	I.T./0.0263		7+			Ir L x-ray
^{190}Ir		189.9606	11.8 d	EC/2.0		(4+)	0.04	+2.8	Os k x-ray
									0.1867
									0.4072
									0.5186
									0.5580
									0.6051
									(0.2 - 1.4)
^{191m}Ir			4.93 s	I.T./0.1714		11/2-	+0.603		Ir k x-ray
									0.1294
^{191}Ir	37.3(5)	190.960591				3/2+	+0.151	+0.82	
^{192m2}Ir			241. y	I.T./0.161		(9+)			Ir k x-ray
^{192m1}Ir			1.44 m	I.T./0.0580		(1+)			Ir L x-ray
									0.0580
									0.3165
^{192}Ir		191.962602	73.83 d	β^-/1.460		(4-)	+1.92	+2.15	Pt k x-ray
									0.31649/83.
									0.46806/48.
^{193m}Ir			10.53 d	I.T./0.0802		11/2-			Ir L x-ray
									0.0803
^{193}Ir	62.7(5)	192.962923				3/2+	+0.164	+0.75	
^{194m}Ir			170. d	β^-/		11			Pt k x-ray
									0.3284
									0.4829
									0.5624
^{194}Ir		193.965075	19.3 h	β^-/2.247	1.92/9	1-	+0.39	+0.34	0.2935
					2.25/86				0.3284
									0.6451
									(0.1 - 2.2)
^{195m}Ir			3.9 h	β^-/	0.41/	(11/2-)			Pt k x-ray
					0.97/				0.3199/9.6
									0.3649/9.5
									0.4329/9.6

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.6849/9.6
^{195}Ir		194.965976	2.8 h	β^-/1.120	1.0/80	(3/2+)			Pt k x-ray
					1.11/13				0.0989/9.7
^{196m}Ir			1.40 h	β^-/	1.16/				Pt k x-ray
									0.3557
									0.3935
									0.4471
									0.5214
									0.6473
^{196}Ir		195.96838	52.s	β^-/3.21	2.1/15	0-			0.3329
					3.2/80				0.3557
									0.7796
^{197m}Ir			8.9 m	β^-/		(11/2-)			0.3465
				I.T./					See Ir[197]
^{197}Ir		196.96964	5.8 m	β^-/2.16	1.5/	(3/2+)			0.0531
					2.0/				0.1351
									0.4306
									0.4697
^{198}Ir		197.9723	8. s	β^-/4.1					0.4074
									0.5070
^{199}Ir		198.97378							
$_{78}$Pt		195.078(2)							
^{166}Pt			0.3 ms	α/	7.11/				
^{167}Pt			0.7 ms	α/	6.99/				
^{168}Pt		167.9880	2.0 ms	α	6.83				0.582/69
									0.594/69
									0.725/62
^{169}Pt		168.9864	3. ms	α					
^{170}Pt		169.9816	14 ms	α	6.55				0.509/100
									0.662/86
									0.214-0.726
^{171}Pt		170.9811	0.03 s	α					
^{172}Pt		171.97730	0.10 s	α/	6.31/94	0+			
^{173}Pt		172.9765	0.34 s	β^+,EC/8.2					
				α/	6.20/				
^{174}Pt		173.97281	0.89 s	β^+,EC/17/5.6		0+			
				α/83/	6.040/				
^{175}Pt		174.9723	2.5 s	β^+,EC/65/7.6					0.0774
				α/35/	5.831/5				0.1354
					5.96/54				0.2128
					6.038/				
^{176}Pt		175.9690	6.3 s	β^+,EC/60/5.1		0+			ann.rad./
				α/40/	5.528/0.6				0.2277
					5.750/41				
^{177}Pt		176.9685	11. s	EC/91/6.8	5.53/				0.0908
				α/9/	5.485/3				
					5.525/6				
^{178}Pt		177.9649	21. s	EC/93/4.5		0+			
				α/7/	5.286/0.2				
					5.442/7				
^{179}Pt		178.9653	33. s	β^+,EC/5.7					
				α/	5.16/				
^{180}Pt		179.9632	52. s	β^+,EC/99.7/3.7		0+			
				α/0.3/	5.140/				
^{181}Pt		180.9632	51. s	β^+,EC/5.2					
^{182}Pt		181.9613	2.7 m	β^+,EC/2.9		0+			ann.rad./
									0.1360
									0.1460
									0.2100

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{183m}Pt			43. s	β^+,EC/		(7/2-)	1.0		ann.rad./
				I.T./					0.3132/26
									0.3164/59
									0.6296/100
									0.058-1.75
^{183}Pt		182.9617	7. m	β^+,EC/4.6			+0.51		ann.rad./
									0.119/100
									0.307/93
									0.260/90
									0.058-1.377
^{184}Pt		183.9599	17.3 m	β^+,EC/2.3					ann.rad./
									0.1549
									0.1919
									0.5484
^{185m}Pt			33. m	β^+,EC/		1/2-	+0.54		
^{185}Pt		184.9607	1.18 h	β^+,EC/3.8		(9/2+)	-0.80	+4.5	ann.rad./
									0.1353
									0.1974
									0.2296
									0.2551
^{186}Pt		185.95943	2.0 h	β^+,EC/1.38		0+			ann.rad./
									0.6115
									0.6892
^{187}Pt		186.9607	2.35 h	β^+,EC/3.1		3/2	-0.41	-1.2	ann.rad./
									Ir k x-ray
									0.1064
									0.1100
									0.2015
									0.2849
									0.7092
^{188}Pt		187.95940	10.2 d	EC/0.51		0+			Ir k x-ray
									0.1876
									0.1951
^{189}Pt		188.96083	10.9 h	β^+,EC/1.97		3/2-	0.43	-1.1	Ir k x-ray
									0.0943
									0.6076
									0.7214
									(0.09 - 1.47)
^{190}Pt	0.01(1)	189.95993	$4.5x10^{11}$ y			0+			
^{191}Pt		190.961684	2.96 d	EC/1.02		(3/2-)	0.50	-0.9	Ir k x-ray
									0.3599
									0.4094
									0.5389
^{192}Pt	0.79(6)	191.961035				0+			
^{193m}Pt			4.33 d	I.T./0.1498		13/2+	-0.75		Pt k x-ray
									0.1355
^{193}Pt		192.962984	60. y	EC/0.0566		(1/2-)	+0.60		Ir k x-rays
^{194}Pt	32.9(6)	193.962663				0+			
^{195m}Pt			4.02 d	I.T./0.2952		13/2+	-0.61	+1.4	Pt k x-ray
									0.0989
^{195}Pt	33.8(6)	194.964774				1/2-	+0.6095		
^{196}Pt	25.3(6)	195.964934				0+			
^{197m}Pt			1.590 h	I.T./97/		13/2+			Pt k x-ray
				β^-/3/					0.0530
									0.3465
^{197}Pt		196.967323	18.3 h	β^-/0.719		1/2-	0.51		Au k x-ray
									0.1914
									0.2688
^{198}Pt	7.2(2)	197.967875				0+			

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{199m}Pt			13.6 s	I.T./0.424		13/2+			Pt k x-ray
									0.3919
^{199}Pt		198.970576	30.8 m	β^-/1.70	0.90/18	(5/2-)			0.3170/4.9
					1.14/14				0.49375/5.7
									0.5430/14.8
									(0.055-1.293)
^{200}Pt		199.97142	12.5 h	β^-/≈0.66		0+			Au k x-ray
									0.13590
									0.22747
									0.24371
^{201}Pt		200.9745	2.5 m	β^-/2.66		(5/2-)			0.070
									0.152
									0.222
									1.760
^{202}Pt		201.9757	1.8 d						0.440
$_{79}$Au		196.96655(2)							
^{171}Au		170.9918	1.0 ms	p/46	1.44/100				
				α/54	7.00				
^{172}Au		171.9901	4 ms	α/7.02	6.86				
^{173m}Au			12 ms	α/92	6.732				
^{173}Au		172.9864	0.020 s	α/94	6.672				
^{174}Au		173.9842	0.12 s	α					
^{175}Au		174.9817	0.20 s	α					
^{176}Au		175.9803	1.2 s	β^+,EC/10.5					
				α/	6.260/80				
					6.290/20				
^{177}Au		176.9772	1.2 s	α/	6.115/				
					6.150/				
^{178}Au		177.9760	2.6 s	α/	5.920/				
^{179}Au		178.9732	7.5 s	α/	5.85/				
^{180}Au		179.9724	8.1 s	EC/8.6	5.65				0.1522
				α/	5.61				0.2564
					5.50				0.5242
									0.6765
									0.8084
									0.8597
^{181}Au		180.9700	11.4 s	EC/97.5/6.3	5.482/				
				α/2.7/					
^{182}Au		181.9686	21. s	β^+,EC/6.9					ann.rad./
				α/0.13/					0.1549
									0.2649
									(0.13 - 1.4)
^{183}Au		182.9676	42. s	EC/5.5			+1.97		0.1630
				α/0.8/					0.2730
									0.3625
^{184m}Au			48 s			(2+)	+1.44	+1.9	0.069(IT)
^{184}Au		183.9675	21. s	EC,β^+/7.1		(5+)	+2.07	+4.7	
				α/0.013/					
^{185m}Au			6.8 m	β^+,EC/					
				I.T./0.145					
^{185}Au		184.9657	4.3 m	β^+,EC/4.71		(5/2-)	+2.17	-1.1	ann.rad./
				α/0.26/					
^{186m}Au			< 2. m	β^+,EC/					0.1915
^{186}Au		185.9659	10.7 m	β^+,EC/6.0		3-	-1.26	+3.1	ann.rad./
				α/8(10)$^{-4}$/					0.1915
									0.2988
^{187m}Au			2.3 s	IT		9/2-			
^{187}Au		186.9646	8.3 m	β^+,EC/3.60		1/2+	+0.54		ann.rad./
									0.9152

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									1.2668
									1.3321
									1.4081
^{188}Au		187.9651	8.8 m	β$^+$,EC/5.3		(1-)	-0.07		ann.rad./
									0.2660
									0.3404
									0.6061
^{189m}Au			4.6 m	β$^+$,EC/		11/2-	+6.19		0.1667
^{189}Au		188.9642	28.7 m	EC/96/3.2		1/2+	+0.49		ann.rad./
				β$^+$/4/					Pt k x-ray
									0.4478
									0.7133
									0.8128
^{190}Au		189.96470	43. m	β$^+$/2/4.44		1-	-0.07		ann.rad./
				EC/98/					Pt k x-ray
									0.2958
									0.3018
									0.5977
^{191m}Au			0.9 s	I.T./0.2663		11/2-	6.6		Au k x-ray
									0.2414
									0.2526
^{191}Au		190.96365	3.2 h	EC/1.83		3/2+	+0.137	+0.72	Pt k x-ray
									0.5864/16
									(0.088-1.30)
^{192}Au		191.96481	4.9 h	β$^+$/5/3.52	2.19/	1-	-0.011	-0.23	ann.rad./
				EC/95/	2.49/				Pt k x-ray
									0.2959
									0.3165
^{193m}Au			3.9 s	I.T./0.2901		11/2-	6.2	+1.98	Au k x-ray
									0.2580
^{193}Au		192.96413	17.6 h	EC/1.07		3/2+	+0.140	+0.66	Pt k x-ray
									0.1862
									0.2556
^{194}Au		193.96534	1.64 d	β$^+$/3/2.49	1.49/	1-	+0.076	-0.24	ann.rad./
				EC/97/					Pt k x-ray
									0.2935
									0.3284/61
^{195m}Au			30.5 s	I.T./0.3186		11/2-	6.2	+1.9	Au k x-ray
									0.2617
^{195}Au		194.965017	186.12 d	EC/0.227		3/2+	+0.149	+0.61	Pt k x-ray
^{196m2}Au			9.7 h	I.T./0.5954		12-	5.7		Au k x-ray
									0.1478
									0.1883
^{196m1}Au			8.1 s	I.T./0.0846		8+			0.0847
^{196}Au		195.966551	6.18 d	EC/92/1.506		2-	+0.591	0.81	Pt k x-ray
^{197m}Au			7.8 s	I.T./0.4094		11/2-	+6.0	+1.7	Au k x-ray
				β$^-$/8/0.686					0.1302
									0.2790
^{197}Au	100.	196.966551				3/2+	+0.14575	+0.55	
^{198m}Au			2.30 d	I.T./0.812		(12-)			Au k x-ray
									0.0972
									0.1803
									0.2419
^{198}Au		197.968225	2.694 d	β$^-$/1.372	0.290/1	2-	+0.5934	+0.64	Hg k x-ray
					0.961/99				0.411794
^{199}Au		198.968748	3.14 d	β$^-$/0.453	0.25/22	3/2+	+0.2715	+0.51	Hg k x-ray
					0.292/72				0.15837
					0.462/6				0.20820
^{200m}Au			18.7 h	β$^-$/84/1.0	0.56/	12-	5.9		Au k x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				I.T./16/					0.2559/71
									0.3680/77
									0.4978/73
									0.5793/72
									0.084-0.904)
^{200}Au		199.97072	48.4 m	β^-/2.24	0.7/15	1-			0.3679/19
					2.2/77				1.2254/10.6
									(0.077-1.570)
^{201}Au		200.97165	26. m	β^-/1.28	1.27/82	3/2+			(0.027-0.732)
^{202}Au		201.9738	29. s	β^-/3.0		(1-)			0.4396
^{203}Au		202.97515	1.0 m	β^-/2.14	≈ 1.9/	3/2+			(0.04-0.37)
^{204}Au		203.9783	40. s	β^-/4.5		(2-)			0.4366
									1.5113
^{205}Au		204.9796	31. s	β^-/					(0.38 - 1.33)
$_{80}$Hg		200.59(2)							
^{172}Hg			≈0.25 ms	α	7.35				
^{173}Hg			0.9 ms	α	7.21				
^{174}Hg			1.9 ms	α	7.07				
^{175}Hg		174.9912	0.02 s	α					
^{176}Hg		175.98733	21 ms	α	6.74/94				
^{177}Hg		176.9863	0.13 s	α					
^{178}Hg		177.98248	0.26 s	EC/50/6.1		0+			
				α/50/	6.43/				
^{179}Hg		178.9818	1.09 s	EC/8.0					
				α/	6.29/				
^{180}Hg		179.9783	2.6 s	EC/5.5		0+			0.1250
				α/	6.12/33				0.3005
					5.69/.03				0.3812
^{181}Hg		180.9778	3.6 s	β^+ EC/74/≈7.3		(1/2-)	+0.507		0.0663
				α/26/					0.0811
									0.0924
									0.1474
									0.1587
									0.2142
									0.2398
^{182}Hg		181.9739	10.8 s	β^+,EC/85/5.0		0+			0.1289
				α/15/	5.87/8.6				0.2168
					5.45/0.03				0.4126
^{183}Hg		182.9744	9. s	β^+,EC/77/6.3		1/2-	+0.524		0.0714
				α/	5.83/				0.0874
					5.91/				0.1538
^{184}Hg		183.9719	30.9 s	β^+,EC/99/4.1		0+			0.0915
				α/1/	5.54/1.3				0.1265
					5.07/2 x 10^{-3}				0.1560
									0.2362
^{185m}Hg			21. s	β^+,EC,IT,α/	5.37/	13/2+	-1.02	+0.2	0.211
									0.292
^{185}Hg		184.9720	51. s	β^+,EC/95/5.8		1/2-	+0.509		(0.02 - 0.55)
^{186}Hg		185.9695	1.4 m	β^+,EC/3.3		0+			0.1119
				α	5.09/0.02				0.2518
^{187m}Hg			1.7 m	β^+,EC/		13/2+	-1.04	+0.5	See Hg[187]
^{187}Hg		186.9698	2.4 m	β^+,EC/4.9		3/2-	-0.594	-0.8	0.1034/32.
									0.2334/100.
									0.2403/33.
									0.27151/31.
									0.3763/38.
									0.5254/30.
									(0.10-2.18)
^{188}Hg		187.9676	3.2 m	β^+,EC/2.3		0+			0.0988

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				α	4.61				0.1148
									0.1424
									0.1900
^{189m}Hg			8.6 m	EC/		13/2+	-1.06	+0.7	0.0780
									0.3210
									0.4345
									0.5655
									(0.08 - 2.170)
^{189}Hg		188.9687	7.6 m	EC/4.2		3/2-	-0.6086	-0.8	0.2005
									0.2038
									0.2386
									0.2485
^{190}Hg		189.9663	20.0 m	EC/1.5		0+			0.1296
									0.1426
^{191m}Hg			51. m	β^+/6/		13/2+	-1.07	+0.6	ann.rad./
				EC/94/					Au k x-ray
									0.2741
									0.4203
									0.5787
									(0.07 - 1.9)
^{191}Hg		190.9671	50. m	β^+,EC/3.2		(3/2-)	-0.62	-0.8	0.1963
									0.2247
									0.2524
^{192}Hg		191.9653	5.0 h	EC/≈0.5		0+			Au k x-ray
									0.1572
									0.2748
									0.3065
^{193m}Hg			11.8 h	β^+,EC/91/		13/2+	-1.05843	+0.92	Hg k x-ray
				I.T./9/0.2901					0.1866
									0.2580
									0.4076
									0.5733
									0.9324
									(0.1 - 1.96)
^{193}Hg		192.96664	3.8 h	EC,B$^+$/2.34		3/2-	-0.6276	-0.7	0.1866
									0.2580
									0.8611
^{194}Hg		193.96538	520. y	EC/0.04		0+			Au L x-rays
^{195m}Hg			1.67 d	I.T./(54)/0.3186		13/2+	-1.04465	+1.1	Hg k x-ray
				EC/(46)/					Au k x-ray
									0.2617
									0.5603
									0.7798
^{195}Hg		194.96664	9.5 h	EC/1.51		1/2-	+0.54147 5		Au k x-ray
									0.0614
									0.7798
^{196}Hg	0.15(1)	195.965814				0+			
^{197m}Hg			23.8 h	I.T./(93)/0.2989		13/2+	-1.02768	+1.2	Hg k x-ray
									Au k x-ray
									0.13398
^{197}Hg		196.967195	2.672 d	EC/0.600		1/2-	+0.52737 4		Au k x-ray
									0.07735
^{198}Hg	9.97(8)	197.966752				0+			
^{199m}Hg			42.6 m	I.T./0.532		13/2+	-1.014703	+1.2	Hg k x-ray
									0.15841
^{199}Hg	16.87(10)	198.968262				1/2-	+0.50588 5		

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{200}Hg	23.10(16)	199.968309				0+			
^{201}Hg	13.18(8)	200.970285				3/2-	-0.560226	+0.39	
^{202}Hg	29.86(20)	201.970625				0+			
^{203}Hg		202.972857	46.61 d	β^-/0.492	0.213/100	5/2-	+0.8489	+0.34	Tl k x-ray
									0.279188
^{204}Hg	6.87(4)	203.973475				0+			
^{205}Hg		204.976056	5.2 m	β^-/1.531	1.33/4	1/2-	+0.6010		0.20378
									(0.2 - 1.4)
^{206}Hg		205.97750	8.2 m	β^-/1.31	0.935/34	0+			Tl k x-ray
					1.3/63				0.3052
									0.6502
^{207}Hg		206.9825	2.9 m	β^-/4.8		(9/2+)			
^{208}Hg		207.9859	0.7 h	β^-					0.474
$_{81}$Tl		204.3833(2)							
^{177m}Tl			0.23 ms	p/51					
				α/49					
^{177}Tl		176,9969	0.017 s	α/73					
				P/27					
^{178}Tl		177.9952	≈0.2 s						
^{179m}Tl			1.7 ms	α	/7.21/80				
				α	/7.10/20				
^{179}Tl		178.9917	0.2 s	α					
^{180}Tl		179.9912	1.5 s	α	6.28/30				
					6.36/30				
					6.21/18				
					6.56/15				
					6.47/7				
^{181m}Tl			1.4 ms	α	6.58/100				
^{181}Tl		180.9869	3.2 ms	α	6.19/100				
^{182}Tl		181.9856	3. s	β^+, EC/10.9					0.351
									(0.26 - 0.41)
^{183m}Tl			0.06 s	α		9/2-			
^{183}Tl		182.9826	5. s	β^+, EC/7.7		1/2+			0.208
^{184}Tl		183.9818	11. s	β^+, EC/(98)/9.2					0.2868
				α/(2)/	6.16/				0.3399
									0.3667
^{185m}Tl			1.8 s	I.T./0.453		(9/2-)			0.1688
				α/5.97	6.01				0.2840
^{185}Tl		184.9791	20. s	EC/β^+/6.6					
^{186m}Tl			4. s	I.T./0.374					0.3738
^{186}Tl		185.9776	28. s	β^+,EC/7.5					0.3567
									0.4026
									0.4053
^{187m}Tl			15.6 s	I.T./≈ 0.33		(9/2+)	+3.8	-2.4	0.2995
^{187}Tl		186.9762	50. s	β^+,EC/6.0		1/2+	1.6		
^{188m}Tl			1.18 m	β^+,EC/		(7+)			Hg k x-ray
									0.4129
									0.5043
									0.5921
^{188}Tl		187.9759	1.2 m	β^+,EC/7.8		(2-)	+0.48	+0.13	See Tl[188m]
									0.4129
^{189m}Tl			1.4 m	β^+,EC/		(9/2-)	+3.878	-2.29	0.2156
									0.2284
									0.3175
									0.4452
^{189}Tl		188.9743	2.3 m	β^+,EC/5.2		(1/2+)			0.3337
									0.4510
									0.5223
									0.9422

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{190m}Tl			3.7 m	β⁺,EC/	4.2/	(7+)	+0.495	+0.29	0.1968
									0.4164
									0.7311
^{190}Tl		189.9738	2.6 m	β⁺,EC/7.0	5.7/	(2-)	+0.25	-0.33	0.4164
									0.6254
									0.6838
									1.0999
^{191m}Tl			5.2 m	β⁺,EC/(98)/		(9/2+)	+3.903	-2.3	0.2157
									0.2647
									0.3256
									0.3359
^{191}Tl		190.9723				(1/2)	1.59		
^{192m}Tl			10.8 m	β⁺,EC/		(7+)	+0.518	0.46	0.1740
									0.4228
									0.6348
									0.7863
									0.7455
^{192}Tl		191.972	9.6 m	β⁺,EC/6.4		(2-)	+0.20	-0.33	0.3975
									0.4228
									0.6908
^{193m}Tl			2.1 m	I.T./(75)/		(9/2-)	+3.948	-2.2	0.3650
^{193}Tl		192.9706	22. m	β⁺,EC/3.6		(1/2+)	+1.591		0.2077
									0.3244
									0.3440
									0.6761
									1.0447
									1.5793
^{194m}Tl			32.8 m	β⁺/(20)/≈0.30		(7+)	+0.540	+0.61	ann.rad./
				EC/(80)/					Hg k x-ray
									0.4282
									0.6363
									0.7490
^{194}Tl		193.9711	34. m	β⁺,EC/5.3		2-	0.140	-0.28	0.3955
									0.4282
									0.6363
^{195m}Tl			3.6 s	I.T./0.483		9/2-			Tl k x-ray
									0.0990
									0.3836
^{195}Tl		194.9697	1.16 h	EC/97/2.8		1/2+	+1.58		ann.rad./
				β⁺/(3)/					Hg k x-ray
									0.2422
									0.5635
									0.8845
									1.3639
									(0.13 - 2.5)
^{196m}Tl			1.41 h	β⁺,EC/95/4.9		(7+)	0.55	+0.76	0.0840
									0.4261
									0.6353
									0.6954
									(0.08 - 1.0)
^{196}Tl		195.9705	1.84 h	β⁺/(15)/4.4		2-	+0.072	-0.18	ann.rad./
				EC/(85)/					Hg k x-ray
									0.4257
									0.6105
									(0.03 - 2.4)
^{197m}Tl			0.54 s	IT/53/0.608		9/2-			Tl k x-ray
				β⁺,EC/47/					0.2262
									0.4118
									0.5872

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.6367
^{197}Tl		196.96954	2.83 h	β^+/(1)/2.18		1/2+	+1.58		Hg k x-ray
				EC/(99)/					0.1522/8.2
									0.4258
^{198m}Tl			1.87 h	β^+,EC/(53)/		7+	+0.64		Hg k x-ray
				IT/47/0.5347					Tl k x-ray
									0.4118
									0.5872
									0.6367
^{198}Tl		197.9405	5.3 h	EC,β^+/(1)/3.5	1.4/	2-			Hg k x-ray
					2.1/				0.4118
					2.4/				0.6367
									0.6759
									(0.23 - 2.8)
^{199}Tl		198.9698	7.4 h	EC/1.4		1/2-	+1.60		Hg k x-ray
									0.2082
									0.2473
									0.4555
^{200}Tl		199.97095	1.087 d	EC/2.46	1.07/	2-	0.04		Hg k x-ray
					1.44/				0.36799
									1.2057
									(0.11 - 2.3)
^{201}Tl		200.97080	3.040 d	EC/0.48		1/2+	+1.605		Hg k x-ray
									0.13528
									0.16740/10.0
^{202}Tl		201.97209	12.23 d	EC/1.36		2-	0.06		Hg k x-ray
									0.43957
^{203}Tl	29.524(14)	202.972329				1/2+	+1.62225 8		
^{204}Tl		203.973848	3.78 y	β^-/97/0.7637	0.763/97	2-	0.09		Hg k x-ray
				EC/(3)/0.347					
^{205}Tl	70.476(14)	204.974412				1/2+	+1.63821 5		
^{206m}Tl			3.76 m	I.T./2.644		12-			Tl k x-ray
									0.2166
									0.2661
									0.4534
									0.6866
									1.0219
^{206}Tl		205.976095	4.20 m	β^-/1.533	1.53/99.9	0-			Pb k x-ray
									0.80313
^{207m}Tl			1.3 s	I.T./1.350		11/2-			Tl k x-ray
									0.3501
									1.0000
^{207}Tl		206.97741	4.77 m	β^-/1.423	1.43/99.8	1/2+	+1.88		0.89723
^{208}Tl		207.982004	3.053 m	β^-/5.001	1.28/23	(5+)	+0.29		Pb k x-ray
					1.52/22				0.27728
					1.796/51				0.51061
									0.58302
									2.61448
^{209}Tl		208.98535	2.16 m	β^-/3.98	1.8 /100	(1/2+)			Pb k x-ray
									1.5670/100
									0.4651/95
									(0.12 - 1.33)
^{210}Tl		209.99006	1.30 m	β^-/5.48	1.3/25	(5+)			Pb k x-ray
					1.9/56				0.081
									0.2981
									0.79788
$_{82}$Pb		207.2(1)							

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/Energy Intensity (MeV/%)
^{178}Pb			≈0.2 ms						
^{180}Pb			5 ms	α/	7.25				
^{181}Pb		180.9967	0.05 s	α/	7.07				
^{182}Pb		181.99268	55 ms	α	6.90				
^{183}Pb		182.9919	0.3 s	α/		1/2+			
^{184}Pb		183.9882	0.48 s	α/	6.63/	0+			
^{185}Pb		184.9876	4.1 s	α/	6.34/				
					6.40/				
					6.48/				
^{186}Pb		185.9835	5. s	β^+,EC/95/5.5		0+			
				α/(5)/	6.32/				
					6.34/<100				
					6.01/<0.2				
^{187m}Pb			15.2 s	β^+,EC/	5.99/	(1/2-)			0.0674
				α/12	6.19/				0.2080
									0.2755
									0.2995
									0.4487
									0.7477
^{187}Pb		186.9839	18.3 s	EC/7.2		13/2+			0.1930
				α/7	6.08/				0.3314
									0.3435
									0.3934
^{188}Pb		187.9811	23. s	EC/(78)/4.8		0+			0.1850
				α/(22)/	5.98/<10				0.7582
					5.61/<0.1				
^{189}Pb		188.9809	51. s	EC/6.1					
				α/	5.58/				
^{190}Pb		189.9782	1.2 m	β^+ (13)/4.1		0+			ann.rad./
				EC/(86)/					Tl k x-ray
				α/(0.9)/	5.58/				0.1415
									0.1512
									0.9422
^{191m}Pb			2.2 m	β^+,EC/		13/2+	-1.17	+0.085	ann.rad./
									0.3871
									0.6135
									0.7122
^{191}Pb		190.9782	1.3 m	β^+,EC/5.5					ann.rad./
									0.9368
^{192}Pb		191.9758	3.5 m	β^+,EC/≈3.4		0+			ann.rad./
				α/.006/	5.11				0.1675
									0.6082
									1.1954
^{193m}Pb			5.8 m	β^+,EC/		13/2+	-1.15	+0.19	ann.rad./
									0.3650
									0.3922
^{193}Pb		192.9761	≈ 2. m	EC/5.2		3/2			
^{194}Pb		193.9740	11. m	β^+,EC/2.7		0+			ann.rad./
				α	4.64				0.2036
^{195m}Pb			15. m	β^+/(8)/		13/2+	-1.132	+0.30	ann.rad./
				EC/(92)/					Tl k x-ray
									0.3836
									0.3942
									0.8784
^{195}Pb		194.976	≈ 15. m	β^+,EC/5.8					ann.rad./
									0.3836
									0.3937
									0.7776
^{196}Pb		195.9727	37. m	β^+,EC/2.1		0+			Tl k x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.2531
									0.5021
^{197m}Pb			43. m	EC/79/		13/2+	-1.104	+0.38	Tl k x-ray
				β^{+}/2/					0.3079
				IT/19/0.3193					0.3877
									0.7743
									(0.2 - 2.2)
^{197}Pb		196.9734	≈ 8. m	EC/97/3.6		(3/2-)	-1.075	-0.08	Tl k x-ray
				β^{+}/3/					0.3755
									0.3858
									0.7611
^{198}Pb		197.9720	2.4 h	EC/1.4		0+			Tl k x-ray
									0.1734
									0.2903
									0.3654
^{199m}Pb			12.2 m	IT/93/0.4248		13/2+			Pb k x-ray
				β^{+},EC/(7)/					0.4255
^{199}Pb		198.9729	1.5 h	EC/(99)/2.9		5/2-	-1.074	+0.08	Tl k x-ray
				β^{+}/(1)/					0.3534
									0.7202
									1.1350
									(0.22 - 2.4)
^{200}Pb		199.97182	21.5 h	EC/0.81		0+			Tl k x-ray
									0.14763
^{201m}Pb			1.02 m	I.T./0.6291		13/2+			Pb k x-ray
									0.6288
^{201}Pb		200.97285	9.33 h	EC/1.90		5/2-	+0.675	-0.009	Tl k x-ray
									0.33120
									0.36131
									(0.11 - 1.8)
^{202m}Pb			3.53 h	IT/90/2.170		9-	-0.228	+0.58	Pb k x-ray
				β^{+}/10/					Tl k x-ray
									0.42219
									0.78700
									0.96271
^{202}Pb		201.97214	5.3x10^{4} y	EC/0.05		0+			Tl L x-ray
^{203m}Pb			6.2 s	I.T./0.8252		13/2+			Pb k x-ray
									0.8203
									0.8252
^{203}Pb		202.97338	2.1615 d	EC/0.98		5/2-	+0.686	+0.10	Tl k x-ray
									0.279188
^{204m}Pb			1.12 h	I.T./2.185		9-			Pb k x-ray
									0.37481
									0.89922
									0.91175
^{204}Pb	1.4(1)	203.973028				0+			
^{205}Pb		204.974467	1.51x10^{7} y	EC/0.0512		5/2-	+0.712	+0.23	Tl L x-ray
^{206}Pb	24.1(1)	205.974449				0+			
^{207m}Pb			0.80 s	I.T./1.632		13/2+			Pb k x-ray
									0.56915
									1.06310
^{207}Pb	22.1(1)	206.975880				1/2-	+0.59258		
^{208}Pb	52.4(1)	207.976636	>2x10^{19} y	SF		0+			
^{209}Pb		208.981075	3.25 h	β^{-}/0.644	0.645/100	9/2+	-1.474	-0.3	
^{210}Pb		209.984174	22.6 y	β^{-}/0.0635	0.017/81	0+			
					0.061/19				
				α	3.72				
^{211}Pb		210.988732	36.1 m	β^{-}/1.37	0.57/5	(9/2+)	-1.404	+0.09	0.40486

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/Energy Intensity (MeV/%)
					1.36/92				0.42700
									0.83186
									(0.09 - 1.27)
^{212}Pb		211.991887	10.64 h	β^-/0.574	0.28/83	0+			Bi k x-ray
					0.57/12				0.23858
^{213}Pb		212.9966	10.2 m	β^-/2.1					
^{214}Pb		213.999797	26.9 m	β^-/1.0	0.67/48	0+			Bi k x-ray
					0.73/42				0.24192
									0.29509
									0.35187
^{215}Pb			36 s						
$_{83}$Bi		208.98038(2)							
^{185}Bi		184.9977	0.04 ms	p/86	1.59				
				α/14					
^{186}Bi		185.9965	10 ms	α	7.16				
					7.26				
^{187m}Bi			≈ 8. ms	α/12					
^{187}Bi		186.9935	32. ms	α/7	7.00/88.3				
					7.61/8.0				
					7.37/3.7				
^{188}Bi		187.9922		α					
^{189m}Bi			7.0 ms	α	7.30				
^{189}Bi		188.9895	0.68 s	α					
^{190}Bi		189.9875	5. s	β^+,EC/(10)/8.7					
				α/(90)/	6.45/				
^{191m}Bi			0.12 ms	α	6.87				
^{191}Bi		190.9861	12. s	β^+,EC/(60)/7.3					
				α/(40)/	6.32/				
^{192}Bi		191.9854	40. s	β^+,EC/(80)/9.0					
				α/(20)/	6.06/				
^{193m}Bi			3.2 s	β^+,EC/		1/2+			
				α/	6.48/				
^{193}Bi		192.9837	1.11 m	β^+,EC/40/7.1		9/2+			
				α/(60)/	5.91/				
^{194}Bi		193.9828	1.8 m	β^+,EC/99.9/8.2		(10-)			0.1661
				α/0.1/					0.1740
									0.2802
									0.421
									0.5754
									0.9650
^{195m}Bi			1.45 m	β^+,EC/(94)/					
				α/(6)/	6.11/				
^{195}Bi		194.9811	2.9 m	β^+,EC/99.8/5.8		3/2-			
				α/(0.2)	5.45/				
^{196}Bi		195.9806	5. m	EC/≈7.4					0.1376
									0.3720
									0.6880
									1.0486
^{197}Bi		196.9789	5. m	β^+,EC/5.2		1/2+			
^{198m}Bi			7.7 s	I.T./0.2485		(10-)			0.2485
^{198}Bi		197.9790	11.8 m	β^+,EC/6.6		(7+)			0.0900
									0.1976
									0.5624
									1.0635
^{199m}Bi			24.7 m	β^+,EC/					ann.rad./
^{199}Bi		198.9776	27. m	β^+,EC/4.3		9/2-	4.6		0.7203
									0.8374
									0.8417
									0.9460

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									1.0528
									1.3056
									(0.12 - 3.2)
^{200m}Bi			31. m	β^+,EC/		(2+)			0.2453
									0.4198
									0.4624
									1.0265
^{200}Bi		199.9781	36. m	EC/(90)/5.9		7+			ann.rad./
				β^+/(10)/					Pb k x-ray
									0.4198
									0.4623
									1.0265
^{201m}Bi			59.1 m	I.T./0.846		(1/2+)			Bi k x-ray
				β^+,EC/					0.8464
^{201}Bi		200.97697	1.8 h	EC/3.84		9/2-	4.8		Pb k x-ray
									0.6288
									0.9357
									1.0138
									(0.13 - 2.4)
^{202}Bi		201.97768	1.72 h	β^+/(3)/5.16		5+	+4.26	-0.72	ann.rad./
				EC/(97)/					Pb k x-ray
									0.57860
									0.92734
									(0.08 - 3.5)
^{203}Bi		202.97687	11.8 h	EC/99.8/3.25		9/2-	+4.02	-0.69	Pb k x-ray
				β^+/(0.2)/	1.35/				0.1865
									0.8203
									0.8969
									1.8475
									(0.1 - 2.9)
^{204}Bi		203.97779	11.2 h	EC/4.44		6+	+4.32	-0.43	Pb k x-ray
									0.37481
									0.89922
									0.98409
^{205}Bi		204.97737	15.31 d	EC/2.71		9/2-	+4.07	-0.59	Pb k x-ray
									0.70347
									1.76435
^{206}Bi		205.97848	6.243 d	EC/3.76		6+	+4.36	-0.39	Pb k x-ray
									0.51619
									0.80313
									0.88100
^{207}Bi		206.978456	35. y	EC/2.399		9/2-	4.08	-0.6	Pb k x-ray
									0.56915
									1.06310
^{208}Bi		207.979727	3.68×10^5 y	EC/2.880		5+	4.63	-0.64	Pb k x-ray
									2.61435
^{209}Bi	100.	208.980384				9/2-	+4.111	-0.37	
^{210m}Bi			3.0×10^6 y	α/	4.420(3)/0.29	9-	+2.73	-0.47	Tl k x-ray
					4.569(3)/3.9				0.2661
					4.584(3)/1.4				0.3052
					4.908(4)/39				0.6502
					4.946(3)/55				
^{210}Bi		209.984105	5.01 d	β^-/1.163	1.16/99	1-	-0.0445	+0.136	0.2661
									0.3.52
^{211}Bi		210.98726	2.14 m	α/(99.7)/	6.279/16	9/2-			Tl k x-ray
				β^-/(0.3)/0.58	6.623/84				0.3501
^{212m2}Bi			7. m	β^-/		(15-)			
^{212m1}Bi			25.0 m	α/(93)/	6.300/40	(9-)			0.120

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				β^-/(7)/	6.340/53				0.233
									0.275
									0.404
									0.727
^{212}Bi		211.991271	1.009 h	β^-/(64)/2.254		(1-)	+0.32	+0.1	Tl k x-ray
				α/(36)/	6.051/25				Po k x-ray
					6.090/9.6				0.2881
									0.72725
									0.78551
									1.62066
^{213}Bi		212.99437	45.6 m	β^-/(98)/1.43	1.02/31	9/2-	+3.72	-0.60	Po k x-ray
				α/(2)/	1.42/66				0.4404
					5.549/0.16				(0.15 - 1.328)
					5.869/2.0				
									1.10006
^{214}Bi		213.99870	19.7 m	β^-/3.27					0.60931
									1.12027
									1.76449
									(0.19 - 3.2)
^{215}Bi		215.0018	7.7 m	β^-/2.3					0.2937
									(0.27 - 0.835)
^{216}Bi		216.0062	2.3 m	β^-/4.0					0.5498
									0.4192
^{217}Bi			97 s	β/					
$_{84}$Po									
^{188}Po			0.4 ms	α	7.92				
					7.35				
^{189}Po			5 ms	α	7.54				
					7.25				
					7.32				
^{190}Po		189.9951	2.4 ms	α/	7.53				
^{191m}Po			0.10 s	α	7.38				
^{191}Po		190.9947	22 ms	α/	7.33				
^{192}Po		191.9915	34. ms	α/8.5	7.17				
^{193m}Po			0.24 s	α/	7.00				
^{193}Po		192.9911	0.45 s	α/	6.95				
^{194}Po		193.9883	0.39 s	α/	6.84/93	0+			
					6.19/0.22				
^{195m}Po			1.9 s	α/	6.70/				
^{195}Po		194.9881	4.6 s	α/	6.61/				
^{196}Po		195.9855	5.8 s	α/(95)/	6.52/94	0+			
				β^+,EC/(5)/≈4.6	5.77/0.02				
^{197m}Po			25.8 s	α/(84)/	6.385(3)/55	13/2+			
				β^+,EC/(16)/					
^{197}Po		196.9856	53. s	α/(44)/	6.282(4)/76	(3/2-)			
				β^+,EC/(56)/6.2					
^{198}Po		197.9834	1.76 m	α/(70)/	6.18/57	0+			
				β^+,EC/(30)/4.0	5.27/7.6×10^{-4}				
^{199m}Po			4.2 m	β^+,EC/(51)/		13/2+	0.99		ann.rad./
				α/(39)/	6.059/24				0.2745
									0.4998
									1.0020
^{199}Po		198.985	5.2 m	β^+,EC/(88)/7.		(3/2-)			Bi k x-ray
				α/(12)/	5.952/7.5				0.1877
									0.3616
									1.0214
									1.0344
^{200}Po		199.9817	11.5 m	β^+,EC/85/3.4		0+			0.14748
				α/(15)/	5.863/11.1				0.32792

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.6176
									0.6709
^{201m}Po			8.9 m	β^+,EC/(57)/		13/2+	1.00		Bi k x-ray
				IT/40/0.418					Po k x-ray
				α/(3)/	5.786/≈3.				0.2726
									0.4123
									0.4179
									0.9670
^{201}Po		200.9822	15.3 m	β^+,EC/98/4.9		3/2-	0.94		Bi k x-ray
				α/(2)/	5.683(3)/1.1				0.2056
									0.2250
									0.8483
									0.9048
^{202}Po		201.9807	45. m	β^+,EC/98/2.8		0+			0.0410
				α/(2)/	5.588/1.9				0.1656
									0.3158
									0.6884
^{203m}Po			1.2 m	IT/96/0.6414		13/2+			Bi k x-ray
				β^- EC/(4)/					Po k x-ray
									0.6414
^{203}Po		202.9814	35. m	β^+,EC/4.2		5/2-	+0.74		0.17516
									0.21477
									0.89350
									0.90863
									1.09095
^{204}Po		203.98031	3.53 h	EC/2.34		0+			Bi k x-ray
				α	5.377/0.66				0.2702
									0.8844
									1.0162
									(0.11 - 1.9)
^{205}Po		204.98117	1.7 h	β^+,EC/3.53		5/2-	+0.76	+0.17	Bi k x-ray
									0.83681
									0.84983
									0.87241
									1.00124
									(0.12 - 2.7)
^{206}Po		205.98047	8.8 d	EC/(95)/1.85		0+			Bi k x-ray
				α/(5)/	5.223/5.5				0.28644
									0.31156
									0.51134
									0.80737
									1.03228
									(0.11 - 1.5)
^{207m}Po			2.8 s	I.T./1.383		19/2-			Po k x-ray
									0.2682
									0.30074
									0.81448
^{207}Po		206.98158	5.80 h	EC,β^+/2.91		5/2-	+0.79	+0.28	Bi k x-ray
									0.74263
									0.91176
									0.99225
^{208}Po		207.981231	2.898 y	α/5.213	4.233/0.0002	0+			
					5.1158/100				
^{209}Po		208.982415	102. y	α/4.976	4.624/0.56	1/2-	≈+0.77		0.26049
					4.879/99.2				0.8964
^{210}Po		209.982857	138.4 d	α/5.407	4.516/0.001	0+			0.80313
					5.304/100				
^{211m}Po			25.2 s	α/	7.273/91	25/2+			Pb k x-ray
					7.994/1.7				0.32808

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/Energy Intensity (MeV/%)
					8.316/0.25				0.56915
					8.875/7.0				0.89723
									1.06310
^{211}Po		210.986637	0.516 s	α/7.594	6.570/0.54	9/2+			0.56915
					6.892/0.55				0.89723
					7.450/98.9				
^{212m}Po			45. s	α/	8.514/2.0	16+			
					9.086/1.0				
					11.650/97				
^{212}Po		211.988852	0.298 μs	α/8.953	8.784/100	0+			
^{213}Po		212.992843	3.7 μs	α/8.537	7.614/0.003	9/2+			
					8.375/100				
^{214}Po		213.995186	163.7 μs	α/7.833	6.904/0.01	0+			0.7995
					7.686/99.99				0.298
^{215}Po		214.999415	1.780 ms	α/7.526	6.950/0.02	(9/2+)			
					6.957/0.03				
					7.386/100				
^{216}Po		216.001905	0.145 s	α/6.906	5.895/0.002	0+			
					6.778/99.99				
^{217}Po		217.0064	< 10. s	α/6.662	6.539/				
^{218}Po		218.008965	3.04 m	α/6.114	5.181/1.00	0+			
$_{85}$At									
^{193}At		192.9998	40 ms	α/					
^{194}At		193.9990	40 ms	α/					
^{195m}At			0.39 s	α	6.96				
^{195}At		194.9965	140 ms	α/	7.11				
^{196m}At			8 μs						0.158
^{196}At		195.9957	0.39 s	α/	7.05/				
^{197m}At			4. s	α		(1/2+)			
^{197}At		196.9939	0.35 s	β$^+$,EC/7.8		(9/2-)			
				α/	6.96/				
^{198m}At			1.5 s	β$^+$,EC/(75)/					
				α/(25)/	6.85/86				
^{198}At		197.9928	5. s	α/	6.75/94				
^{199}At		198.9910	7.1 s	β$^+$,EC/8/5.6		9/2-			
				α/(92)/	6.64/				
^{200m}At			4.3 s	β$^+$,EC/(80)		10-			
				α/(20)/	6.536/12				
^{200}At		199.990	43. s	β$^+$,EC/65/≈8.0		5+			
				α/(35)/	6.412/44				
					6.465/57				
^{201}At		200.9885	1.48 s	β$^+$,EC/29/5.9		9/2-			
				α/(71)/6.474	6.344/				
^{202m}At			ð 1.5 s	I.T./0.391					
^{202}At		201.9885	3.02 m	β$^+$,EC/88/7.2		5+			ann.rad./
				α/(12)/	6.135/7.7				0.4413
					6.225/4.3				0.5697
									0.6753
^{203}At		202.9868	7.4 m	β$^+$,EC/69/5.1		9/2-			0.1458
				α/(31)/6.210	6.088/				0.2459
									0.6414
									1.0020
									1.0340
^{204}At		203.9873	9.1 m	β$^+$,EC/95/6.5		(5+)			Po k x-ray
				α/(5)/	5.951/				0.3271
									0.4254
									0.5156
									0.6837
^{205}At		204.98604	26. m	β$^+$,EC/90/4.54		(9/2-)			Po k x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				α/(10)/6.020	5.902/				0.1543
									0.6696
									0.7194
^{206}At		205.98660	29.4 m	β⁺,EC/99/5.72		5+			Po k x-ray
				α/(1)/5.881	5.703/				0.20186
									0.39561
									0.47716
									0.70071
^{207}At		206.98578	1.81 h	β⁺,EC/90/3.91		9/2-			Po k x-ray
				α/(10)/5.873	5.758/				0.16801
									0.58842
									0.81448
^{208}At		207.98657	1.63 h	β⁺,EC/99/4.97		(6+)			Po k x-ray
				α/(1)/5.752	5.626/0.01				0.1770
					5.641/0.53				0.2060
									0.6601
									0.6852
									0.8450
									1.0281
^{209}At		208.98616	5.4 h	β⁺,EC/96/3.49		(6+)			Po k x-ray
				α/(4)/5.757	5.647/4.1				0.10422
									0.54503
									0.78189
									0.79020
									(0.1 - 2.6)
^{210}At		209.98713	8.1 h	EC/99.8/3.98		5+			Po k x-ray
				α/(0.2)/5.632	5.361/0.05				0.24535
					5.442/0.05				0.52758
									1.18143
									1.43678
									1.48335
									(0.04 - 2.4)
^{211}At		210.987481	7.21 h	EC/(58)/0.787		9/2-			Po k x-ray
				α/(42)/5.980	5.211/0.004				0.66956
					5.868/42				0.6870
									0.74263
^{212m}At			0.119 s	α/	7.837/65	(9-)			
					7.897/33				
^{212}At		211.990735	0.314 s	α/7.828	7.058/0.4	(1-)			
					7.088/0.6				
					7.618/15				
					7.681/84				
^{213}At		212.992922	0.11 μs	α/9.254	9.080/	9/2-			
^{214m}At			0.76 μs	α/8.762		(9-)			
^{214}At		213.996357	0.56 μs	α/8.987	8.819/100	(1-)			
^{215}At		214.99864	0.10 ms	α/8.178	7.626/0.045	(9/2-)			0.40486
					8.023/99.9				
^{216}At		216.002408	0.30 ms	α/7.947	7.595/0.2	(1-)			
					7.697/2.1				
					7.800/97				
^{217}At		217.00471	32. ms	α/7.202	6.812/0.06	(9/2-)			0.2595
					7.067/99.9				0.3345
									0.5940
^{218}At		218.00868	1.6 s	α/6.883	6.654/6				
					6.695/90				
					6.748/4				
^{219}At		219.0113	50. s	α/6.390	6.275/				
^{220}At		220.0153	3.71 m	β¯/3.7					(0.24-0.70)
^{221}At		221.0181	2.3 m	β					

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{222}At		222.0223	0.9 m	β					
^{223}At		223.0253	50. s	β					
$_{86}$Rn									
^{196}Rn		195.9977	≈ 3 ms	α/	7.49				
^{197m}Rn			0.02 s	α	7.36				
^{197}Rn		196.9983	0.07 s	α/	7.26				
^{198}Rn		197.9988	0.05 s	α					
^{199m}Rn			0.3 s	α		(13/ 2+)			
^{199}Rn		198.9983	0.62 s	α/		3/2-			
^{200}Rn		199.9957	1.06 s	α/(98)/	6.901/	0+			0.4329
				EC/(2)/5.					0.5043
^{201m}Rn			3.8 s	EC/(10)/		13/2+			
				α/(90)/	6.773/				
^{201}Rn		200.9955	7.0 s	α/(80)/	6.725/	(3/2-)			
				EC/(20)/	α/6.778				
^{202}Rn		201.9932	9.9 s	α/(12)/	6.641/	0+			0.5695
				EC/(88)/					0.2876-0.6255
^{203m}Rn			28. s	α/	6.551	13/2+	-0.96	+1.3	
^{203}Rn		202.9948	45. s	α/(66)/6.629	6.499/	0			
				EC/(34)/≈7.4					
^{204}Rn		203.9914	1.24 m	α/(68)/	6.420/	0+			
				EC/(32)/3.8					
^{205}Rn		204.9917	2.8 m	α/(23)/6.390	6.123(3)/0.02	(5/2-)	+0.80	+0.06	0.2652
				EC/(77)/5.2	6.262(3)/23				0.3553
									0.4648
									0.6205
									0.6753
									0.7300
^{206}Rn		205.9902	5.7 m	α/(68)/6.384	6.258(3)/	0+			0.06170
				EC/(32)/3.3					0.0968
									0.3245
									0.3862
									0.4822
									0.4973
									0.7728
^{207}Rn		206.9907	9.3 m	β$^+$,EC/77/4.6		5/2-	+0.82	+0.22	At k x-ray
				α/(23)/6.252	5.995(4)/0.02				0.32947
					6.068(3)/0.15				0.34455
					6.126(3)/22.8				0.36767
									0.40267
									0.74723
									(0.18 - 1.4)
^{208}Rn		207.98963	24.3 m	α/(60)/6.260	5.469(2)/ 0.003	0+			
				EC/(40)/2.85	6.140(2)/60				
^{209}Rn		208.99038	29. m	β$^+$/(83)/3.93	2.16/2.3	5/2-	+0.8388	+0.31	At k x-ray
				α/(17)/	5.887(3)/0.04				0.27933
					5.898(3)/0.02				0.33753
					6.039(2)/16.9				0.40841
									0.68942
									0.74594
									(0.18 - 3.2)
^{210}Rn		209.98968	2.4 h	α/(96)/6.157	5.351(2)/ 0.005	0+			At k x-ray
				EC/(4)/2.37	6.039(2)/96				0.19625
									0.45824
									0.57104
									0.64868

TABLE OF ISOTOPES (CONTINUED)

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									(0.14 - 1.7)
^{211}Rn		210.99059	14.6 h	β^+,EC/74/2.89		1/2-	+0.60		At k x-ray
				α/(26)/5.964	5.619(1)/0.7				0.16877
					5.784(1)/16.4				0.25022
					5.851(1)/8.8				0.37049
									0.67412
									0.67839
									1.36298
									(0.11 - 2.7)
^{212}Rn		211.990689	24. m	α/6.385	5.587(4)/0.05	0+			
					6.260(4)/ 99.95				
^{213}Rn		212.99387	20 ms	α/8.243	7.552(8)/2	9/2+			0.540
					8.087(8)/98				
^{214}Rn		213.99535	0.27 μs	α/9.209	9.037(9)/	0+			
^{215}Rn		214.99873	2.3 μs	α/8.840	8.674(8)/	(9/2+)			
^{216}Rn		216.00026	45. μs	α					
^{217}Rn		217.003915	0.6 ms	α/7.885	7.500/0.1	9/2+			
					7.742(4)/100				
^{218}Rn		218.005586	35. ms	α/7.267	6.534(1)/0.16	0+			0.6093
					7.133(1)/99.8				0.6653
^{219}Rn		219.009475	3.96 s	α/6.946(1)	6.3130(5)/ 0.05	(5/2+)	-0.44	+0.93	Po k x-ray
					6.425(3)/7.5				0.13057
					6.5309(4)/ 0.12				0.27113
					6.5531(3)/ 12.2				0.40170
					6.8193(3)/81				(0.1 - 1.05)
^{220}Rn		220.011384	55.6 s	α/6.404	5.7486(5)/ 0.07	0+			
					6.2883(1)/ 99.9				
^{221}Rn		221.0156	25. m	α/(22)/6.148	5.778(3)/1.8	7/2+	-0.020	-0.38	Fr L x-ray
				β^-/(78)/1.2	5.788(3)/2.2				0.07384
					6.037(3)/18				0.08323
									0.0610
									0.18639
^{222}Rn		222.017570	3.823 d	α/5.590	4.987(1)/0.08	0+			0.510
					5.4897(3)/ 99.9				
^{223}Rn		223.0218	23. m	β^-/			-0.78	+0.80	
^{224}Rn		224.0241	1.8 h	β^-/		0+			0.1085
									0.2601
									0.2655
^{225}Rn		225.0284	4.5 m	β^-/		7/2	-0.70	+0.84	
^{226}Rn		226.0309	7.4 m	β^-/					
^{227}Rn		227.0354	2. s	β^-/					
^{228}Rn		228.0381	65. s	β^-/					
$_{87}$Fr									
^{199}Fr			12 s	α	7.66				
^{200}Fr		200.0065	≈ 20 ms	α	7.47				
^{201}Fr		201.0046	0.05 s	α/	7.36/	(9/2-)			
^{202}Fr		202.0033	0.34 s	α/7.590	7.237(8)/100				
^{203}Fr		203.0014	0.55 s	α/7.280	7.132(5)/	(9/2-)			
^{204}Fr		204.001	2.1 s	α/	7.03/96				
					6.97/90				
					7.01/74				
^{205}Fr		204.9987	3.9 s	α/7.050	6.914(5)/	(9/2-)			
^{206m}Fr			0.7 s	α/	6.93				0.531(IT)

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{206}Fr		205.9985	16.0 s	α/7.416	6.792(5)/84				
^{207}Fr		206.9969	14.8 s	α/6.900	6.766(5)/	9/2-	+3.9	-0.16	
^{208}Fr		207.99713	59.1 s	α/(77)/6.770	6.636(5)/	7+	-4.8	+0.004	
				EC/(23)/6.99					
^{209}Fr		208.99592	50.0 s	α/(89)/5.1	6.646(3)/	9/2-	+3.9	-0.24	0.7978
				EC/(11)/5.16					(0.1103-1.384)
^{210}Fr		209.99640	3.2 m	α/6.670	6.543(5)/	6+	+4.4	+0.19	0.2030
				EC/6.26					0.6438
									0.8175
									0.9008
^{211}Fr		210.99553	3.10 m	α/6.660	6.534(5)/	9/2-	+4.0	-0.19	0.220
				EC/4.61					0.2799
									0.5389
									0.9169
^{212}Fr		211.99618	20. m	EC/(57)/5.12	6.261(1)/16	(5+)	+4.6	-0.10	Rn x-ray
				α/(43)/6.529	6.335(1)/4				0.08107
					6.335(1)/4				0.08378
					6.343(1)/1.3				0.2277
					6.383(1)/10				1.1856
					6.406(1)/9.5				1.2748
					6.08-6.18				0.014-1.178
^{213}Fr		212.99617	34.6 s	α/6.905	8.476(4)/51	9/2-	+4.0	-0.14	
^{214m}Fr			3.4 ms	α/	8.547(4)/46	9-			
					6.775-8.046				
^{214}Fr		213.99895	5.1 ms	α/8.587	7.409(3)/0.3	(1-)			
					7.605(8)/1.0				
					7.940(3)/1.0				
					8.355(3)/4.7				
					8.427(3)/93				
^{215}Fr		215.00033	0.12 μs	α/9.537	9.360(8)/	(9/2-)			
^{216}Fr		216.00319	0.70 μs	α/9.175	9.005(10)/95				(0.045-0.160)
^{217}Fr		217.00462	0.016 ms	α/8.471	8.315(8)/	(9/2-)			
^{218m}Fr			22. ms	α					
^{218}Fr		218.00756	1. ms	α/8.014	7.384(10)/0.5	(1-)			
					7.542(15)/1.0				
					7.572(10)/5				
					7.732(10)/0.5				
					7.867(2)/93				
^{219}Fr		219.00924	21. ms	α/8.132	6.802(2)/0.25	(9/2-)			
					6.967(2)/0.6				
					7.146(2)/0.25				
					7.313(2)/99				
^{220}Fr		220.012313	27.4 s	α/6.800	6.582(1)/10	1+	-0.67	+0.47	0.0450
					6.630(2)/6				0.061
					6.641(1)/12				0.1060
					6.686(1)/61				0.1539
					6.39-6.58				0.1617
^{221}Fr		221.01425	4.8 m	α/6.457	5.9393(7)/ 0.17	(5/2-)	+1.58	-1.0	At k x-ray
					5.9797(7)/ 0.49				0.0995
					6.0751(7)/ 0.15				0.21798
					6.1270(7)/				0.4091
					6.2433(3)/1.3				
					6.3410(7)/ 83.4				
^{222}Fr		222.01754	14.3 m	β^-/2.03	1.78/	2-	+0.63	+0.51	
				α/5.850					
^{223}Fr		223.019731	22.0 m	β^-/1.149	1.17/65	(3/2+)	+1.17	+1.17	0.05014

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.07972
									(0.13 - 0.9)
^{224}Fr		224.02323	3.0 m	β^-/2.82		1-	+0.40	+0.517	0.13150
									0.21575
									0.8367
									(0.1 - 2.21)
^{225}Fr		225.02561	3.9 m	β^-/1.87		3/2	+1.07	+1.3	
^{226}Fr		226.0293	49. s	β^-/3.6		1	+0.071	-1.35	0.18606
									0.25373
^{227}Fr		227.0318	2.48 m	β^-/2.5		1/2	+1.50		
^{228}Fr		228.0357	39. s	β^-/≈3.5		2-	-0.76	+2.4	
^{229}Fr		229.0384	50. s	β^-/					
^{230}Fr		230.0425	19. s	β^-/		(3)			
^{231}Fr		231.0454	17. s	β^-/					
^{232}Fr		232.0500	5. s	β^-/					
$_{88}$Ra									
^{202}Ra			≈ 3 ms	α	7.86				
^{203m}Ra			0.03 s	α	7.62				
^{203}Ra		203.0092	≈ 4 ms	α	7.58				
^{204}Ra		204.0065	0.06 s	α	7.48				
^{205m}Ra			≈ 0.17 s						
^{205}Ra		205.0062	0.22 s	α	7.34				
^{206}Ra		206.0038	0.4 s	α/7.416	7.272(5)/	0+			
^{207}Ra		207.0037	1.3 s	α/7.270	7.133(5)/				
^{208}Ra		208.0018	1.4 s	α/7.273	7.133(5)/	0+			
^{209}Ra		209.0019	4.6 s	α/7.150	7.008(5)/	5/2	+0.87	+0.40	
^{210}Ra		210.0005	3.7 s	α/7.610	7.020(5)/	0+			
^{211}Ra		211.0009	13. s	α/7.046	6.912(5)/	(5/2-)	+0.878	+0.48	
				EC/5.0					
^{212}Ra		211.99978	13.0 s	α/7.033	6.901(2)/	0+			
^{213m}Ra			2.1 ms	IT					
^{213}Ra		213.00034	2.7 m	EC/(20)/3.88		(1/2-)	+0.613		0.1024
				α/(80)/6.860	6.521(3)/4.8				0.11010
					6.622(3)/39				0.2125
					6.730(3)/36				
^{214}Ra		214.00009	2.46 s	α/7.272	7.14/99.8/	0+			0.642
					6.51/0.2				
^{215}Ra		215.00270	1.7 ms	α/8.864	7.883(6)/2.8	(9/2+)			0.773/100
					8.171(3)/1.4				0.852/74
					8.700(3)/95.9				0.055-1.048
^{216}Ra		216.00352	0.18 µs	α/9.526	9.349(8)/	0+			
^{217}Ra		217.00631	1.6 µs	α/9.161	8.992(8)/	9/2-			
^{218}Ra		218.00712	26. µs	α/8.547	8.390(8)/	0+			
^{219}Ra		219.01006	0.010 s	α/8.132	7.680(10)/65				
					7.982(9)/35				
^{220}Ra		220.01101	18. ms	α/7.593	7.39/5	0+			0.465
					7.45/95				
^{221}Ra		221.01391	29. s	α/6.879	6.254(10)/0.7	5/2	-0.180	+1.9	
					6.578(5)/3				
					6.585(3)/8				
					6.608(3)/35				
					6.669(3)/21				
					6.758(3)/31				
^{222}Ra		222.015361	36.2 s	α/5.590	6.237(2)/3.0	0+			0.324
					6.556(2)/97				0.1448-0.8402
^{223}Ra		223.018497	11.43 d	α/5.979	5.287(1)/0.15	(3/2+)	+0.271	+1.25	Rn k x-ray
					5.338(1)/0.13				0.12231
					5.365(1)/0.13				0.14418
					5.433(5)/2.3				0.15418

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
					5.502(1)/1.0				0.15859
					5.540(1)/9.2				0.26939
					5.607(3)/24				0.32388
					5.716(3)/52				0.33328
					5.747(1)/9				0.44494
					5.857(1)/0.32				(0.10 - 0.7)
					5.872(1)/0.85				
^{224}Ra		224.020202	3.66 d	α/5.789	5.034(10)/ 0.003	0+			Rn k x-ray
					5.047(1)/ 0.007				0.2407
					5.164(5)/ 0.007				0.4093
					5.449(2)/4.9				0.6501
					5.685(2)/95				
^{225}Ra		225.023603	14.9 d	β¯/0.36	0.32/100	(3/2+)	-0.734		Ac k x-ray
				α	5.01/2×10^{-5}				0.0434
					4.98×10^{-6}				
^{226}Ra		226.025402	1599. y	α/4.870	4.194(1)/ 0.001	0+			Rn k x-ray
			>4×10^{18} y	Sf/4×10^{-14}	4.343(1)/ 0.006				0.1861
					4.601(1)/5.5				0.2624
					4.784(1)/94				
^{227}Ra		227.029170	42. m	β¯/1.325	1.03/	(3/2+)	-0.404	+1.5	Ac L x-ray
					1.30/				Ac k x-ray
									0.02739
^{228}Ra		228.031063	5.76 y	β¯/0.046	0.039/50	0+			0.0135
					0.014/30				(0.006-0.0306)
					0.026/20				
^{229}Ra		229.0348	4.0 m	β¯/1.76	1.76/	(3/2+)	+0.503	+3.1	0.0145-0.1715
^{230}Ra		230.03708	1.5 h	β¯/1.0	0.7/	0+			0.0631
									0.0720
									0.2028
									0.4698
									0.4787
^{231}Ra		231.0412	1.7 m	β¯					
^{232}Ra		232.0437	4. m	β¯					
^{233}Ra		233.0480	30. s	β¯					
^{234}Ra		234.051	≈ 30. s	β¯/					
$_{89}$Ac									
^{206m}Ac			0.04 s	α	7.79				
^{206}Ac			≈ 26 ms	α	7.75				
^{207}Ac		207.0121	27 ms	α/	7.69				
^{208m}Ac			≈25. ms	α/	7.72				
^{208}Ac		208.0115	≈0.1 s	α/	7.62				
^{209}Ac		209.0096	≈0.10 s	α/	7.58				
^{210}Ac		210.0093	0.34 s	α/7.610	7.462(8)/				
^{211}Ac		211.0076	0.20 s	α/7.620	7.480(8)/				
^{212}Ac		212.0078	0.9 s	α/7.520	7.379(8)/				
^{213}Ac		213.0066	0.73 s	α/7.500	7.364(8)/	(9/2-)			
^{214}Ac		214.0069	8.2 s	α/(86)/7.350	7.007(8)/3	(5+)			
				EC/(14)/6.34	7.082(5)/38				
					7.214(5)/45				
^{215}Ac		215.0065	0.17 s	α/7.750	7.60/99.2	(9/2-)			0.399
					7.21/0.46				0.582
					7.03/0.20				0.654
					6.96/0.14				
^{216m}Ac			0.44 ms	α/	8.198(8)/1.7	(9-)			
					8.283(8)/2.5				

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
					9.028(5)/49				
					9.106(5)/46				
^{216}Ac		216.00871	≈ 0.3 ms	α/9.241	8.990(2)/10	(1)			
					9.070(8)/90				
^{217m}Ac			0.7 μs	α/	10.540/100				
^{217}Ac		217.00933	0.07 μs	α/9.832	9.650(10)/100	9/2-			
^{218}Ac		218.01162	1.1 μs	α/9.380	9.205(15)/				
^{219}Ac		219.01241	0.012 ms	α/8.830	8.664(10)/	(9/2-)			
^{220}Ac		220.0148	26. ms	α/8.350	7.610(20)/23				
					4.680(20)/21				
					7.790(10)/13				
					7.850(10)/24				
					7.985(10)/4				
					8.005(10)/5				
					8.060(10)/6				
					8.195(10)/3				
^{221}Ac		221.01558	52. ms	α/7.790	7.170(10)/2				
					7.375(10)/10				
					7.440(15)/20				
					7.645(10)/70				
^{222m}Ac			63. s	α/(>89)/	6.710(20)/7				
				EC/(1)/	6.750(20)/13				
				I.T./(<10)/	6.810(20)/24				
					6.840(20)/9				
					6.890(20)/13				
					6.970(20)/7				
					7.000(20)/13				
^{222}Ac		222.01782	5. s	α/7.141	6.967(10)/6	1-			
					7.013(2)/94				
^{223}Ac		223.01913	2.1 m	α/(99)/6.783	6.131(2)/0.12	(5/2-)			0.0725
				EC/(1)/0.59	6.177(2)/0.94				0.0839
					6.293(1)/0.47				0.0927
					6.326(1)/0.3				0.0990
					6.332(2)/0.14				0.1917
					6.360(1)/0.22				0.2158
					6.397(1)/0.13				0.3588
					6.448(1)/0.2				0.4768
					6.473(1)/3.1				
					6.523(2)/0.6				
					6.528(1)/3.1				
					6.563(1)/13.6				
					6.582(3)/0.3				
					6.646(1)/44				
					6.661(1)/31				
^{224}Ac		224.021708	2.7 h	EC/(90)/1.403	5.841(1)/0.5	0-			Ra L kx-ray
				α/(10)/6.323	5.860(1)/0.75				Ra k x-ray
					5.875(1)/1.7				0.08426
					5.941(1)/4.4				0.13150
					6.000(1)/6.7				0.1571
					6.013(1)/1.4				0.21575
					6.056(1)/22				0.2619
					6.138(1)/26				(0.03 - 0.3)
					6.154(1)/1.0				
					6.204(1)/12				
					6.210(1)/20				
^{225}Ac		225.02322	10.0 d	α/5.935	5.286(1)/0.2	3/2			Fr k x-ray
					5.444(3)/0.1				0.9958
					5.554(1)/0.1				0.9982
					5.608(1)/1.1				0.1084

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
					5.636(1)/4.5				0.1116
					5.681(1)/1.4				0.1451
					5.722(1)/2.9				0.1539
					5.731(1)/10				0.15724
					5.791(1)/9				0.18799
					5.793(1)/18				0.19575
									0.2162
									0.21686
									(0.025 - 0.52)
^{226}Ac		226.026089	1.224 d	EC/(17)/0.640		(1-)			Ra k x-ray
				β^-/(83)/1.116					Th k x-ray
				α/(0.006)/5.51	5.399(5)/ 0.006				0.07218
									0.15816
									0.23034
^{227}Ac		227.027747	21.77 y	β^-/98.6/0.045	0.045/54	(3/2-)	+1.1	+1.7	0.0838/23.
				α/(1.4)/5.043	4.869(1)/0.09				0.0811/14.
					4.938(1)/0.52				0.2696/13.
					4.951(1)/0.65				(0.044 - 1.27)
^{228}Ac		228.031014	6.15 h	β^-/2.127	1.11/32	(3+)			Th L x-ray
					1.85/12				Th k x-ray
					2.18/11				0.12903
									0.33842
									0.91116
									0.96897
									(0.2 - 1.96)
^{229}Ac		229.03293	1.04 h	β^-/1.10	1.1/	(3/2+)			0.07450
									0.16451
									0.26188
									0.5085
									0.56916
^{230}Ac		230.0360	2.03 m	β^-/2.7	1.4/	1+			Th k x-ray
									0.45497
									0.50820
									(0.12 - 2.5)
^{231}Ac		231.0386	7.5 m	β^-/2.1	2.1/100	(1/2+)			0.14379
									0.18574
									0.22140
									0.28250
									0.3070
^{232}Ac		232.0420	2.0 m	β^-/3.7		(2-)			
^{233}Ac		233.0446	2.4 m	β^-/		(1/2+)			
^{234}Ac		234.0484	40. s	β^-/		(1+)			
$_{90}$Th		232.0381(1)							
^{209}Th			≈ 0.01 s	α	8.08				
^{210}Th		210.0150	≈ 12 ms	α	7.90				
^{211}Th		211.0149	0.04 s	α	7.79				
^{212}Th		212.0129	≈ 30. ms	α/	7.80/	0+			
^{213}Th		213.0130	0.14 s	α/7.840	7.692(10)/				
^{214}Th		214.0115	0.09 s	α/7.825	7.677(10)/	0+			
^{215}Th		215.0117	1.2 s	α/7.660	7.33(10)/8	(1/2-)			0.134
					7.395(8)/52				0.192
					7.524(8)/40				
^{216m}Th			0.14 ms	α	9.93				
^{216}Th		216.01105	28. ms	α/8.071	7.92/99.46	0+			0.628
					7.30/0.54				
^{217}Th		217.01306	0.25 ms	α/9.424	9.27/94.6				
					8.46/3.8				
					8.73/1.6				

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{218}Th		218.01327	0.11 μs	α/9.847	9.665(10)/	0+			
^{219}Th		219.01552	1.05 μs	α/9.510	9.340(20)/				
^{220}Th		220.01573	10. μs	α/8.953	8.790(20)/	0+			
^{221}Th		221.01817	1.7 ms	α/8.628	7.743(8)/6				
					8.146(5)/56				
					8.4272(5)/39				
^{222}Th		222.01845	2.8 ms	α/8.129	7.982(8)/9.7	0+			
					7.600(15)/3				
^{223}Th		223.02079	0.65 s	α/7.454	7.29(1)/41(5)				
					7.32(1)/29(5)				
					7.350(15)/20(5)				
					7.390(15)/10(4)				
^{224}Th		224.02146	1.05 s	α/7.305	6.768(5)/1.2				
					6.997(5)/19				
					7.170(5)/79				
^{225}Th		225.02394	8.72 m	EC/(10)/0.68		(3/2+)			
				α/(90)/6.920	6.441(2)/15				
					6.479(2)/43				
					6.501(3)/14				
					6.627(3)/3				
					6.650(5)/3				
					6.700(5)/2				
					6.743(3)/7				
					6.796(2)/9				
^{226}Th		226.024891	30.83 m	α/6.454	6.026(1)/0.2	0+			Ra k x-ray
					6.041(1)/0.19				0.1112
					6.098(1)/1.3				0.2421
					6.2283(4)/23				0.1310
					6.3375(4)/75				0.1733-0.9295
^{227}Th		227.027699	18.72 d	α/6.146		(3/2+)			Ra L x-ray
									Ra k x-ray
									0.05014
									0.23597
									0.25624
									(0.02 - 1.0)
^{228}Th		228.028731	1.913 y	α/5.520	5.1770(2)/0.18	0+			
					5.2114(1)/0.4				
					5.3405(1)/26.7				
					5.4233(1)/73				
^{229}Th		229.031754	7.9x10^{3} y	α/5.168	4.814/9.3	5/2+	+0.46	+4.	
					4.845(5)/56				
					4.9008(5)/10.2				
					4.689-5.077				
^{230}Th		230.033126	7.54x10^{4} y	α/4.771	4.4383(6)/0.03	0+			0.0677/0.46
					4.4798(6)/0.12				0.1439/0.078
			>2.x10^{18} y	SF/<4×10^{-12}	4.6211(6)/23.4				
					4.6876(6)/76.3				
^{231}Th		231.036296	1.063 d	β^-/0.390	0.138/22	5/2+			Pa L x-ray
					0.218/20				Pa k x-ray
					0.305/52				0.02564
									0.084203/
									(0.02 - 0.3)

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{232}Th	100.	232.038050	$1.40x10^{10}$ y	α/4.081	3.830(10)/0.2	0+			0.0590
			$1.2x10^{21}$ y	SF/$1.1x10^{-9}$	3.952(5)/23				0.124
					4.010(5)/77				
^{233}Th		233.041576	22.3 m	β¯/1.245	1.245/	1/2+			Pa L x-ray
									Pa k x-ray
									0.02938
									0.08653
									0.45930
									(0.02 - 1.2)
^{234}Th		234.043596	24.10 d	β¯/0.273	0.102/20	0+			Pa L x-ray
					0.198/72				0.06329/4.1
									0.09235/2.4
									0.09278/2.4
^{235}Th		235.04751	7.2 m	β¯/1.9					0.4162
									0.6594
									0.7272
									0.747
									0.9318
^{236}Th		236.0497	37.5 m	β¯/≈ 1.0					Pa k x-ray
									0.1107
^{237}Th		237.0539	5.0 m	β¯					
$_{91}$Pa		231.03588(2)							
^{212}Pa			≈ 5 ms	α	8.27				
^{213}Pa		213.0212	7 ms	α	8.24				
^{214}Pa		214.0207	17 ms	α	8.12				
^{215}Pa		215.0190	15. ms	α	8.08/100				
^{216}Pa		216.0190	0.19 s	α/	7.95/51				0.134
					7.82/45				
					7.79/4				
^{217m}Pa			1.5 ms	α/	10.16/80				
					9.55/17				
					9.69/3				
^{217}Pa		217.0183	3.4 ms	α/8.490	8.340(10)/100				
^{218}Pa		218.0200	0.12 ms	α/	9.54/31				0.092
					9.61/69				
^{219}Pa		219.0199	0.05 µs	α					
^{220}Pa		220.0219	0.8 µs	α					
^{221}Pa		221.0219	6. µs	α	9.08(3)				
^{222}Pa		222.0237	≈ 4.3 ms	α/8.700	8.180/50				
					8.330/20				
					8.540/30				
^{223}Pa		223.0240	≈ 6.5 ms	α/8.340	8.006(10)/55				
					8.196(10)/45				
^{224}Pa		224.0256	0.84 s	α/7.630	7.555(10)/ 75(3)				0.1945
					7.46(1)/25(3)				(0.028-0.412)
^{225}Pa		225.0261	1.8 s	α/7.380	7.195(10)/30				
					7.245(10)/70				
^{226}Pa		226.02792	1.8 m	α/(74)/6.987	6.728(10)/0.7				
				EC/(26)/2.83	6.823(10)/35				
					6.863(10)/39				
^{227}Pa		227.02879	38.3 m	α/(85)/6.582	6.357(4)/7	(5/2-)			0.0649
				EC/(15)/1.02	6.376(10)/2.2				0.0669
					6.401(4)/8				0.1100
					6.416(4)/13				
					6.423(10)/10				
					6.465(4)/43				
^{228}Pa		228.03100	22. h	EC/(98)/2.111		(3+)	+3.5		Th k x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				α/(2)	5.779/0.23				0.409/100
					5.805/0.15				0.4631/222
					6.078/0.4				0.91116/242
					6.105/0.25				0.96464/120
					6.118/0.22				0.96897/149
									0.058-1.96
^{229}Pa		229.03209	1.5 d	EC/(99.8)/0.32		(5/2)			0.04244
				α/(0.2)/5.836	5.536(2)/0.02				(0.024 - 0.18)
					5.579(2)/0.09				
					5.668(2)/0.05				
^{230}Pa		230.034532	17.4 d	EC/(90)/1.310	0.51/	(2-)	2.0		Th L x-ray
				β^-/(10)/0.563					Th k x-ray
									0.4437
									0.45477
									0.89876
									0.91856
									0.95199
									(0.053-1.07)
^{231}Pa		231.035878	3.25x10^4 y	α/5.148	4.6781(5)/1.5	3/2-	2.01	-1.7	Ac L x-ray
					4.7102(5)/1.0				Ac k x-ray
			>2x10^{17} y	SF/<1.6x10^{-15}	4.7343(5)/8.4				0.01899
					4.8513(5)/1.4				0.027396
					4.9339(5)/3				0.03823
					4.9505(5)/ 22.8				0.04639
					4.9858(5)/1.4				0.25586
					5.0131(5)/ 25.4				0.26029
					5.0292(5)/20				0.28367
					5.0318(5)/2.5				0.30007
					5.0587(5)/11				0.30264
									0.33007
									(0.02 - 0.61)
^{232}Pa		232.03858	1.31 d	β^-/1.34		(2-)			U k x-ray
									0.10900
									0.15009
									0.89439
									0.96934
									(0.10 - 1.17)
^{233}Pa		233.040239	27.0 d	β^-/0.571	0.15/40	3/2-	+4.0	-3.0	U L x-ray
					0.256/60				U k x-ray
									0.30017
									0.31201
									0.34059
^{234m}Pa			1.17 m	β^-/99.9/2.29		(0-)			U k x-ray
				IT/0.13/					0.25818/0.07
									0.76641/0.32
									1.0009/0.85
									(0.06 - 1.96)
^{234}Pa		234.043303	6.69 h	β^-/2.197	0.51/	(4+)			U L x-ray
									U k x-ray
									0.1312/0.03
									0.5695/0.02
									0.9256/0.02
									(0.02 - 1.99)
^{235}Pa		235.04544	24.4 m	β^-/1.41	1.4/97	(3/2-)			0.0308-0.65893
^{236}Pa		236.0487	9.1 m	β^-/2.9	1.1/40	(1-)			U k x-ray
					2.0/50				0.64235

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
					3.1/10				0.68759
									1.7630
									(0.04 - 2.18)
^{237}Pa		237.0511	8.7 m	β^-/2.3	1.1/60	(1/2+)			0.4986
					1.6/30				0.5293
					2.3/10				0.5407
									0.8536
									0.8650
									(0.04 - 1.4)
^{238}Pa		238.0545	2.3 m	β^-/3.5	1.2/	(3-)			0.10350
					1.7/				0.1785
									0.4484
									0.6350
									0.6800
									1.01446
									(0.04 - 2.5)
^{239}Pa		239.0571	1.8 h						
$_{92}$U		238.02891(3)							
^{217}U			≈16 ms	α	8.005				
^{218}U		218.0235	≈0.002 s	α	8.63(3)/				
^{219}U		219.0249	0.04 ms	α	9.68(4)/				
^{222}U		222.0261	≈ 1.µs	α					
^{223}U		223.0277	0.02 s	α/	8.78(4)/				
^{224}U		224.02759	≈ 1. ms	α/	8.46/100				
^{225}U		225.02938	0.09 s	α/	7.89/58				
					7.83/37				
					7.62/5				
^{226}U		226.02933	0.5 s	α/7.560	7.55/82	0+			
					7.37/15				
					7.32/3				
^{227}U		227.03113	1.1 m	α/7.200	6.870/				
^{228}U		228.03137	9.1 m	α/6.803	6.404(6)/0.6	0+			0.095
					6.440(5)/0.7				0.152
					6.589(5)/29				0.187
					6.681(6)/70				0.246
^{229}U		229.03350	58. m	EC/(80)/1.31	6.223/3	(3/2+)			
				α/(20)/6.473	6.297(3)/11				
					6.332(3)/20				
					6.360(3)/64				
^{230}U		230.033927	20.8 d	α/5.992	5.5866(3)/ 0.01	0+			Th L x-ray
			>4x10^{10} y	SF/<10^{-10}	5.6624(3)/ 0.26				0.07218
					5.6663(3)/ 0.38				0.15421
					5.8178(3)/32				0.23034
					5.8887(3)/67				(0.081-0.8565)
^{231}U		231.03626	4.2 d	EC/0.36		(5/2-)			Pa L x-ray
				α/(10^{-3})	5.46/1.6 x 10^{-3}				Pa k x-ray
					5.47/1.4 x 10^{-3}				0.02564
					5.40/1. x 10^{-3}				0.08420
^{232}U		232.037146	70. y	α/5.414	4.9979(1)/ 0.003	0+			
			2.6x10^{15} y	SF/2.7x10^{-12}	5.1367(1)/0.3				
					5.2635(1)/31				
					5.3203(1)/69				
^{233}U		233.039627	1.592x10^{5} y	α/4.909	4.7830(8)/ 13.2	5/2+	+0.59	3.66	Th L x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/Energy Intensity (MeV/%)
			>2.7x10^{17} y	SF/6x10^{-11}	4.8247(8)/ 84.4				0.04244
					4.510-4.804				0.09714
									(0.0252-1.119)
^{234}U	0.0055(5)	234.040945	2.455x10^{5} y	α/4.856	4.604(1)/0.24	0+			0.05323/0.156
			1.5x10^{16} y	SF/1.6x10^{-9}	4.7231(1)/ 27.5				0.12091
					4.776(1)/72.5				
^{235m}U			26. m	IT/0.0007		1/2+			
^{235}U	0.720(1)	235.043922	7.04x10^{8} y	α/4.6793	4.1525(9)/0.9	7/2-	-0.38	4.9	Th L x-ray
			1.0x10^{19} y	SF/7x10^{-9}	4.2157(9)/5.7				Th k x-ray
					4.3237(9)/4.6				0.10917
					4.3641(9)/11				0.14378
					4.370(4)/6				0.16338
					4.3952(9)/55				0.18574
					4.4144(9)/2.1				0.20213
					4.5025(9)/1.7				0.20533
					4.5558(9)/4.2				0.22140
					4.5970(9)/5.0				(0.03 - 0.79)
^{236}U		236.045561	2.342x10^{7} y	α/4.569	4.332(8)/0.26	0+			Th L x-ray
			2.5x10^{16} y	SF/9x10^{-8}	4.445(5)/26				0.04937
					4.494(3)/74				0.11275
^{237}U		237.048723	6.75 d	β^-/0.519	0.24/	1/2+			Np L x-ray
					0.25/				Np k x-ray
									0.05953
									0.20801
^{238}U	99.2745(15)	238.050784	4.47x10^{9} y	α	4.0395/0.23	0+			Th L x-ray
			8.2x10^{15}y	SF/5x10^{-5}	4.147(5)/23				0.04955/.06
					4.196(5)/77				0.1135/.01
^{239}U		239.054289	23.5 m	β^-/1.265	1.2/	5/2+			(0.522-0.681)
					1.3/				
^{240}U		240.056585	14.1 h	β^-/0.39	0.36/	0+			Np L x-ray
									0.04410
									0.05558
									0.06760
^{242}U		242.0629	16.8 m	β^-/≈ 1.2					
$_{93}$Np									
^{225}Np		225.0339	> 2 µs						
^{226}Np		226.0351	0.03 s	α/	8.04(2)/				
^{227}Np		227.0350	0.51 s	α/	7.65(2)/				
					7.68(1)/				
^{228}Np		228.0362	61. s	EC/60(7)/					
				α/40(7)/,SF					
^{229}Np		229.0363	4.0 m	α/7.010	6.890(20)				
^{230}Np		230.0378	4.6 m	EC/97/3.6					
				α/3	6.660(20)				
^{231}Np		231.03823	48.8 m	EC/98 /1.8		5/2			0.2629
				α/2 /6.368	6.280/2				0.3475
									0.3703
^{232}Np		232.0400	14.7 m	EC/99/2.7		(4-)			U L x-ray
									U k x-ray
									0.3268
									0.81925
									0.86683
^{233}Np		233.0410	36.2 m	EC/1.2		(5/2+)			U L x-ray
									U k x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									0.29887
									0.31201
^{234}Np		234.04289	4.4 d	β^+,EC/1.81	0.79/	(0+)			U L x-ray
									U k x-ray
									1.5272
									1.5587
									1.6022
^{235}Np		235.044055	1.085 y	EC/99.9/0.124		5/2+			U k x-ray
				α/0.001/5.191					
^{236m}Np			22.5 h	EC/52/		(1-)			U L x-ray
				β^-/48/					Pu L x-ray
									U k x-ray
									0.64235
									0.68759
^{236}Np		236.04657	1.55x10^5 y	EC/91/0.94		(6-)			U L x-ray
				β^-/9/0.49					U k x-ray
									0.10423
									0.16031
^{237}Np		237.048166	2.14x10^6 y	α/4.957	4.6395(5)/6.5	5/2+	+3.14	+3.89	Pa L x-ray
			1x10^{18} y	SF/2.1x10^{-10}	4.766(5)/9.7				Pa k x-ray
					4.7715(5)/ 22.7				0.029378/15
					4.7884(5)/ 47.8				0.08653/12
					4.558-4.873				(0.03-0.28)
^{238}Np		238.050940	2.117 d	β^-/1.292	1.2/	2+			Pu L x-ray
									Pu k x-ray
									0.98447/25.2
									1.02855/18.3
									(.044-1.026)
^{239}Np		239.052931	2.355 d	β^-/0.722	0.341/30	5/2+			Pu L x-ray
					0.438/48				Pu k x-ray
									0.10613
									0.228186/11
									0.27760/15
									(0.04-0.50)
^{240m}Np			7.22 m	β^-/99.9/	2.18/	(1+)			0.25143
				IT/0.1/					0.26333
									0.55454
									0.59735
^{240}Np		240.05617	1.032 h	β^-/2.20	0.89/	5+			0.1471/
									0.5664
									0.6008
^{241}Np		241.0583	13.9 m	β^-/1.3	1.3/	5/2+			0.1330/
									0.1740
									0.280
^{242m}Np			2.2 m	β^-/		(1+)			0.15910
									0.2651/
									0.78570
									0.9448/
^{242}Np		242.0616	5.5 m	β^-/2.7	2.7/	6+			0.6209
									0.73620
									0.78074
									1.47340
									(0.04-2.37)
^{243}Np		243.0643	1.9 m						
^{244}Np		244.0678	2.3 m						
$_{94}$Pu									

TABLE OF ISOTOPES (CONTINUED)

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{228}Pu		228.0387		α/	7.81(2)/				
^{229}Pu		229.0362	4.0 m	α/	7.46(3)/				
^{230}Pu		230.03964	4.6 m	α/	7.05/				
^{231}Pu		231.04126	8.6 m	EC/90					
				α/10	6.72				
^{232}Pu		232.04118	34. m	EC/>80/1.1		0+			
				α/<20/6.716	6.542(10)/38				
					6.600(10)/62				
^{233}Pu		233.04299	20.9 m	EC(99.9)/1.9					0.1503
				α/0.1/6.416	6.300(20)/0.1				0.1804
									0.2353
									0.5002
									0.5346/
									1.0352/
^{234}Pu		234.04331	8.8 h	EC/94/0.39		0+			
				α/6/6.310	6.035(3)/ 0.024				
					6.149(3)/1.9				
					6.200(3)/4.0				
^{235}Pu		235.0453	25.3 m	EC/99+/1.2		(5/2+)			
				α/0.003/5.957	5.850(20)/ 0.003				
^{236}Pu		236.046048	2.87 y	α/5.867	5.611/0.21	0+			0.0476/0.07
			$1.5x10^{9}$ y	SF/$1.9x10^{-7}$	5.7210/30.5				0.109/0.02
					5.7677(1)/ 69.3				(0.17 - 0.97)
^{237}Pu		237.048403	45.7 d	EC/99.9/0.220		7/2-			Np L x-ray
				α/0.003/5.747	5.334(4)/ 0.0015				Np k x-ray
					5.356(4)/ 0.0006				0.026344
					5.650(4)/ 0.0007				0.03319
									0.05954
									(0.03-0.5)
^{238}Pu		238.049553	87.7 y	α/5.593	5.3583(1)/ 0.10	0+			U k x-ray
			$4.75x10^{10}$ y	SF/$1.8x10^{-7}$	5.465(1)/28.3				0.04347
					5.4992(1)/ 71.6				(0.04-1.1)
^{239}Pu		239.052156	$2.410x10^{4}$ y	α/5.244	5.055/0.047	1/2+	+0.203		U k x-ray
			$8.x10^{15}$ y	SF/$3x10^{-10}$	5.076/0.078				0.05162
					5.106/11.9				0.05682
					5.144/17.1				0.12928
					5.157/70.8				0.37502
					(4.74 -5.03)				0.41369
^{240}Pu		240.053807	$6.56x10^{3}$ y	α/5.255	5.0212(1)/ 0.07	0+			U L x-ray
			$1.14x10^{11}$ y	SF/$5.7x10^{-6}$	5.1237(1)/ 26.4				0.04524
					5.1681(1)/ 73.5				0.10423
									(0.04-0.97)
^{241}Pu		241.056844	14.4 y	β^-/99+/0.0208	4.853(7)/ $3x10^{-4}$	5/2+	-0.683	+6.	0.14854
				α/0.002/5.139	4.8966(7)/ 0.002				0.1600
			<$6.x10^{16}$ y	SF/>$2.4x10^{-14}$					
^{242}Pu		242.058736	$3.75x10^{5}$ y	α/4.983	4.7546(7)/ 0.098	0+			U L x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
			6.77×10^{10} y	SF/5.5×10^{-4}	4.8564(7)/ 22.4				0.04491
					4.9006(7)/78				0.10350
^{243}Pu		243.061996	4.956 h	β^-/0.582	0.49/21	7/2+			Am L x-ray
					0.58/60				0.0417
									0.0839
^{244}Pu		244.064197	8.00×10^{7} y	α/99.9/4.665	4.546(1)/19.4	0+			U L x-ray
			6.6×10^{10} y	SF/0.12	4.589(1)/80.5				0.0439
^{245}Pu		245.06774	10.5 h	β^-/1.21	0.93/57	(9/2-)			Am L x-ray
					1.21/11				Am k x-ray
									0.2804/
									0.30832
									0.32752
									0.56014
									(0.03-1.2)
^{246}Pu		246.07020	10.85 d	β^-/0.40	0.150/85	0+			Am L x-ray
					0.35/10				Am k x-ray
									0.04379
									0.22371
^{247}Pu		247.0741	2.3 d						
$_{95}$Am									
^{232}Am		232.0466	0.9 m	EC/≈ 5.0					
^{234}Am		234.0478	2.3 m	EC/4.2					
^{235}Am		235.0480	≈ 15 m	EC					Pu K x-ray
^{236}Am		236.0456	≈4.4 m						
^{237}Am		237.0503	1.22 h	EC/99.98/1.7		(5/2-)			Pu k x-ray
				α/0.02/6.20	6.042(5)/0.02				0.14559
									0.28026
									0.43845
^{238}Am		238.05198	1.63 h	EC/2.26		1+			Pu L x-ray
				α/0.0001/6.04	5.940/0.0001				Pu k x-ray
									0.91870
									0.96278
^{239}Am		239.053018	11.9 h	EC/99.99/0.803		5/2-			Pu L x-ray
				α/0.01/5.924	5.734(2)/ 0.001				Pu k x-ray
					5.776(2)/ 0.008				0.18172
									0.22818
									0.27760
^{240}Am		240.05529	2.12 d	EC/1.38		(3-)			Pu L x-ray
				α/5.592	5.378(1)/ 16×10^{-4}				Pu k x-ray
									0.88878
									0.98764
									(0.1-1.3)
^{241}Am		241.056822	432.7 y	α/5.637	5.2443(1)/ 0.002	5/2-	+1.58	+3.1	Np L x-ray
			1.2×10^{14} y	SF/3.6×10^{-10}	5.3221(1)/ 0.015				0.02634
					5.3884(1)/1.4				0.033192
					5.4431(1)/ 12.8				0.059536
					5.4857(1)/ 85.2				(0.03-1.128)
					5.5116(1)/ 0.20				
					5.5442(1)/ 0.34				
^{242m}Am			141. y	IT/99.5/0.048		5-	+1.0	+6.5	Am L x-ray

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				α/0.5/5.62	5.141(4)/ 0.026				0.04863
			>3.x10^{12} y	SF/<4.7x10^{-9}	5.2070(2)/0.4				0.08648
									0.10944
									0.16304
^{242}Am		242.059542	16.02 h	β$^-$/83/0.665	0.63/46	1-	+0.388	-2.4	Pu L x-ray
				EC/17/0.750	0.67/37				Cm L x-ray
									Pu k x-ray
									0.0422
									0.04453
^{243}Am		243.061372	7.37x10^{3} y	α/5.438	5.1798(5)/1.1	5/2-	+1.5	+2.9	0.04354
			2.x10^{14} y	SF/3.7x10^{-9}	5.2343(5)/11				0.07467
					5.2766(5)/88				0.08657
					5.394(5)/0.12				0.11770
					5.3500(5)/ 0.16				0.14197
^{244m}Am			≈ 26. m	β$^-$/1.498		(1-)			0.0429
^{244}Am		244.064279	10.1 h	β$^-$/1.428					Am L x-ray
									Cm k x-ray
									0.7460
									0.9000
^{245}Am		245.066444	2.05 h	β$^-$/0.894	0.65/19	(5/2+)			Cm L x-ray
					0.90/77				Cm k x-ray
									0.25299
^{246m}Am			25.0 m	β$^-$/	1.3/79.	2-			Cm L x-ray
					1.60/14				Cm k x-ray
					2.1/7				0.27002
									0.79881
									1.06201
									1.07885
									(0.04-2.29)
^{246}Am		246.06977	39. m	β$^-$/2.38	1.2/	(7-)			Cm L x-ray
									Cm k x-ray
									0.1529
									0.2046
									0.6786
^{247}Am		247.0722	22. m	β$^-$/1.7					Cm L x-ray
									Cm k x-ray
									0.2267/
									0.2853/
$_{96}$Cm									
^{235}Cm		235.0516							
^{236}Cm		236.0514		EC/1.7					
^{237}Cm		237.0529		EC/2.5					
^{238}Cm		238.05302	2.4 h	EC/>90/0.97		0+			
				α/<10/6.632	6.520(50)/<10				
^{239}Cm		239.0548	≈ 3. h	EC/1.7					
									0.0407
									0.1466
									0.1874
^{240}Cm		240.055519	27. d	α/6.397	5.989/0.014	0+			
					6.147/0.05				
			1.9x10^{6} y	SF/3.9x10^{-6}	6.2478(6)/ 28.8				
					6.2906(6)/ 70.6				
^{241}Cm		241.057646	32.8 d	EC/99/0.768		1/2+			Am k x-ray
				α/1/6.184	5.8842(4)/ 0.12				0.13241

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
					5.9291(4)/ 0.18				0.16505
					5.9389(4)/ 0.69				0.18028
									0.43063
									0.47181
^{242}Cm		242.058828	162.8 d	α/6.216	5.9694(1)/ 0.035	0+			Pu L x-ray
					6.069(1)/25				0.04408
			7.0x10^{6} y	SF/6.4x10^{-6}	6.1129(1)/74				0.10189
									(0.04-1.2)
^{243}Cm		243.061381	29.1 y	α/6.167	5.6815(5)/0.2	5/2+	0.41		Pu L x-ray
					5.6856(5)/1.6				Pu k x-ray
			5.5x10^{11} y	SF/5.3x10^{-9}	5.7420(5)/ 10.6				0.10612
					5.7859(5)/ 73.3				0.20975
					5.9922(5)/6.5				0.22819
					6.0103(5)/1.0				0.27760
					6.0589(5)/5				0.28546
					6.0666(5)/1.5				0.33431
									(0.04-0.7)
^{244}Cm		244.062745	18.1 y	α/5.902	5.6656/0.02	0+			Pu L x-ray
					5.7528/23				0.04282
			1.32x10^{7} y	SF/1.4x10^{-4}	5.8050/77				0.09885
					5.515/0.004				0.15262
^{245}Cm		245.065485	8.48x10^{3} y	α/5.623	5.235(10)/0.3	7/2+	0.5		Pu L x-ray
					5.3038(10)/ 5.0				Pu k x-ray
			1.4x10^{12} y	SF/6.1x10^{-7}	5.3620(7)/93				0.04195
					5.4927(11)/ 0.8				0.13299
					5.5331(11)/ 0.6				0.13606
									0.17494
^{246}Cm		246.067217	4.76x10^{3} y	α/5.476	5.343(3)/21	0+			Pu L x-ray
			1.8x10^{7} y	SF/0.026	5.386(3)/79				0.04453
^{247}Cm		247.070346	1.56x10^{7} y	α/5.352	4.818(4)/4.7	9/2-	0.37		Pu k x-ray
					4.8690(20)/71	9/2-			0.2792
					4.941(4)/1.6				0.2886
					4.9820(20)/ 2.0				0.3471
					5.1436(20)/ 1.2				0.4035
					5.2104(20)/ 5.7				
					5.2659(20)/ 13.8				
^{248}Cm		248.072341	3.48x10^{5} y	α/99.92/5.162	4.931(5)/0.07	0+			
					5.0349(2)/ 16.5				
			4.15x10^{6} y	SF/8.38	5.0784(2)/ (75)/1				
^{249}Cm		249.075946	64.15 m	β^-/0.900	0.9/	1/2+			Bk k x-ray
									0.56039
									0.63431
^{250}Cm		250.07835	$\approx$ 9.7x10^{3} y		SF/85.8	0+			

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				α/5.27					
^{251}Cm		251.08228	16.8 m	β^-/1.42	0.90/16	(1/2+)			0.3896/
									0.5299
									0.5425
^{252}Cm		252.0849	< 2 d						
$_{97}$Bk									
^{238}Bk		238.0583	2.4 m	EC/5.0					
^{239}Bk		239.0584							
^{240}Bk		240.0598	≈ 4.8 m						
^{242}Bk		242.0621	7.0 m	EC/3.0					
^{243}Bk		243.063001	4.5 h	EC/99.8/1.508	6.542(4)/0.03	(3/2-)			0.1466
				α/0.15/6.871	6.5738(2)/ 0.04				0.1874
					6.7180(22)/ 0.02				0.755
					6.7581(20)/ 0.02				0.840
									0.946
^{244}Bk		244.0652	4.4 h	EC/99.99/2.26		(4-)			0.1445
				α/0.01/6.778	6.625(4)/ 0.003				0.1876
					6.667(4)/ 0.003				0.2176
									0.9815
									0.9215/
^{245}Bk		245.066355	4.94 d	EC/99.9/0.810		3/2-			Cm L x-ray
				α/0.1/6.453	5.8851(5)/ 0.03				Cm k x-ray
					6.1176(9)/ 0.01				0.25299
					6.1467(5)/ 0.02				0.3809
					6.3087(5)/ 0.014				0.3851
					6.3492(5)/ 0.018				
^{246}Bk		246.0687	1.80 d	EC/1.35		(2-)			Cm L x-ray
									Cm k x-ray
									0.79881
									1.08142
^{247}Bk		247.07030	$1.4x10^3$ y	α/5.889	5.465(5)/1.5	(3/2-)			0.04175
					5.501(5)/7				0.0839
					5.532(5)/45				0.268
					5.6535(20)/ 5.5				
					5.678(2)/13				
					5.712(2)/17				
					5.753(2)/4.3				
					5.794(2)/5.5				
^{248}Bk		248.07311	23.7 h	β^-/70/0.87	0.86/	(1-)			Cm L x-ray
				EC/30/0.72					Cf L x-ray
									Cm k x-ray
									Cf k x-ray
									0.5507
^{249}Bk		249.074980	320. d	β^-/0.125	0.125/100	7/2+	2.0		$0.327/10^{-5}$
				α/0.001/5.525	5.390(1)/ 0.0002				$0.308/10^{-6}$
			$1.8x10^9$ y	$SF/4.9x10^{-8}$	5.4174(6)/ 0.001				
^{250}Bk		250.078309	3.217 h	β^-/1.780	0.74/	2-			Cf L x-ray
									Cf k x-ray
									0.98912

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
									1.03184
									(0.04-1.6)
^{251}Bk		251.08075	56. m	β¯/1.09		(3/2-)			0.02481
									0.1528
									0.1776
^{252}Bk		252.0843	1.8 m						
$_{98}$Cf									
^{237}Cf		237.0621	2.1 s	α,SF/10					
^{238}Cf		238.0614	21 ms	SF/					
^{239}Cf		239.0626	≈ 0.7 m	α					
^{240}Cf		240.0623	1.1 m	α/7.719	7.590(10)/	0+			
				SF/ ≈2.1					
^{241}Cf		241.0637	4. m	EC/3.3					
				α/7.60	7.335(5)/				
^{242}Cf		242.06369	3.5 m	α/7.509	7.351(6)/20	0+			
				SF/œ0.014	7.385(4)/80				
^{243}Cf		243.0654	11. m	EC/86/2.2	7.060(6)/20	(1/2+)			
				α/14/7.40	7.170/4				
^{244}Cf		244.065990	20. m	α/7.328	7.168(5)/25	0+			
					7.210(5)/75				
^{245}Cf		245.068038	44. m	α/36/7.255	7.15/91.7				Cm K x-ray
				EC/64/1.569	6.983/0.31				0.5709
					7.09/7				0.6014
					7.065/0.68				0.6163
^{246}Cf		246.068798	1.49 d	α/6.869	6.6156(10)/ 0.18	0+			Cm L x-ray
					6.7086(7)/ 21.8				0.04221
			$1.8x10^{3}$ y	SF/$2.3x10^{-4}$	6.7501(7)/ 78.0				0.0945
									0.147
^{247}Cf		247.07099	3.11 h	EC/99.96/0.65		7/2+			Bk k x-ray
				α/0.04/6.55	6.301(5)/				0.2941
									0.4778
^{248}Cf		248.07218	334. d	α/6.369	6.220(5)/17	0+			
			$3.2x10^{4}$ y	SF/0.0029	6.262(5)/83				
^{249}Cf		249.074846	351. y	α/6.295	5.7582(2)/3.7	9/2-			Cm L x-ray
					5.8119(2)/84				Cm k x-ray
			$8.x10^{10}$ y	SF/$4.4x10^{-7}$	5.8488(2)/1.0				0.25299
					5.9029(2)/2.8				0.33351
					5.9451(2)/4.0				0.38832
					6.1401(2)/1.1				(0.0376-1.103)
					6.1940(2)/2.2				
^{250}Cf		250.076399	13.1 y	α/6.129	5.8913(4)/0.3	0+			Cm L x-ray
			$1.7x10^{4}$ y	SF/0.077	5.9889(4)/15				0.04285
					6.0310(4)/ 84.5				
^{251}Cf		251.079579	$9.0x10^{2}$ y	α/6.172	5.56448(7)/ 1.5	1/2+			
					5.632(1)/4.5				
					5.648(1)/3.5				
					5.6773(6)/35				
					5.762(3)/3.8				
					5.7937(7)/2.0				
					5.8124(8)/4.2				
					5.8514(6)/27				
					6.0140(7)/ 11.6				
					6.0744(7)/2.7				

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/Energy Intensity (MeV/%)
^{252}Cf		252.081619	2.65 y	α/96.9/6.217	5.7977(1)/0.23	0+			Cm L x-ray
			86. Y	SF/3.1/	6.0756(4)/15.2				0.04339
					6.1184(4)/81.6				0.1002
^{253}Cf		253.08512	17.8 d	β^-/99.7/0.29	0.27/100	(7/2+)			
				α/0.3/6.126	5.921(5)/0.02				
^{254}Cf		254.08732	60.5 d	SF/99.7/		0+			
				α/0.3/5.930	5.792(5)/0.05				
					5.834(5)/0.26				
^{255}Cf		255.0910	1.4 h	β^-/0.7					
^{256}Cf		256.0934	12. m	SF					
$_{99}$Es									
^{241}Es		241.0687	≈ 8 s	α	8.11				
^{242}Es		242.0697	16 s	α	7.92				
^{243}Es		243.0696	21. s	α/>30/	7.89/>30				
				EC/<70/4.0					
^{244}Es		244.0709	37. s	EC/76/4.6					
				α/4/	7.57/4				
^{245}Es		245.0713	1.3 m	α/40/7.858	7.74				
				EC/60/3.1					
^{246}Es		246.0730	7.7 m	EC/90/3.9					
				α/10/	7.35				
^{247}Es		247.07365	4.8 m	EC/93/2.48					
				α/7/	7.32				
^{248}Es		248.0755	26. m	EC/99.7/3.1					
				α/0.3/	6.87				
^{249}Es		249.07640	1.70 h	EC/99.4/1.45		(7/2+)			0.3795
				α/0.6/	6.77				0.8132
^{250m}Es			2.2 h	EC/		(1-)			Cf L x-ray
				β^+					Cf k x-ray
									0.9891
									1.0319
^{250}Es		250.0787	8.6 h	EC/2.1		(6+)			Cf L x-ray
									Cf k x-ray
									0.30339
									0.34948
									0.82883
^{251}Es		251.07998	1.38 d	EC/99.5/0.38		(3/2-)			
				α/0.5/	6.462/0.05				
					6.492/0.4				
^{252}Es		252.08297	1.29 y	α/76/	6.632/61.0	(5-)			
				EC/24/1.26	6.562/10.3				
^{253}Es		253.084818	20.47 d	α/	6.633/89.8	7/2+	+4.10	7.	0.04180
			6.3×10^5 y	SF/8.9×10^{-6}	6.5916/6.6				0.3892
^{254m}Es			1.64 d	β^-/99.6/	0.475	2+	2.9	3.7	Fm L x-ray
				α/0.3/6.67	6.382	2+			Fm k x-ray
			>10. Y	SF/0.045					0.6488
									0.6938
^{254}Es		254.088017	276. d	α/	6.429	(7+)			0.064
			$>2.5 \times 10^7$ y	SF/$<3 \times 10^{-6}$					
^{255}Es		255.09027	40. d	β^-/92/0.29		(7/2+)			
				α/8/	6.26				
			2.6×10^3 y	SF/0.0042	6.300				
^{256m}Es			7.6 h	β^-/		(8+)			0.218
									0.232
									0.862
^{256}Es		256.0936	25. m	β^-/1.7		(1+)			

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{257}Es		257.0960	7.7 d	β⁻					
$_{100}$Fm									
^{242}Fm		242.0734	0.8 ms	SF/>96					
^{243}Fm		243.0745	0.2 s	α/	8.55				
				<SF/0.4					
^{244}Fm		244.0741	3.3 ms	SF/>97		0+			
^{245}Fm		245.0754	4. s	α/	8.15/				
				SF/<0.1					
^{246}Fm		246.07528	1.2 s	α/85/	8.24/	0+			
				SF/15/					
^{247m}Fm			9. s	α/	8.18/				
^{247}Fm		247.0768	35. s	α/8.20	7.87/70				
				EC/2.9	7.93/30				
^{248}Fm		248.07718	36. s	α/99.9/8.001	7.83/20	0+			
				SF/0.1/	7.87/80				
^{249}Fm		249.0790	3. m	EC/2.4		(7/2+)			
				α/	7.53				
^{250m}Fm			1.8 s	IT/					
				SF/<8x10^{-5}					
^{250}Fm		250.07951	30. m	α/	7.43/	0+			
				EC/0.8					
				SF/0.007					
^{251}Fm		251.08157	5.3 h	EC/98/1.47		(9/2-)			
				α/2/	6.833				
^{252}Fm		252.08246	1.058 d	α/7.154	6.998/15	0+			
				SF/0.0023	7.039/85				
^{253}Fm		253.085175	3.0 d	EC(88%)/0.333	6.676/	1/2+			Es k x-ray
				α/12/	6.943/				0.2719
^{254}Fm		254.086847	3.240 h	α/	7.150	0+			
				SF/0.059	7.192				
^{255}Fm		255.089955	20.1 h	α/	6.9635(5)/5.0	7/2+			
			1.0x10^{4} y	SF/2.3x10^{-5}	7.0225(5)/ 93.4				
^{256}Fm		256.09177	2.63 h	SF/91		0+			
				α/19	6.92/				
^{257}Fm		257.09510	100.5 d	α/99.79	6.519	(9/2+)			0.1794
				SF/0.21					0.2410
^{258}Fm		258.0971	0.37 ms	SF/					
^{259}Fm		259.1006	1.5 s	SF/					
^{260}Fm			≈4 ms	SF/					
$_{101}$Md									
^{245m}Md			≈ 0.4 s	α	8.64,8.68				
^{245}Md		245.0810	0.9 ms	SF					
^{246}Md		246.0819	1.0 s	α	8.74				
					8.50-8.56				
^{247m}Md			≈0.2 s	SF/					
^{247}Md		247.0818	3. s	α	8.43				
^{248}Md		248.0828	7. s	EC/80/5.3	8.32/15				
				α/20/	8.36/5				
				SF/<0.05					
^{249}Md		249.0830	24. s	EC>/<80/3.7					
				α/>20/8.46	8.030(20)/				
^{250}Md		250.0845	50. s	EC/94/4.6	7.75/4				
				α/6/8.25	7.83/2				
^{251}Md		251.0849	4.0 m	EC/>94/3.1					
				α/<6/	7.55/				
^{252}Md		252.0866	2. m	EC/>50/3.9					
				α/<50/	7.73/				
^{253}Md		253.0873	≈6 m	EC/2.0					

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{254m}Md			30. m	EC/					
^{254}Md		254.0897	10. m	EC/2.7					
^{255}Md		255.09108	27. m	EC/92/1.04	α/7.33/93	(7/2-)			0.121/100
				α/8/	7.27/5				0.115/65
				SF/ð0.15	7.75/1				0.136/35
					7.71/1				0.141-0.453
^{256}Md		256.0941	1.30 h	EC/89/2.13	7.21/71				Fm k x-ray
				α/11/	7.14/22				0.121/409
				SF/<2.6	7.68/2.5				0.115/266
					7.25/2.5				0.136/143
					7.64/2.1				0.634/119
									0.141-1.374
^{257}Md		257.095535	5.5 h	EC/85/0.41	7.074	(7/2-)			Fm k x-ray
				α/15,SF/ð1	7.014				(0.181-0.389)
^{258m}Md			57. m	EC/		(1-)			Fm k x-ray
				SF/ð30					
^{258}Md		258.098427	51.5 d	α/7.40	6.718(2)/	(8-)			0.3678
				SF/œ0.003	6.763(4)/				0.057 - 0.448
^{259}Md		259.1005	1.64 h	SF/>98.7		7/2+			
				α/<1.3					
^{260}Md		260.104	≈ 27.8 d	SF/73-100					
$_{102}$No									
^{250}No		250.0875	0.25 ms	SF/		0+			
^{251}No		251.0889	0.76 s	α/	8.62/96				
				SF/0.26	8.58/4				
^{252}No		252.08897	2.3 s	α/74/8.551	8.42	0+			
				SF/26/	8.37				
^{253}No		253.0907	1.7 m	α/	8.010(20)	(9/2-)			
				EC/3.2					
^{254m}No			0.28 s	I.T./					
				SF/ð.2					
^{254}No		254.09095	49. s	α/	8.09	0+			
				EC/1.1					
				SF/0.17					
^{255}No		255.09323	3.1 m	α/62/	8.12/	1/2+			0.187
				EC/38/2.01	7.93				
					8.08				
^{256}No		256.09428	2.9 s	α/	8.43	0+			
				SF/0.5					
^{257}No		257.09685	25. s	α/	8.22	(7/2+)			
				SF/<1.5	8.27				
					8.32				
^{258}No		258.0983	≈ 1.2 ms	SF/		0+			
^{259}No		259.1011	58. m	α/78/7.794	7.52	(9/2+)			
				EC/22/0.5	7.55				
				SF/<9.7					
^{260}No		260.103	0.11 s	SF/					
^{262}No		262.108	≈ 8. ms	SF/					
$_{103}$Lr									
^{251}Lr		251.0944	39 m	SF					
^{252}Lr		252.0953	≈0.36 s	α	9.02/73				
				SF/<1	8.97/27				
^{253m}Lr			≈0.57 s	α	8.79				
				SF/1					
^{253}Lr		253.0953	1.5 s	α/	8.72				
				SF/≈5					
^{254}Lr		254.0965	13. s	α/	8.45				
				EC/5.2					
				SF/<0.1					

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
^{255}Lr		255.0967	22. s	α/	8.37/60				
				EC/3.2	8.43/40				
				SF/<0.1					
^{256}Lr		256.0988	28. s	α/99.7/8.554	8.43/				
				EC/4.2	8.39				
				SF/<0.03					
^{257}Lr		257.0996	0.65 s	α/	8.80	7/2+			
				EC/2.5	8.80				
				SF/<0.03					
^{258}Lr		258.1019	3.9 s	α/	8.60/46				
				EC/3.4	8.62/25				
				SF/<5	8.56/20				
					8.65/9				
^{259}Lr		259.1030	6.1 s	α/80	8.44(1)				
				SF/20					
^{260}Lr		260.1056	3. m	α/	8.03				
^{261}Lr		261.1069	40. m	SF					
^{262}Lr		262.1097	3.6 h	EC/2.					
				SF/<10					
$_{104}$Rf									
^{253}Rf		253.1007	≈ 48. μs	SF					
				α/<10					
^{254}Rf		254.1002	23. μs	SF/>98.5					
				α/<1.5					
^{255}Rf		255.1015	1.6 s	α	8.72/55				
				SF/45	8.77/25				
					8.80/7				
					8.69/3.5				
					8.83/3.5				
					8.89/2.5				
					8.92/2.5				
^{256}Rf		256.10118	6.2 ms	SF/99.68					
				α/0.32	8.81				
^{257}Rf		257.1031	4.7 s	α/9.22	8.77				0.117
				EC/11	9.01				
				SF/<1.4	8.95				
					8.62				
^{258}Rf		258.1036	12. ms	SF/87					
				α/13					
^{259}Rf		259.1056	3.4 s.	α/9.09/93	8.77(2)/				
				SF/7	8.86/				
^{260}Rf		260.1064	20. ms	SF/					
^{261}Rf		261.1088	1.1 m	α/8.78,SF/<10	8.28/				
^{262}Rf		262.1099	2.1 s	SF/>99.2					
^{263}Rf		263.1125	10. m	SF,α					
$_{105}$Db									
^{255}Db		255.1074	≈ 1.5 s	α,					
				SF/≈20					
^{256}Db		256.1081	1.9 s	α/64	9.02/≈64				
				EC/35	8.89/≈12				
				SF/0.05	9.08/≈12				
					9.12/≈12				
^{257}Db		257.1079	1.5 s	α/	8.97/33				
				SF/<6	9.07/38				
					9.12/5.5				
					8.94/9				
					9.02/9				
					8.89/5.5				
^{258}Db		258.1094	4.2 s	α/	9.20/				

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
				E.C/5.3	9.16/				
				SF/<33					
^{259}Db		259.1097	≈ 1.2 s	SF/					
^{260}Db		260.1114	1.5 s	α/	9.05/				
				SF/<9.6	9.08/				
					9.13/				
^{261}Db		261.1121	1.8 s	α/	8.93/				
				SF/<18					
^{262}Db		262.1141	34. s	SF/<33					
				α/	8.45/				
					8.53/				
					8.67/				
^{263}Db		263.1151	≈0.45 m	SF/57/, α/43/	8.35/43				
$_{106}$Sg									
^{258}Sg		258.1132	≈ 2.9 ms	SF					
				α/<20					
^{259}Sg		259.1147	0.5 s	α/	9.62				
				SF/<20	9.35				
					9.03				
^{260}Sg		260.11444	4. ms	α/50	9.76				
				SF/50	9.72				
					9.81				
^{261}Sg		261.1162	0.3 s	α,SF/<10	9.56				
^{263}Sg		263.1183	0.8 s	α	9.06				
				SF/<30	9.25				
^{265}Sg		265.1211	≈7.4 s	α/>65	8.84/46				
				SF/<35	8.76/23				
					8.94/23				
					8.69/8				
^{266}Sg		266.1219	≈21. s	α/	8.77/66				
				SF/<82	8.52/33				
^{269}Sg									
$_{107}$Bh									
^{260}Bh		260.122		α					
^{261}Bh		261.1218	12. ms	α/,SF<10	10.40				
					10.10				
					10.03				
^{262m}Bh			8. ms	α/	10.37				
				SF/<12	10.24				
^{262}Bh		262.1230	0.10 s	α/	10.06				
				SF/<12	9.91				
					9.74				
^{264}Bh		264.1247	0.44 s	α/	9.48				
				SF/	9.62				
^{266}Bh		266.1270	≈1 s	9.29					
^{267}Bh		267.1277	≈17 s	8.83					
$_{108}$Hs									
^{263}Hs		263.1287		α/					
^{264}Hs		264.1284	≈ 0.08 ms	α/,SF/≈50	11.0				
^{265m}Hs			≈0.75 ms	α	10.57/63				
					10.73				
					10.52				
					10.34				
^{265}Hs		265.1300	2.0 ms	α/	10.30/90				
				SF/<1	10.43				
					10.37				
					10.25				
^{267}Hs		267.1371	33 ms	α/>88	9.88				
					9.83				

Elem. or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2p)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	g-ray/Energy Intensity (MeV/%)
					9.75				
^{269}Hs		269.1341	9.3 s	α	9.23				
					9.17				
^{273}Hs			≈1.2 s	α	9.78				
					9.47				
^{277}Hs			≈11 m	SF					
$_{109}$Mt									
^{266m}Mt			≈1.2 ms	α	10.46-10.81				
^{266}Mt		266.1379	≈0.7 ms	α	10.48-11.31				
^{267}Mt		267.138	19 ms	α					
^{268}Mt		268.1388	0.07 s	α/>68	10.10,10.24				
$_{110}$110									
^{267}110		267.1440	≈ 3 μs	α/>32	11.6				
^{269}110		269.1451	0.17 ms	α/>75	11.11				
^{271m}110			≈1.1 ms	α	10.68				
					10.74				
^{271}110		271.1461	≈ 56 ms	α	10.71				
^{273m}110			0.076 ms	α	11.8				
^{273}110		273.1492	118 ms	α/	9.73				
^{277}110			≈3.0 ms	α	10.2				
^{280}110			≈7.5 s		SF/				
^{281}110			≈ 1 m	α	8.83				
$_{111}$111									
^{272}111		272.1535	≈ 1.5 ms	α/>68	10.82				
$_{112}$112									
^{277}112			≈ 0.24 ms	α	11.45				
					11.65				
^{281}112			≈ 0.89 ms	α	10.7				
^{283}112			≈ 1. m		sf/>0.7				
				α/<0.3					
^{284}112			≈9.8 s	α	9.17				
^{285}112			≈11. m	α	8.67				
$_{114}$114									
^{285}114			≈ 0.58 ms	α	11.3				
^{287}114			≈ 5.5 s	α	10.3				
^{288}114			≈1.9 s	α	9.84				
^{289}114			≈ 20. s	α	9.71				
$_{116}$116									
^{289}116			≈ 0.60 ms	α	11.6				
$_{118}$118									
^{293}118			≈ 0.12 ms	α	12.4				

TABLE OF THE ISOTOPES

Norman E. Holden

This table presents an evaluated set of values for the experimental quantities which characterize the decay of radioactive nuclides. A list of the major references used in this evaluation is given below. When uncertainties are not listed, they are assumed to be five or less in the last digit quoted. If they exceed five in the last digit, the value is prefaced by an approximate sign. The effective literature cutoff date for data in this edition of the Table is December, 2000.

Table Layout

Column No.	Column Title	Description
1	Isotope or Element	For elements, the atomic number and chemical symbol are listed. For nuclides, the mass number and chemical symbol are listed. Isomers are indicated by the addition of m, m1, or m2.
2	Isotopic Abundance	in atom percent.
3	Atomic Mass or Atomic Weight	Atomic mass relative to ^{12}C = 12. Atomic weight is given on the same scale.
4	Half-life	Half-life in decimal notation. µs = microseconds; ms = milliseconds; s = seconds; m = minutes; h = hours; d = days; and y = years.
5	Decay Mode/Energy	Decay modes are α = alpha particle emission; β^- = negative beta emission; β^+ = positron emission; EC = orbital electron capture; IT = isomeric transition from upper to lower isomeric state; n = neutron emission; SF = spontaneous fission. Total disintegration energy in MeV units.
6	Particle Energy/Intensity	End point energies of beta transitions and discrete energies of alpha particles in MeV and their intensities in percent.
7	Spin and Parity	Nuclear spin or angular momentum of the nuclides in units of h/2"; parity is positive or negative.
8	Magnetic Dipole Moment	Magnetic dipole moments in nuclear magneton units.
9	Electric Quadrupole Moment	Electric quadrupole moments in barn units (10^{-24} cm^2).
10	Gamma Ray Energy/Intensity	Gamma ray energies in MeV and intensities in percent. Ann. rad. refers to the 511.006 keV photons emitted in the annihilation of positrons in matter.

General Nuclear Data References

The following references represent the major sources of the nuclear data presented, along with subsequent published journals and reports:

1. G. Audi, O. Bersillon, J. Blachot, A.H. Wapstra, *The Nubase Evaluation of Nuclear and Decay Properties,* Nuclear Physics A624, 1 (1997).
2. International Commission on Atomic Weights, *Atomic Weights of the Elements - 1995,* Pure & Applied Chemistry 68, 2339 (1996).
3. J.R. Parrington, H.D. Knox, S. Breneman, E.M. Baum, F. Feiner, *Chart of the Nuclides, 15th Edition,* Knolls Atomic Power Lab. (1996)
4. N.E. Holden, *Total and Spontaneous Fission Half-lives for Uranium, Plutonium, Americium and Curium Nuclides,* Pure & Applied Chemistry 61, 1483 (1989).
5. N.E. Holden, *Half-lives of Selected Nuclides,* Pure & Applied Chemistry 62, 941 (1990).
6. N.E. Holden, *Review of Thermal Neutron Cross Sections and Isotopic Composition of the Elements,* BNL-NCS-42224 (March 1989).
7. P. Raghavan, *Table of Nuclear Moments,* Atomic Data Nuclear Data Tables 42, 189 (1989).
8. E. Brown, R. Firestone, *Radioactivity Handbook,* Wiley Interscience Press (1986).
9. J.K. Tuli, *Nuclear Wallet Cards,* Brookhaven National Laboratory (July 1995).
10. N.E.Holden, D.C.Hoffman, *Spontaneous Fission Half-lives for Ground State Nuclides,* Pure & Applied Chemistry 72 1525 (2000).
11. N. Stone, Table of New Nuclear Moments, private communication, www.nndc.bnl.gov/nndc/stone_moments/moments.html (Dec 2000)

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Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
$_{0}$n		1.008664924	614. S	β$^-$/0.78235		0.782/100.	1/2+	-1.913043	
$_{1}$H		1.00794(7)							
^{1}H	99.985(1)	1.007825032				1/2+	+2.79285		
^{2}H	0.015(1)	2.014101778				1+	+0.85744	+2.86 mb	
^{3}H		3.016049268	12.33 y	β$^-$/0.01859		0.01860/100.		1/2+	+2.97896
^{4}H		4.0278	1.9x10^{-22} s		n/	/100	2-		
^{5}H		5.040	8.x10^{-23} s	n/	/100				
^{6}H		6.0449	3.x10^{-22} s						
$_{2}$He		4.002602(2)							
^{3}He	1.37x10^{-4}	3.016029309				1/2+	-2.12762		
^{4}He	≈100.	4.002603250				0+			
^{5}He		5.01222	7.6x10^{-22} s		n,_		3/2-		
^{6}He		6.018888	0.807 s	β$^-$/3.508,d		3.510/100.	0+		
^{7}He		7.02803	3.x10^{-21} s	n		(3/2)-			
^{8}He		8.03392	0.119 s	β$^-$/10.65, t	13/88.	0+			0.9807/84.
				n/	/12.				0.4776/5.
^{9}He		9.0438	7.x10^{-21} s	n /100 (1/2-)					
^{10}He		10.0524	3.x10^{-21} s	2n /100 0+					
$_{3}$Li		6.941(2)							
^{4}Li		4.0272	9.x10^{-23} s	p/	/100	2-			
^{5}Li		5.01254	≈3.x10^{-22} s		p/		3/2-		
^{6}Li	7.5(2)	6.0151223				1+	+0.82205	-0.8 mb	
^{7}Li	92.5(2)	7.0160041				3/2-	+3.25644	-0.041	
^{8}Li		8.022486	0.84 s	β$^-$/16.004	12.5/100.	2+	+1.6536	+0.032	
				_/	_(1.6)				
^{9}Li		9.026789	0.178 s	β$^-$/13.606	13.5/75.	3/2-	3.439	-0.027	
				β$^-$/	11/25.				
^{10}Li		10.03590	4.x10^{-22} s	β$^-$ /20.84					
^{11}Li		11.04380	8.4 ms	β$^-$/20.6		3/2(-)	3.668	-0.031	3.367/35.
				n,2n,3n,_	n//106.				(0.22-2.81)
^{12}Li		12.054	<0.01 &s						
$_{4}$Be		9.012182(3)							
^{5}Be		5.041							
^{6}Be		6.01973	5.0x10^{-21} s		2p,_		0+		
^{7}Be		7.0169293	53.28 d	EC/0.8618		3/2-			0.4776/10.4
^{8}Be		8.00530509	≈7.x10^{-17} s		2_/0.046		0+		
^{9}Be	100.	9.0121822				3/2-	-1.1776	+0.0529	
^{10}Be		10.0135338	1.52x10^{6} y	β$^-$/0.5559	0.555/100.	0+			
^{11}Be		11.02166	13.8 s	β$^-$,β$^-$_/11.51		11.48/61.	1/2+		2.125/35.5
									(0.478-7.97)
^{12}Be		12.02692	24. ms	β$^-$,(n)/11.71		n//0.5	0+		(0.95 - 4.4)
^{13}Be		13.0361	≈ 3.x10^{-21} s						
^{14}Be		14.0428	4.3 ms	β$^-$,(n)/16.2		n//100.	0+		
$_{5}$B		10.811(7)							
^{7}B		7.0299	4.x10^{-22} s	p					
^{8}B		8.024607	0.770 s	β$^+$, 2_/17.979	13.7(β$^+$)/93.	2+	1.0355	0.068	ann.rad.
^{9}B		9.013329	8x10^{-19} s	p2_/		3/2-			
^{10}B	19.9(2)	10.0129371				3+	+1.8006	+0.085	
^{11}B	80.1(2)	11.0093055				3/2-	+2.6886	+0.0406	
^{12}B		12.014352	0.0202 s	β$^-$/13.369		1+	+1.0027	0.0132	4.438/1.3
				β$^-$ _/1.6/					3.215/0.00065
^{13}B		13.017780	0.0174 s	β$^-$ /13.437	13.4	3/2-	+3.17778	0.037	3.68/7.6
				β$^-$ n/0.25/	2.43(n)/0.09				
					3.55(n)/0.16				
^{14}B		14.02540	14. ms	β$^-$ /20.64		2-	1.185	0.0298	6.094/90.
^{15}B		15.03110	10.4 ms	β$^-$,(n)/19.09			(3/2-)	2.66	0.038
^{16}B		16.0398	<1.9x10^{-10} s						
^{17}B		17.0469	5.1 ms	β$^-$,(n)/22.7				2.54	
^{18}B		18.056	<0.026 μ						

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TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{19}B		19.0637	3.3 ms	β^-,(n)/26.5		n//125.			
$_{6}$C		12.0107(8)							
^{8}C		8.03768	$2.0x10^{-21}$ s		p		0+		
^{9}C		9.031040	127. ms	β^+ ,p, 2_/16.498		(3/2-)	-1.391		ann.rad.
^{10}C		10.0168532	19.3 s	β^+ /3.648		1.865	0+		ann.rad.
									0.71829/100.
^{11}C		11.011433	20.3 m	β^+ ,EC/1.982	0.9608/99.	3/2-	-0.964	0.0333	ann.rad.
^{12}C	98.93(8)	12.000000000					0+		
^{13}C	1.07(8)	13.003354838					1/2-	+0.70241	
^{14}C		14.003241991		5715. y	β^- /0.15648	0.1565/100.		0+	
^{15}C		15.010599	2.45 s	β^- /9.772	4.51/68.	1/2+	1.32		5.298/68.
					9.82/32.				(7.30-9.05)
^{16}C		16.014701	0.75 s	β^- ,n/8.012			0+		
^{17}C		17.02258	0.19 s	β^- ,n/13.17					1.375
									1.849
									1.906
^{18}C		18.02676	0.09 s	β^- ,n/11.81			0+		
^{19}C		19.0353	0.05 s	n					
^{20}C		20.0403	0.01 s			0+			
^{21}C		21.0493	<0.03 μs						
^{22}C		22.056	9 ms	β^-,n	n//99.	0+			
$_{7}$N		14.00674(7)							
^{10}N		10.0426							
^{11}N		11.0268	$5.x10^{-22}$ s						
^{12}N		12.018613	11.00 ms	β^+,β^+_/17.338 16.38/95.		1+	+0.457	+10. mb	ann.rad.
									4.438/2.
^{13}N		13.0057386	9.97 m	β^+ /2.2204		1.190/100.	1/2-	0.3222	
^{14}N	99.632(7)	14.003074007					1+	+0.40376	+0.0200
^{15}N	0.368(7)	15.00010897				1/2-	-0.28319		
^{16}N		16.006100	7.13 s	β^- /10.419		4.27/68.	2-		6.129/68.8
					10.44/26.				7.115/4.7
				β^-, _	1.85/.0012				(0.99-8.87)
^{17}N		17.00845	4.17 s	β^- ,β^- n/8.68		3.7/100.	1/2-	0.352	0.871/3.
				0.4-1.7n/95.					2.1842/0.3
				β^- _/	8.0, 8.2				
^{18}N		18.01408	0.62 s	β^- /13.90	9.4/100.	1-	0.328	0.012	0.822/61.
									1.65/60.5
									1.982/98.
									(0.535-7.13)
^{19}N		19.01703	0.32 s	β^-/12.53					(0.096-3.14)
^{20}N		20.02337	0.14 s	β^- /17.97					
^{21}N		21.0271	0.08 s						
^{22}N		22.0344	0.02 s						
^{23}N		23.0405	15 ms	β^-,n	n//80.				
^{24}N		24.050	<0.052 μs						
$_{8}$O		15.9994(3)							
^{12}O		12.03440	≈$1.x10^{-21}$ s		2p				
^{13}O		13.02481	8.9 ms	β^+,p/17.77	1.56 (p)/	(3/2-)	1.389	0.026	ann.rad.
									4.438/0.56
^{14}O		14.0085953	70.60 s	β^+ /5.1430		1.81/99.	0+		ann.rad.
									2.312/99.4
^{15}O		15.0030655	122.2 s	β^+ /2.754		1.723/100.	1/2-	0.7195	ann.rad.
^{16}O	99.757(16)	15.994914622					0+		
^{17}O	0.038(1)	16.9991315				5/2+	-1.8938	-0.026	
^{18}O	0.205(14)	17.999160				0+			
^{19}O		19.003579	26.9 s	β^- /4.820	3.25/60.	5/2+	1.5320	3.7 mb	0.197/95.9
					4.60/40.				1.3569/50.4
									(0.11-4.18)
^{20}O		20.004076	13.5 s	β^- /3.814		0+			1.057/100.

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{21}O		21.00866	3.4 s	β^- /8.11					(0.28-4.6)
^{22}O		22.00997	2.2 s	β^- /6.5					(0.64-1.86)
^{23}O		23.0157	0.08 s						
^{24}O		24.0204	≈65 ms		β^-,n	n//18.			1.83/28
									0.52/14.
									1.31/12.
^{25}O		25.029	<0.05 μs						
^{26}O		26.038	<0.04 μs						
$_{9}$F		18.9984032(5)							
^{14}F		14.036							
^{15}F		15.0180	5.x10^{-22} s	p		(1/2+)			
^{16}F		16.01147	≈1.x10^{-20} s		p		0-		
^{17}F		17.0020952	64.5 s	β^+ /2.761	1.75/	5/2+	+4.721	0.058	ann.rad.
^{18}F		18.000938	1.830 h	β^+ ,EC/1.656	0.635/97.	1+			ann.rad.
^{19}F	100.	18.9984032				1/2+	+2.62887	0.072	
^{20}F		19.9999813	11.00 s	β^- /7.0245	5.398/100.	2+	+2.0934	0.042	1.634/100.
									3.33/0.009
^{21}F		20.999949	4.16 s	β^- /5.684	3.7/8.	5/2+	3.9		0.3507/90.
					5.0/63.				1.395/15.
					5.4/29.				(1.746-4.684)
^{22}F		22.00300	4.23 s	β^- /10.82	3.48/15.	4+			1.2746/100.
					4.67/7.				2.0826/82.
					5.50/62.				(0.82-4.37)
^{23}F		23.00357	2.2 s	β^- /8.5		5/2+			1.701/48.
									2.129/34.
									(0.493-3.83)
^{24}F		24.0081	0.3 s	β^- /13.5					1.9816/
^{25}F		25.0121	≈50 ms		β^-,(n)	n//14.			1.70/39.
									(0.57-2.19)
^{26}F		26.0196	10 ms	β^-,(n)	n//11.				2.02/67.
									1.67/19.
^{27}F		27.0269	5. ms	β^-,(n)	n//90.				
^{29}F		29.043	3. ms	β^-,(n)	n//100.				
^{31}F									
$_{10}$Ne		20.1797(6)							
^{16}Ne		16.02575	4.x10^{-21} s	2p		0+			
^{17}Ne		17.01770	109. ms	β^+ .p/14.53		1.4-10.6/	1/2-		ann.rad./
									0.495
^{18}Ne		18.005697	1.67 s	β^+ /4.446		3.416/92.	0+		ann.rad./
									1.0413/7.8
									(0.658-1.70)
^{19}Ne		19.001880	17.22 s	β^+ /3.238		2.24/99.	1/2+	-1.885	ann.rad./
									(0.11-1.55)
^{20}Ne	90.48(3)	19.992440176					0+		
^{21}Ne	0.27(1)	20.99384674				3/2+	-0.66180	+0.103	
^{22}Ne	9.25(3)	21.9913855				0+		-0.19	
^{23}Ne		22.9944673	37.2 s	β^- /4.376	3.95/32.	5/2+	-1.08		0.440/33.
					4.39/67.				(1.64-2.98)
^{24}Ne		23.99362	3.38 m	β^- /2.47	1.10/8.	0+			0.4723/100.
					1.98/92.				0.874/7.9
^{25}Ne		24.99779	0.61 s	β^- /7.30	6.3/	1/2+			0.0895/96.
					7.3/				(0.98-3.69)
^{26}Ne		26.00046	197 ms	β^- /7.3		0+			0.233/
^{27}Ne		27.0076	32 ms	β^-, n/12.7			(3/2+)		
^{28}Ne		28.0121	18. ms	β^-, n/12.3		n//11.	0+		2.06/19.
									0.86/3.
^{29}Ne		29.0194	15. ms	β^-,(n)/15.4		n//27.	(3/2+)		2.92/54.
									(0.22-1.18)
^{30}Ne		30.024	7. ms	β^-, (n)	n//9.	0+			

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{31}Ne		31.033	>0.26 μs						
^{32}Ne		32.040	>0.20 μs				0+		
$_{11}$Na		22.989770(2)							
^{18}Na		18.0272							
^{19}Na		19.01388	0.03 s	β^+ ,p/11.18					
^{20}Na		20.00735	0.446 s	β^+ /13.89			2+	+0.3694	ann.rad./
				_	2.15/				1.634/79.
^{21}Na		20.997655	22.48 s	β^+ /3.547	2.50/95.	3/2+	+2.3863	+0.05	ann.rad./
									0.351/5.
^{22}Na		21.9944366	2.605 y	β^+ /90/2.842		0.545/90.	3+	+1.746	ann.rad./
				EC/10/					1.2745/99.9
^{23}Na	100.	22.9897697				3/2+	+2.21752	+0.104	
^{24m}Na			20.2 ms	I.T.,β^-		1+			0.4723/100.
^{24}Na		23.9909633	14.96 h	β^- /5.5158		1.389/>99.	4+	+1.690	1.3686/100.
									2.754/100.
									(0.997-4.238)
^{25}Na		24.989954	59.3 s	β^- /3.835	2.6/7.	5/2+	+3.683	-0.10	0.3897/12.7
					3.15/25.				0.5850/13.
					4.0/65.				0.9747/14.9
									(0.836-2.80)
^{26}Na		25.99259	1.07 s	β^- /9.31		3+	+2.851	-0.08	1.809/98.9
^{27}Na		26.99401	0.290 s	β^- /9.01	7.95/	5/2+	+3.90	0.24	0.9847/87.4
				β^- ,n/					1.698/11.9
^{28}Na		27.9989	31. ms	β^- /14.0	12.3/	1+	+2.43	-0.02	1.473/37.
				β^- ,n/					2.389/18.6
^{29}Na		29.0028	44. ms	β^- ,n/13.3	11.5/	3/2+	+2.45	-1.3	2.560/36.
									(1.04-3.99)
^{30}Na		30.0092	50. ms	β^- /17.5		2	+2.08		1.483/46.
^{31}Na		31.0136	17.2 ms	/15.9		(3/2-)	+2.31		1.483/14.
				β^- ,n					(0.05-3.54)
^{32}Na		32.0197	13.5 ms	β^- /19.1					0.886/60.
^{33}Na		33.027	8.1 ms	β^- /20.					0.886/16.
^{34}Na		34.035	5. ms	β^- /24.					0.886/60.
^{35}Na		35.044	1.5 ms	β^- /24					
$_{12}$Mg		24.3050(6)							
^{20}Mg		20.01886	96. ms	β^+ ,p/10.73			0+		
^{21}Mg		21.01171	122. ms	β^+ ,p/13.10			5/2+		0.332/51.
^{22}Mg		21.999574	3.86 s	β^+ /4.786		3.05/	0+		0.0729/60.
									0.5820/100.
									(1.28-1.93)
^{23}Mg		22.994125	11.32 s	β^+ /4.057	3.09/92.	3/2+	0.536	1.25	0.440/8.2
^{24}Mg	78.99(4)	23.9850419				0+			
^{25}Mg	10.00(1)	24.9858370				5/2+	-0.85545	+0.199	
^{26}Mg	11.01(3)	25.9825930				0+			
^{27}Mg		26.9843407	9.45 m	β^- /2.6103		1.59/41.	1/2+		0.17068/0.9
					1.75/58.				0.84376/72.
					2.65/0.3				1.01443/28.
^{28}Mg		27.983877	20.9 h	β^- /1.832	0.459/95.	0+			0.0306/95.
									0.4006/36.
									0.9418/36.
									1.342/54.
^{29}Mg		28.98855	1.3 s	β^- /7.55	5.4/	3/2+			0.960/15.
									1.398/16.
									2.224/36.
^{30}Mg		29.9905	0.32 s	β^- /7.0		0+			0.224/85.
^{31}Mg		30.9966	0.24 s	β^- /11.7		(3/2+)			1.61/26.
^{32}Mg		31.9992	0.12 s	β^- /10.3		0+			2.765/25.
^{33}Mg		33.0056	0.09 s	β^- /13.7					1.848/
^{34}Mg		34.0091	0.02 s	β^- /11.3		0+			

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{35}Mg		35.0175	0.07 s			(7/2-)			
^{36}Mg		36.022	>0.2 μs			0+			
^{37}Mg		37.031	>0.26 μs				(7/2-)		
^{38}Mg						0+			
$_{13}$Al		26.981538(2)							
^{21}Al		21.028	<0.035 μs						
^{22}Al		22.0195	59. ms	β^+ /18.6		4+			ann.rad./
				β^+,p,2p,_/					
^{23m}Al			≈0.35 s		β^+,p/0.17				0.554
									0.839
^{23}Al		23.00727	0.47 s	β^+ /12.24					ann.rad./
				β^+ ,p/					
^{24m}Al			0.129 s	I.T./0.4259					
				β^+	13.3	1+			1.3686/5.3
^{24}Al		23.999941	2.07 s	β^+ /13.878,p		3.40/48.	4+		1.078(2)/16.
					4.42/41.				1.368(2)/96.
					6.80/3.				2.753(2)/43.
					8.74/8.				4.315(3)/15.
									5.392(3)/20.
									7.0662(2)/41.
^{25}Al		24.990429	7.17 s	β^+ /4.277		3.27/	5/2+	3.646	ann.rad./
									1.6115(2)/100.
									0.975(2)/5.
^{26m}Al			6.345 s	β^+ /	3.2/	0+			ann.rad./
^{26}Al		25.9868917	7.1x10^5 y	β^+ /82/4.0042	1.16/	5+	+2.804	+0.17	ann.rad./
				EC/18/				1.8087/99.8	
^{27}Al	100.	26.9815384				5/2+	+3.64151	+0.140	
^{28}Al		27.9819102	2.25 m	β^- /4.6422	2.865/100.	3+	3.24	0.18	1.7778(6)/100.
^{29}Al		28.980445	6.5 m	β^- /3.680	1.4/30.	5/2+			1.2732(8)/89.
					2.5/70.				2.0282(8)/4.
									2.4262(8)/7.
^{30}Al		29.98296	3.68 s	β^- /8.56	5.05/	3+			1.26313(3)/35.
									2.23525(5)/65.
^{31}Al		30.98395	0.64 s	β^- /8.00	6.25/				0.75223(3)/18.
									1.69473(3)/59.
									2.31664(4)/73.
^{32}Al		31.9881	33. ms	β^- /13.0		1+			
^{33}Al		32.9909	41. ms						
^{34}Al		33.9969	≈42. ms		β^- /17.1				
^{35}Al		34.9999	30 ms						
^{36}Al		36.0064	0.09 s						
^{37}Al		37.010	>1 μs						
^{38}Al		38.0169	>0.2 μs						
^{39}Al		39.022	>0.2 μs						
^{40}Al									
^{41}Al									
$_{14}$Si		28.0855(3)							
^{22}Si		22.0345	29. ms	β^+,p	1.99/20	0+			
^{23}Si		23.0255	40.7 ms	β^+,p/5.9	1.32,2.40,2.83				
^{24}Si		24.01155	0.14 s	β^+ ,p/10.81		1.51,4.09,1.73	0+		ann.rad./
					1.13-4.38				
^{25}Si		25.00411	221 ms	β^+ ,p/12.74			5/2+		ann.rad./
^{26}Si		25.992330	2.23 s	β^+ /5.066		3.282/	0+		ann.rad./
									0.8294(8)/22.
^{27}Si		26.9867048	4.14 s	β^+ /4.8118		3.85/100.	5/2+	-0.8554	ann.rad./
									2.211(5)/0.2
^{28}Si	92.22(2)	27.97692653				0+			
^{29}Si	4.69(1)	28.97649472				1/2+	-0.5553		
^{30}Si	3.09(1)	29.97377022				0+			

TABLE OF ISOTOPES (CONTINUED)

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^{31}Si		30.9753633	2.62 h	β^- /1.4920		1.471/99.9	3/2+		1.2662(5)/0.05
^{32}Si		31.974148	1.6x10^2 y	β^- /0.224	0.213/100.	0+			
^{33}Si		32.97800	6.1 s	β^- /5.85	3.92	(3/2+)	1.21		1.4313(5)/13.
									1.8477/100.
									2.538(2)/10.
^{34}Si		33.97858	2.8 s	β^- /4.60	3.09/	0+			0.42907(5)/60.
									1.17852(2)/64.
									1.60756(5)/36.
^{35}Si		34.98458	0.9 s	β^- /10.50					
^{36}Si		35.9867	0.5 s	β^- /7.9		0^+			
^{37}Si		36.9930	≈0.09 s						
^{38}Si		37.9960	>1 μs			0^+			
^{39}Si		39.0023	>1 μs						
^{40}Si		40.0058	>0.2 μs			0^+			
^{41}Si		41.013	>0.2 μs						
^{42}Si		42.016	>0.2 μs			0^+			
$_{15}$P		30.973761(2)							
^{24}P		24.0344							
^{25}P		25.0203	<0.03 μs						
^{26}P		26.0118	≈20. ms		β^+ ,p/18.1		3+		
^{27}P		26.99919	0.3 s	β^+,p /11.63			1/2+		
^{28}P		27.992312	270. ms	β^+ /14.332		3.94/13.	3+		ann.rad./
					5.25/13.				1.779(2)/98.
					6.96/16.				2.839(2)/2.8
					8.8/7.				3.040(2)/3.2
					11.49/52.				4.498(2)/12.
									7.537(2)/9.
^{29}P		28.981801	4.14 s	β^+ /4.9431		3.945/98.	1/2+	1.2349	ann.rad./
									1.273/1.32
									2.426/0.39
^{30}P		29.9783138	2.50 m	β^+ /4.2323		3.245/99.9	1+		ann.rad./
									2.230(3)/0.07
^{31}P	100.	30.9737615				1/2+	+1.13160		
^{32}P		31.9739071	14.28 d	β^- /1.7106	1.710/100.	1+	-0.2524		
^{33}P		32.971725	25.3 d	β^- /0.249	0.249/100.	1/2+			
^{34}P		33.973636	12.4 s	β^- /5.374	3.2/15.	1+			1.78-4.1/
					5.1/85.				2.127(5)/15.
^{35}P		34.973314	47. s	β^- /3.989	2.34/100.	1/2+			1.572(1)/100.
^{36}P		35.97826	5.7 s	β^- /10.41					0.902/77.
									3.291/100.
^{37}P		36.97961	2.3 s	β^- /7.90					0.6462/
									1.5829/
^{38}P		37.9845	0.6 s	β^- /12.4					1.2923/
									2.224/
^{39}P		38.9864	≈0.16 s						
^{40}P		39.9911	≈0.26 s						
^{41}P		40.9948	0.12 s						
^{42}P		42.0001	0.11 s						
^{43}P		43.0033	33. ms	β^-,(n)/					
^{44}P		44.010	>0.2 μs						
^{45}P		45.015	>0.2 μs						
^{46}P		46.024	>0.2 μs						
$_{16}$S		32.066(6)							
^{26}S		26.0278	≈ 10 ms				0^+		
^{27}S		27.0188	21. ms	β^+, 2p /18.3					
^{28}S			0.13 s			0^+			
^{29}S		28.99661	0.188 s	β^+ /13.79			5/2+		ann.rad./
				β^+ ,p/					
^{30}S		29.984903	1.18 s	β^+ /6.138		4.42/78.	0+		ann.rad./

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Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
					5.08/20.				0.678/79.
^{31}S		30.979555	2.56 s	β^+ /5.396		4.39/99.	1/2+	0.48793	ann.rad./
									1.2662(5)/1.2
^{32}S	94.93(31)	31.9720707				0+			
^{33}S	0.76(2)	32.9714585				3/2+	+0.64382	-0.68	
^{34}S	4.29(28)	33.9678668				0+			
^{35}S		34.9690321	87.2 d	β^- /0.1672	0.1674/100.	3/2+	+1.00	+0.047	
^{36}S	0.02(1)	35.9670809				0+			
^{37}S		36.9711257	5.05 m	β^- /4.8653		1.64/94.	7/2-		0.9083(4)/0.06
					4.75/5.6				3.1033(2)/94.2
^{38}S		37.97116	2.84 h	β^- /2.94	1.00/	0+			0.1962(4)/0.2
									1.9421(3)/84.
^{39}S		38.97514	11.5 s	β^- /6.64					1.301/52.
									1.697/44.
^{40}S		39.9755	9. s	β^- /4.7		0+			
^{41}S		40.9800	≈2.6 s						
^{42}S		41.9815	≈0.56 s		β,(n)/		0+		
^{43}S		42.987	0.22 s						
^{44}S		43.9883	0.12 s	β^-, n/9.		0+			
^{45}S		44.9948	0.08 s	β^-,n/					
^{46}S		45.9996	>0.2 µs			0+			
^{47}S		47.008	>0.2 µs						
^{48}S		48.013	>0.2 µs			0+			
^{49}S		49.022	<0.2 µs						
$_{17}$Cl		35.4527(9)							
^{28}Cl		28.0285							
^{29}Cl		29.0141	<0.02 µs						
^{30}Cl		30.0048	<0.03 µs						
^{31}Cl		30.99242	0.15 s	β^+ ,p/11.98		1.52	3/2+		ann.rad./
^{32}Cl		31.98569	297. ms	β^+ /12.69		4.75/25.	1+	1.11	ann.rad./
					6.18/10.				1.548(2)/3.5
					7.48/14.				2.2305(1)/92.
					9.47/50.				2.4638(1)/4.
					11.6/1.				2.885(1)/1.
									4.770(1)/20.
^{33}Cl		32.977452	2.511 s	β^+ /5.583		4.51/98.	3/2+	+0.752	ann.rad./
									0.8409/0.52
									1.966/0.45
									2.866/0.44
^{34m}Cl			32.2 m	β^+ /	1.35/24.	3+			ann.rad./
					2.47/28.				
				I.T./					0.1457(8)/42.
									2.1276(5)/42.
^{34}Cl		33.9737620	1.528 s	β^+ /5.4922		4.50/100.	0+		ann.rad./
^{35}Cl	75.78(4)	34.96885271				3/2+	+0.82187	-0.0825	
^{36}Cl		35.9683069	3.01x10^{5} y	β^- /0.7086		0.7093/98.	0+	+1.28547	-0.018
				β^+,EC/1.1421	0.115/0.002				ann.rad./
^{37}Cl	24.22(4)	36.96590260				3/2+	+0.68412	-0.0649	
^{38m}Cl			0.715 s	I.T./		5-		0.6714/100	
^{38}Cl		37.9680106	37.2 m	β^- /4.9168		1.11/31.	2-	2.05	1.64216(1)/31.
					2.77/11.				2.16760(2)/42.
					4.91/58.				
^{39}Cl		38.968008	55.6 m	β^- /3.442	1.91/85.	3/2+			0.25026(1)/47.
					2.18/8.				1.26720(5)/54.
					3.45/7.				0.986-1.517
^{40}Cl		39.97042	1.38 m	β^- /7.48		2-			0.6431(3)/6.
									1.4608(1)/77.
									2.8402(2)/17.
^{41}Cl		40.9707	34. s	β^- /5.7	3.8/				(0.167-1.359)

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{42}Cl		41.9732	6.8 s	β^- /9.4					
^{43}Cl		42.9742	3.3 s	β^- /8.0					
^{44}Cl		43.9785	≈0.43 s		β^-,n/12.3				
^{45}Cl		44.980	0.40 s	β^-, n/11.					
^{46}Cl		45.984	0.22 s	β^-, n/14.9					
^{47}Cl		46.988	>0.2 μs	β^-, n/15.					
^{48}Cl		47.995	>0.2 μs						
^{49}Cl		48.9999	>0.17 s						
^{50}Cl		50.008							
^{51}Cl		51.014	>0.2 μs						
$_{18}$Ar		39.948(1)							
^{30}Ar		30.0216	<0.02 μs					0+	
^{31}Ar		31.0121	≈14.1 ms		β^+ /18.4	p/2.08/100.		5/2	
				β^+, 2p/<10^{-4}		p/1.42/37			
				β^+, 3p/<10^{-3}		p/0.45-11.67			
^{32}Ar		31.99766	98. ms	β^+ ,p/11.2			0+		ann.rad./
^{33}Ar		32.98993	174. ms	β^+ /11.62		3.12/	1/2+	-0.72	ann.rad./
				β^+ ,p/					0.810(2)/48.
^{34}Ar		33.980270	0.844 s	β^+/6.061	5.0/95.	0+			ann.rad./
									0.6658(1)/2.5
									3.1290(1)/1.3
^{35}Ar		34.975257	1.77 s	β^+/5.965	4.94/93.	3/2+	+0.633	-0.08	ann.rad./
									1.2185(5)/1.22
									1.763(1)/0.25
									2.964(1)/0.2
^{36}Ar	0.3365(30)	35.9675463				0+			
^{37}Ar		36.9667759	35.0 d	EC/.813		3/2+	+1.15	+0.076	
^{38}Ar	0.0632(5)	37.9627322				0+			
^{39}Ar		38.964313	268. y	β^-/0.565	0.565/100.	7/2-	-1.59	-0.12	
^{40}Ar	99.6003(30)	39.962383123					0+		
^{41}Ar		40.964501	1.82 h	β^-/2.492	1.198/	7/2-			1.29364(5)/99.
									1.6770(3)/0.05
^{42}Ar		41.96305	33. y	β^-/0.60	0.60/100.	0+			
^{43}Ar		42.9657	5.4 m	β^-/4.6					0.4791(2)/10.
									0.7380(1)/43.
									0.9752(1)/100.
									1.4400(3)/39.
^{44}Ar		43.96537	11.87 m	β^-/3.55		0+			0.182-1.866
^{45}Ar		44.96809	21.5 s	β^-/6.9		7/2-			0.0610/25.
									1.020/35.
									3.707/34.
^{46}Ar		45.96809	8.4 s	β^-/5.70		0+			1.944/
^{47}Ar		46.9722	≈0.7 s		β^-				
^{48}Ar		47.9751							
^{49}Ar		48.9822	>0.17 μs		β^-				
^{50}Ar		49.986	>0.17 μs		β^-				
^{51}Ar		50.993	>0.2 μs	β^-					
^{52}Ar		51.998	10 ms	β^-					
^{53}Ar		52.994		β^-					
$_{19}$K		39.0983(1)							
^{32}K		32.0219							
^{33}K		33.0073	<0.025 μs						
^{34}K		33.9984	<0.04 μs						
^{35}K		34.98801	0.19 s	β^+ /11.88			3/2+		ann.rad./
				β^+ ,p/					1.751/14.
									2.5698/26.
									2.9827/51.
^{36}K		35.98129	0.342 s	β^+ /12.81		5.3/42.	2+	+0.548	ann.rad./
					9.9/44.				1.97044(5)/82.

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									2.20783(5)/30.
									2.43343(2)/32.
^{37}K		36.9733769	1.23 s	β^+ /6.149		5.13/	3/2+	+0.2032	ann.rad./
									2.7944(8)/2.
									3.602(2)/0.05
^{38m}K			0.924 s	β^+ /6.742		5.02/100.	0+		ann.rad./
^{38}K		37.969080	7.63 m	β^+ /5.913		2.60/99.8	3+	+1.37	ann.rad./
									2.1675(3)/99.8
									3.9356(5)/0.2
^{39}K	93.2581(44) 38.9637069					3/2+	+0.39146	+0.049	
^{40}K	0.0117(1)	39.9639987	1.26x10^9 y	β^- /1.3111	1.312/89.	4-	-1.29810	-0.061	ann.rad./
				β^+ ,EC/1.505		1.50/10.7			1.4608/10.5
^{41}K	6.7302(44)	40.9618260				3/2+	+0.21487	+0.060	
^{42}K		41.9624031	12.36 h	β^- /3.525	1.97/19.	2-	-1.1425		0.31260(2)/0.3
					3.523/81.				1.5246(3)/18.
^{43}K		42.96072	22.3 h	β^- /1.82	0.465/8.	3/2+	+0.163		0.2211(2)/4.
					0.825/87.				0.3729(2)/88.
					1.24/3.5				0.3971(2)/11.
					1.814/1.3				0.6178(2)/81.
^{44}K		43.96156	22.1 m	β^- /5.66	5.66/34.	2-	-0.856	0.36821/2.2	
									1.15700(1)/58.
									2.15079(2)/22.
^{45}K		44.96070	17.8 m	β^- /4.20	1.1/23.	3/2+	+0.173		0.1743(5)/80.
					2.1/69.				1.2607(8)/7.
					4.0/8.				1.7056(6)/69.
									2.3542(5)/14.
^{46}K		45.96198	1.8 m	β^- /7.72	6.3/	2-	-1.05		1.347(1)/91.
									3.700(5)/28.
^{47}K		46.96168	17.5 s	β^- /6.64	4.1/99.	1/2+	+1.93		0.56474(3)/15.
					6.0/1.				0.58575(3)/85.
								2.0131/100	
^{48}K		47.96551	6.8 s	β^- /12.09	5.0/	(2-)			0.67122(1)/4.
									0.6723(5)/20.
									0.78016(1)/32.
									3.83153(7)/80.
^{49}K		48.9675	1.26 s	β^- /11.0					2.025/
									2.252/
^{50}K		49.9728	0.472 s	β^- /14.2					
^{51}K		50.9764	0.365 s	β^- /					
^{52}K		51.983	0.105 s	β^-					
^{53}K		52.987	30. ms	β^-		3/2+			
^{54}K		53.994	10. ms	β^-					
$_{20}$Ca		40.078(4)							
^{34}Ca		34.0141	<0.035 μs						
^{35}Ca		35.0048	25.7 ms	β^+,p/15.6		p/1.43/49			
					1.9-8.8				
^{36}Ca		35.99309	0.10 s	β^+,(p)/10.99		2.52			ann.rad./
				β^+ ,n/					
^{37}Ca		36.98587	0.18 s	β^+ /11.64		3.103	3/2+		ann.rad./
				β^+ ,n/					1.369
^{38}Ca		37.976319	0.44 s	β^+ /6.74		0+			ann.rad./
									1.5677(5)/25.
									3.210(2)/1.
^{39}Ca		38.970718	0.861 s	β^+ /6.531		5.49/100.	3/2+	1.02168	ann.rad./
^{40}Ca	96.941(156) 39.9625912					0+			
^{41}Ca		40.9622783	1.02x10^5 y	EC/0.4214		7/2-	-1.5948	-0.08	
^{42}Ca	0.647(23)	41.9586183				0+			
^{43}Ca	0.135(10)	42.9587668				7/2-	-1.3173	-0.05	
^{44}Ca	2.086(110)	43.955481				0+			

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{45}Ca		44.956186	162.7 d	β^- /0.257	0.257/100.	7/2-	-1.327	+0.05	
^{46}Ca	0.004(3)	45.953693	>0.4(10^{16} y		$\beta^-\beta^-$		0+		
^{47}Ca		46.954546	4.536 d	β^- /1.992	0.684/84.	7/2-	-1.38	+0.02	1.297/75
					1.98/16.				(0.041-1.88)
^{48}Ca	0.187(21)	47.952533	4.3(10^{19} y	$\beta^-\beta^-$			0+		
^{49}Ca		48.955673	8.72 m	β^- /5.262	0.89/7.	3/2-			3.0844(1)/92.
					1.95/92.				4.0719(1)/7.
^{50}Ca		49.95752	14. s	β^- /4.97	3.12/	0+			0.2569/98.
									(0.0715 -1.59)
^{51}Ca		50.9615	10. s	β^- /7.3		(3/2-)			
^{52}Ca		51.9651	4.6 s	β^- /8.0					
^{53}Ca		52.9701	0.09 s	β^- /10.9					
^{54}Ca		53.975							
^{55}Ca		54.981							
^{56}Ca		55.986							
$_{21}$Sc		44.955910(8)							
^{36}Sc		36.0149							
^{37}Sc		37.0030							
^{38}Sc		37.9947	<0.3 µs						
^{39}Sc		38.98479	<0.3 µs	p					
^{40}Sc		39.977964	0.182 s	β^+ /14.320		5.73/50.	4-		ann.rad./
					7.53/15.				0.752/41.
					8.76/15.				3.732/99.5
					9.58/20.				(1.12-3.92)
^{41}Sc		40.9692513	0.596 s	β^+ /6.4953	5.61/100.	7/2-	+5.431	-0.156	ann.rad./
^{42m}Sc			61.6 s	β^+ /	2.82/	7+			ann.rad./
									0.4375(5)/100.
									1.2270(5)/100.
									1.5245(5)/100.
^{42}Sc		41.9655168	0.682 s	β^+ /6.4259	5.32/100.	0+			ann.rad./
^{43}Sc		42.961151	3.89 h	β^+ ,EC/2.221	0.82/22.	7/2-	+4.62	-0.26	ann.rad./
					1.22/78.				0.3729(1)/22.
^{44m}Sc			58.2 h	I.T./0.27		6+	+3.88		0.27124(1)/87.
				EC/3.926					(1.00-1.16)
^{44}Sc		43.959403	3.93 h	β^+, EC/3.653	1.47/	2+	+2.56	+0.10	ann.rad./
								1.157/100	
^{45}Sc	100.	44.955910				7/2-	+4.75649	-0.220	
^{46m}Sc			18.7 s	I.T./0.14253		1-			0.14253(2)/62.
^{46}Sc		45.955170	83.81 d	β^- /2.367	0.357/100.	4+	+3.03	+0.12 0.8893/ 100	
								1.121/100	
^{47}Sc		46.952408	3.349 d	β^- /0.600	0.439/69.	7/2-	+5.34	-0.22	0.15938(1)/68.
					0.601/31.				
^{48}Sc		47.95224	43.7 h	β^- /3.99	0.655/	6+		0.9835/100	
									1.03750(1)/97.
								1.3121/100	
^{49}Sc		48.950024	57.3 m	β^- /2.006	2.00/99.9.	7/2-			1.7619(3)/0.05
^{50}Sc		49.95219	1.71 m	β^- /6.89	3.05/76.	(5+)			0.5235(1)/88.
					3.60/24.				1.1210(1)/100.
									1.5537(2)/100.
^{51}Sc		50.95360	12.4 s	β^- /6.51	4.4/	7/2-			1.4373(4)/52.
					5.0/				0.718-2.144
^{52}Sc		51.9566	8.2 s	β^- /9.0		(3+)			
^{53}Sc		52.9592	> 3. ms	β^- /8.1					
^{54m}Sc			≈ 7 µs				(5+)		0.110/IT
^{54}Sc		53.9630	0.23 s	β^- /11.6					0.100/50

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TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									1.70/40
									0.50/40
^{55}Sc		54.967	0.12 s	β^- /13					
^{56}Sc		55.973							
^{57}Sc		56.977							
^{58}Sc		57.983							
$_{22}$Ti		47.867(1)							
^{38}Ti		38.0098	<0.12 μs						
^{39}Ti		39.0013	28. ms	β^+ /15.4					
^{40}Ti		39.9905	52. ms	β^+ /11.7	p/2.17/28				
				β^+,p	3.73/23				
					1.7/22				
					0.242-5.74				
^{41}Ti		40.98313	80. ms	β^+ ,p/12.93		p/4.73/107	3/2+		ann.rad./
					3.10/67				
					3.75/39				
					0.744-6.73				
^{42}Ti		41.97303	0.20 s	β^+ /7.000		6.0/			ann.rad./
									0.6107(5)/56.
^{43}Ti		42.96852	0.50 s	β^+ /6.87	5.80/	7/2-	0.85		ann.rad./
^{44}Ti		43.959690	60. y	EC/0.268		0+		0.06787/91	
								0.07832/97	
^{45}Ti		44.958124	3.078 h	β^+/86/2.062	1.04	7/2-	0.095	0.015	ann.rad./
				EC/14/				(0.36-1.66)	
^{46}Ti	8.25(3)	45.952630				0+			
^{47}Ti	7.44(2)	46.951764				5/2-	-0.78848	+0.30	
^{48}Ti	73.72(3)	47.947947				0+			
^{49}Ti	5.41(2)	48.947871				7/2-	-1.10417	+0.24	
^{50}Ti	5.18(2)	49.944792				0+			
^{51}Ti		50.946616	5.76 m	β^- /2.471	1.50/92.	3/2-			0.3197(2)/93.
					2.13/				0.6094-0.9291
^{52}Ti		51.94690	1.7 m	β^- /1.97	1.8/100.	0+			0.0170(5)/100.
									0.1245/100
^{53}Ti		52.9497	33. s	β^- /5.0	(2.2-3)/	3/2-			0.1008(1)/20.
									0.1276(1)/45.
									0.2284(1)/39.
									1.6755(5)/45.
									(1.72-2.8)/
^{54}Ti		53.9509	1.5 s	β^- /4.3					
^{55}Ti		54.9551	0.32 s	β^- /7.4					
^{56}Ti		55.9580	0.19 s	β^- /7.0					
^{57}Ti		56.963	0.06 s	β^- /11.					
^{58}Ti		57.966	≈47 ms						
^{59}Ti		58.972	0.06 s						
^{60}Ti		59.976	>0.15 μs						
^{61}Ti		60.982	>0.15 μs						
$_{23}$V		50.9415(1)							
^{40}V		40.0111							
^{41}V		40.9997							
^{42}V		41.9912	<0.055 μs						
^{43}V		42.9807	>0.8 s	β^+ /11.3					
^{44}V		43.9744	0.09 s	β^+ ,_/13.7					ann.rad./
^{45}V		44.96578	0.54 s	β^+ /7.13		7/2-			
^{46}V		45.960200	0.4223 s	β^+ /7.051		6.03/100.	0+		ann.rad./
^{47}V		46.954907	32.6 m	β^+ ,EC/2.928		1.90/99.+	3/2-		ann.rad./
									1.7949(8)/0.19
									(0.2-2.16)
^{48}V		47.952254	15.98 d	β^+ /4.012		0.698/50.	4+	2.01	ann.rad./
								0.9835/100	

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Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									(1.3-2.4)
^{49}V		48.948517	337. d	EC/0.602		7/2-	4.47		
^{50}V	0.250(4)	49.947163	>1.4x10^{17}y	EC, β$^-$		6+	+3.34569	+0.21	
^{51}V	99.750(4)	50.943964				7/2-	+5.148706	-0.04	
^{52}V		51.944780	3.76 m	β$^-$ /3.976	2.47/	3+			1.4341(1)/100.
^{53}V		52.944342	1.56 m	β$^-$ /3.436	2.52/	7/2-			1.0060(5)/90.
									1.2891(3)/10.
^{54m}V			0.9 μs			(5+)			0.108/IT
^{54}V		53.94644	49.8 s	β$^-$ /7.04	1.00/5.	3+			0.8348/97.
					2.00/12.				0.9887/80.
					2.95/45.				2.259/46.
					5.20/11.				(0.56-3.38)
^{55}V		54.9472	6.5 s	β$^-$ /6.0	6.0/	(7/2-)			0.5177/73.
									(0.224-1.21)
^{56}V		55.9504	0.23 s	β$^-$ /9.1					0.70/50.
									0.34/40.
									1.00/30.
^{57}V		56.9524	0.33 s	β$^-$ /8.1					0.30/60.
									0.60/30.
									0.80/30.
^{58}V		57.9567	0.20 s	β$^-$ /11.6					
^{59}V		58.9593	0.13 s	β$^-$ /9.9					0.90/80.
^{60}V		59.965	0.20 s	β$^-$ /14.					0.102-0.208
^{61}V		60.967	0.04 s						0.646
^{62}V		61.973	≈ 65 ms						
^{63}V		62.977	>0.15 μs						
^{64}V			>0.15 μs						
$_{24}$Cr		51.9961(6)							
^{42}Cr		42.0064	>0.35 μs						
^{43}Cr		42.9977	21. ms						
^{44}Cr		43.9855	53. ms	β$^+$,(p) /10.3		p/0.95-3.1			
^{45}Cr		44.9792	0.05 s	β$^+$,p/12.5			7/2-		ann.rad./
^{46}Cr		45.96836	0.3 s	β$^+$ /7.60					ann.rad./
^{47}Cr		46.96291	0.51 s	β$^+$ /7.45		3/2-			ann.rad./
^{48}Cr		47.95404	21.6 h	EC/1.66					ann.rad./
									0.116(2)/95.
									0.305(10)/100.
^{49}Cr		48.951341	42.3 m	β$^+$,EC/2.631		1.39/	5/2-	0.476	ann.rad./
					1.45/				0.09064(1)/51.
					1.54/				0.15293(1)/27.
									(0.062-1.6)
^{50}Cr	4.345(13)	49.946050				0+			
^{51}Cr		50.944772	27.70 d	EC/0.7527		7/2-	-0.934	0.3201/10.2	
^{52}Cr	83.789(18)	51.940512				0+			
^{53}Cr	9.501(17)	52.940653				3/2-	-0.47454	-0.15	
^{54}Cr	2.365(7)	53.938885				0+			
^{55}Cr		54.940844	3.497 m	β$^-$ /2.603	2.5/	3/2-			1.5282(2)/0.04
									(0.13-2.37)
^{56}Cr		55.94065	5.9 m	β$^-$ /1.62	1.50/100.	0+			0.026(2)/100.
									0.083(3)/100.
^{57}Cr		56.9438	21. s	β$^-$ /5.1	3.3/	3/2-	0.0834		0.850/8.
					3.5/				(0.083-2.62)
^{58}Cr		57.9443	7.0 s	β$^-$ /4.0					(0.131-0.683)
^{59m}Cr			0.10 ms			(9/2+)			0.208/IT
									0.193
									0.102
^{59}Cr		58.9487	1.0 s	β$^-$ /7.7					1.236
^{60}Cr		59.9497	0.6 s	β$^-$ /6.0					
^{61}Cr		60.9541	0.26 s	β$^-$ /8.8					0.354-1.860

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{62}Cr		61.9558	0.19 s	β^- /7.3					0.285
^{63}Cr		62.962	0.11 s						
^{64}Cr		63.964	0.04 s						
^{65}Cr		64.970	>0.15 μs						
^{66}Cr			>0.15 μs						
^{67}Cr									
$_{25}$Mn		54.938049(9)							
^{44}Mn		44.0069	<0.105 μs						
^{45}Mn		44.9945	<0.07 μs						
^{46}Mn		45.9867	≈41. ms	β^+ /17.1					
^{47}Mn		46.9761	≈0.1 s	β^+ /12.3					
^{48}Mn		47.9689	0.15 s	β^+ /13.5	5.79/58.	4+			
					4.43/10.				
^{49}Mn		48.95962	0.38 s	β^+ /7.72	6.69/	5/2-			ann.rad./
^{50m}Mn			1.74 m	β^+ /7.887	3.54/	5+			ann.rad./
									1.0980/94.
									0.783/91.
									(0.66-3.11)
^{50}Mn		49.954244	0.283 s	β^+ /7.6330	6.61/	0+			ann.rad./
^{51}Mn		50.948215	46.2 m	β^+ ,EC/3.208	2.2/	5/2-	3.568	0.4	ann.rad./
									0.7491(1)/0.26
									(1.148-1.164)
^{52m}Mn			21.1 m	β^+ /98/5.09	2.631/	2+	0.0076		ann.rad./
				I.T./2/0.378					0.3778 (I.T.)
									1.43406(1)/98.
									(0.7-4.8)
^{52}Mn		51.945570	5.591 d	β^+ /4.712	0.575/	6+	+3.063	+0.5	ann.rad./
				EC/					0.74421(1)/90.
									1.4341/100
^{53}Mn		52.941294	3.7x10^6 y	EC/0.5970		7/2-	5.024		
^{54}Mn		53.940363	312.1 d	EC/1.377		3+	+3.282	+0.33 0.8340/ 100	
^{55}Mn	100.	54.938049				5/2-	+3.4687	+0.32	
^{56}Mn		55.938909	2.579 h	β^- /3.6954		0.718/18.	3+	+3.2266	0.84675/99
					1.028/34.				1.81072(4)/27.
								2.113/14.5	
^{57}Mn		56.938287	1.45 m	β^- /2.691		5/2-			
^{58}Mn		57.93999	65 s	β^- /6.25	3.8/	3+			0.45916(2)/20.
					5.1/				0.81076(1)/82.
									1.32309(5)/53.
^{59}Mn		58.94045	4.6 s	β^- /5.19	4.5/				0.471/
									0.531-0.726
^{60m}Mn			1.77 s	β^- /IT	5.7/	3+			0.824/
^{60}Mn		59.9433	50. s	β^- /8.6		0+			1.969/
^{61}Mn		60.9446	0.67 s	β^- /7.4		(5/2)-			
^{62}Mn		61.9480	0.67 s	β^- /10.4		(3+)			0.877/
									0.942-1.299
^{63}Mn		62.9498	0.28 s	β^- /8.8					0.356,0.450
^{64m}Mn			> 0.1 ms						0.135/IT
^{64}Mn		63.9537	87 ms	β^- /11.8					0.746
^{65}Mn		64.9561	0.09 s	β^- /10.					0.366
^{66}Mn		65.961	66 ms						0.471
^{67}Mn		66.964	42 ms						
^{68}Mn			28 ms						
^{69}Mn			14 ms						
$_{26}$Fe		55.845(2)							
^{45}Fe		45.0146	>0.35 μs						
^{46}Fe		46.0008	≈0.02 s		β^+ /13.1				
^{47}Fe		46.9929	≈0.03 s		β^+ /15.6				

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{48}Fe		47.9806	≈ 44. ms		β^+ /11.2				
^{49}Fe		48.9763	70. ms	β^+ /13.0		(7/2-)			ann.rad./
^{50}Fe		49.9630	0.15 s	β^+ /8.2					0.651
^{51}Fe		50.95683	0.31 s	β^+ /8.02		(5/2-)			ann.rad./
^{52m}Fe			46. s	β^+ /4.4		(12+)			ann.rad./
									(0.622-2.286)/
^{52}Fe		51.94812	8.28 h	β^+ /57/2.37	0.804/	0+			ann.rad./
				EC/43/					0.16868(1)/99.
				I.T./					0.377 (I.T.)/
^{53m}Fe			2.6 m	I.T./3.0407		19/2-			0.7011(1)/99.
									1.0115(1)/87.
									1.3281(1)/87.
									2.3396(1)/13.
^{53}Fe		52.945312	8.51 m	β^+ /3.743		2.40/42.	7/2-		ann.rad./
					2.80/57.				0.3779(1)/42.
									(1.2 - 3.2)
^{54}Fe	5.845(35)	53.939615				0+			
^{55}Fe		54.938298	2.73 y	EC/0.2314		3/2-			
^{56}Fe	91.754(36)	55.934942				0+			
^{57}Fe	2.119(10)	56.935398				1/2-	+0.0906	0.16	
^{58}Fe	0.282(4)	57.933280				0+			
^{59}Fe		58.934880	44.51 d	β^- /1.565	0.273/48.	3/2-	- 0.336		1.099/57
					0.475/51.				1.292/43.
									(0.14-1.48)
^{60}Fe		59.934077	1.5x10^6 y	β^- /0.237	0.184/100.	0+		0.0586/100	
^{61m}Fe			0.25 μs			(9/2+)			0.654/IT
									0.207
^{61}Fe		60.93675	6.0 m	β^- /3.98	2.5/13.				1.205/44.
					2.63/54.				1.028/43.
					2.80/31.				(0.12-3.37)
^{62}Fe		61.93677	68. s	β^- /2.53	2.5/100.	0+			0.5061(1)/100.
^{63}Fe		62.9404	6. s	β^- /6.3		5/2-			0.995/
									(1.365-1.427)
^{64}Fe		63.9411	2.0 s	β^- /4.9					
^{65m}Fe			0.4 μs			(5/2-)			0.364/IT
^{65}Fe		64.9449	1.3 s	β^- /7.9					
^{66}Fe		65.9460	0.44 s	β^- /5.7					0.471-1.425
^{67m}Fe			≈0.04 ms				(5/2-)		0.367/IT
^{67}Fe		66.9500	0.48 s	β^- /8.8					0.189
^{68}Fe		67.953	0.15 s	β^- /≈7.6					
^{69}Fe		68.958	0.17 s						
^{70}Fe			>0.15 μs						
^{71}Fe			>0.15 μs						
^{72}Fe			>0.15 μs						
$_{27}$Co		58.933200(9)							
^{48}Co		48.0018							
^{49}Co		48.990	<0.035 μs						
^{50}Co		49.9812	44. ms	β^+ /17.0	2.03-2.79				
^{51}Co		50.9705	>0.2 μs	β^+ /12.8					
^{52}Co		51.9632	0.12 s	β^+ /14.0					0.849-1.942
^{53m}Co			0.25 s	β^+ ,p/		19/2-			ann.rad./
^{53}Co		52.95423	0.26 s	β^+ /8.30		7/2-			ann.rad./
^{54m}Co			1.46 m	β^+ /8.44	4.25/100.	7+			ann.rad./
									0.411(1)/99.
									1.130(1)/100.
									1.408(1)/100.
^{54}Co		53.948464	0.1932 s	β^+ /8.2430		7.34/100.	0+		ann.rad./
^{55}Co		54.942003	17.53 h	β^+ /3.4513		0.53/	7/2-	+4.822	ann.rad./
				EC/	1.03/				0.9312/75.

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
					1.50/				0.4772/20.
									(0.092-3.11)
^{56}Co		55.939844	77.3 d	β$^+$ /4.566	1.459/18.	4+	3.85	+0.25	ann.rad./
				EC/				0.8468/99.9	
									1.2383/68.
									(0.26-3.61)
^{57}Co		56.936296	271.8 d	EC/0.8361		7/2-	+4.72	+0.5 0.12206/86	
									(0.014-0.706)
^{58m}Co			9.1 h	I.T./		5+			0.02489/0.035
^{58}Co		57.935757	70.88 d	β$^+$ /2.307		2+	+4.04	+0.22	ann.rad./
				EC/				0.81076/99	
^{59}Co	100.	58.933200				7/2-	+4.63	+0.41	
^{60m}Co			10.47 m	I.T./99.8/0.059		2+	+4.40	+0.3 0.0586/2.0	
				β$^-$ /0.2/1.56					
^{60}Co		59.933822	5.271 y	β$^-$ /2.824	0.315/99.7	5+	+3.799	+0.44 1.1732/ 100	
								1.3325/100	
^{61}Co		60.932479	1.650 h	β$^-$ /1.322	1.22/95.	7/2-		0.0674/86.	
								0.842-0.909	
^{62m}Co			13.9 m	β$^-$ /	0.88/25.	5+			1.1635(3)/70.
					2.88/75.				1.1730(3)/98.
									2.0039(3)/19.
^{62}Co		61.93405	1.50 m	β$^-$ /5.32	1.03/10.	2+			1.1292(3)/13.
					1.76/5.				1.1730(3)/83.
					2.9/20.				1.9851(1)/3.
					4.05/60.				2.3020(1)/19.
^{63}Co		62.93362	27.5 s	β$^-$ /3.67	3.6/	7/2-			0.08713(1)/49.
									0.9817(3)/2.6
									0.156-2.17
^{64}Co		63.93581	0.30 s	β$^-$ /7.31	7.0/	1+			
^{65}Co		64.93648	1.14 s	β$^-$ /5.96		(7/2)-			
^{66m2}Co			>0.1 ms			(8-)			0.252/IT
									0.214
									0.175
^{66m1}Co			1.2 μs			(5+)			0.175/IT
^{66}Co		65.9398	0.25 s	β$^-$ /10.0					(1.245-1.425)
^{67}Co		66.9406	0.43 s	β$^-$ /8.4					0.694
^{68}Co		67.9444	0.19 s	β$^-$ /11.7					
^{69}Co		68.9452	0.20 s	β$^-$ /9.3					
^{70}Co		69.950	0.09 s	β$^-$ 13.					
^{71}Co		70.952	0.21 s	β					
^{72}Co		71.956	0.09 s	β					
^{73}Co			>0.15 μs						
^{74}Co			>0.15 μs						
^{75}Co			>0.15 μs						
$_{28}$Ni		58.6934(2)							
^{49}Ni			>0.35 μs						
^{50}Ni		49.9959	>0.3 μs						
^{51}Ni		50.9877	>0.2 μs	β$^+$ /16.0					
^{52}Ni		51.9757	38. ms	β$^+$ /11.7					
^{53}Ni		52.9685	0.05 s	β$^+$,p/13.3			7/2-		ann.rad./
^{54}Ni		53.95791	0.14 s	β$^+$ /8.80					0.937
^{55}Ni		54.95134	0.20 s	β$^+$ /8.70	7.66/	7/2-			ann.rad./
^{56}Ni		55.94214	6.08 d	EC/2.14		0+			0.15838/99
				β$^+$/< 10^{-6}					0.81185(3)/87.
									0.2695-0.7500
^{57}Ni		56.939800	35.6 h	β$^+$ /3.264		0.712/10.	3/2-	- 0.798	ann.rad./
				EC/	0.849/76.				1.3776/78.
									(0.127-3.177)

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{58}Ni	68.0769(89)		57.935348			0+			
^{59}Ni		58.934351	≈7.6x10^{4} y		EC/		3/2-		
^{60}Ni	26.2231(77)		59.930790			0+			
^{61}Ni	1.1399(6)	60.931060				3/2-	-0.75002	+0.16	
^{62}Ni	3.6345(17)	61.928348				0+			
^{63}Ni		62.929673	100. y	β^- /0.066945		0.065/	1/2-		
^{64}Ni	0.9256(9)	63.927969				0+			
^{65}Ni		64.930088	2.517 h	β^- /2.137	0.65/30.	5/2-	0.69		0.36627(3)/5.
					1.020/11.				1.11553(4)/16.
					2.140/58.				1.48184(5)/23.
^{66}Ni		65.92912	54.6 h	β^- /0.23		0+			
^{67m}Ni			13.3 µs			9/2+			0.313/IT
									0.694
^{67}Ni		66.93157	21. s	β^- /3.56	3.8/	1/2-	+0.601		1.0722/100.
									1.6539/100.
									(0.10-1.98)
^{68m2}Ni			0.34 µs			0+			0.511
^{68m1}Ni			0.86 ms			(5-)			0.814/IT
									2.033
^{68}Ni		67.93185	29. s	β^- /2.06					
^{69m2}Ni			0.44 µs			(17/2)			0.148/IT
									0.593
									1.959
^{69m1}Ni			3.5 s						
^{69}Ni		68.9352	11. s	β^- /5.4					0.6807(3)/100.
									(0.207-1.213)
^{70m}Ni			0.21 µs			(8+)			0.183/IT
									0.448
									0.970
									1.259
^{70}Ni		69.9361	6.0 s	β^- /3.5					
^{71}Ni		70.9400	2.56 s	β^- /6.9					
^{72}Ni		71.9413	1.6 s	β^- /5.2					
^{73}Ni		72.946	0.84 s	β^- /9.					
^{74}Ni		73.948	1.1 s	β^- /7.					
^{75}Ni		74.953	≈ 0.47 s						
^{76}Ni		75.955	≈ 0.24 s						
^{77}Ni		76.961	>0.15 µs						
^{78}Ni		77.964	>0.15 µs						
$_{29}$Cu		63.546(3)							
^{52}Cu		51.9972							
^{53}Cu		52.9856	<0.3 µs						
^{54}Cu		53.9767	<0.075 µs						
^{55}Cu		54.9655	>0.2 µs	β^+ /13.2					
^{56}Cu		55.9586	0.08 s	β^+ /15.3					0.511/233
									2.700/100
									1.23-2.78
^{57}Cu		56.94922	196. ms	β^+ /8.77		3/2-			0.77-3.01
^{58}Cu		57.944541	3.21 s	β^+ /8.563	4.5/15.	1+			ann.rad./
				EC/	7.439/83.				0.0403(4)/5.
									1.4483(2)/11.
									1.4546(2)/16.
^{59}Cu		58.939504	1.36 m	β^+ /4.800		1.9/	3/2-		ann.rad./
					3.75/				0.3393(1)/8.
									0.8780(1)/12.
									1.3015(1)/15.
									(0.4 - 2.6)
^{60}Cu		59.937368	23.7 m	β^+ /6.127		2.00/69.	2+	+1.219	ann.rad./

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
				EC/	3.00/18.				1.3325/88.
					3.92/6.				1.7915/45.
									(0.12-5.048)
^{61}Cu		60.933462	3.35 h	β^+ /2.237		0.56/3.	3/2-	+2.14	ann.rad./
					0.94/5.				0.2830/13.
					1.15/2.				0.6560/11.
					1.220/51.				(0.067-2.123)
^{62}Cu		61.932587	9.67 m	β^+ /98/3.948		2.93/98.	1+	-0.380	ann.rad./
				EC/					1.17302(1)/0.6
									(0.87-3.37)
^{63}Cu	69.17(3)	62.929601				3/2-	+2.2233	-0.211	
^{64}Cu		63.929768	12.701 h	β^- /39/0.579		0.578/	1+	-0.217	ann.rad./
				β^+ /19/1.6751		0.65/			1.3459(3)/0.6
				EC/41/					
^{65}Cu	30.83(3)	64.927794				3/2-	+2.3817	-0.195	
^{66}Cu		65.928873	5.09 m	β^- /2.642	1.65/6.	1+	-0.282		0.8330(1)/0.22
					2.7/94.				1.0392(2)/9.2
^{67}Cu		66.92775	2.580 d	β^- /0.58	0.395/56.	3/2-			0.09125(1)/7.
					0.484/23.				0.09325(1)/17.
					0.577/20.				0.18453(1)/47.
^{68m}Cu			3.79 m	I.T./86/		6-			0.0843(5)/70.
				β^- /14/1.8					0.1112(5)/18.
									0.5259(5)/74.
									(0.64-1.34)
^{68}Cu		67.92964	31. s	β^- /4.46	3.5/40.	1+			1.0774(5)/58.
					4.6/31.				1.2613(5)/17.
									(0.15-2.34)
^{69m}Cu			0.36 μs			(13/2+)			0.075/IT
									0.190/IT
									0.680
									1.871
^{69}Cu		68.92943	2.8 m	β^- /2.68	2.48/80.	3/2-	+2.84		0.5307(3)/3.
									0.8340(5)/6.
									1.0065(8)/10.
^{70m}Cu			47. s	β^- /	2.52/10.	5-			0.8848(2)/100.
									0.9017(2)/90.
									1.2517(5)/60.
									(0.39-3.06)
^{70}Cu		69.93241	5. s	β^- /6.60	5.42/54.	1+			0.8848(2)/54.
					6.09/46.				
^{71m}Cu			0.28 μs			(19/2)			0.133/IT
									0.494
									0.939
									1.189
^{71}Cu		70.93262	20. s	β^- /4.56		3/2-			0.490/
^{72m}Cu			1.76 μs			(4-)			0.051/IT
									0.082
									0.138
^{72}Cu		71.9357	6.6 s	β^- /8.2		(1+)			0.652/
^{73}Cu		72.9365	4.2 s	β^- /6.3	5.8/43				0.450/100
					6.25/42				0.307-1.559
^{74}Cu		73.9401	1.6 s	β^- /9.9					
^{75}Cu		74.9414	1.2 s	β^- /7.9					
^{76}Cu		75.9455	0.64 s	β^- /11.					
^{77}Cu		76.947	0.47 s	β^- /≈10.					
^{78}Cu		77.952	0.34 s	β^- /12.					
^{79}Cu		78.954	0.19 s	β^- /11.					
^{80}Cu		79.962	>0.15 μs						
$_{30}$Zn		65.39(2)							

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Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{54}Zn		53.9929							
^{55}Zn		54.9840							
^{56}Zn		55.9724	0.04 s						
^{57}Zn		56.9649	0.04 s	β^+,p/14.6			(7/2-)		ann.rad./
^{58}Zn		57.9546	0.09 s	β^+					
^{59}Zn		58.94927	183. ms	β^+,p/9.09		8.1/	3/2-		ann.rad./
									(0.491-0.914)
^{60}Zn		59.94183	2.40 m	β^+ /97/4.16			0+		ann.rad./
				EC/3/					0.669/47.
									(0.062-0.947)
^{61}Zn		60.93951	1.485 m	β^+ /5.64	4.38/68.	3/2-			ann.rad./
									0.4748/17.
									(0.15-3.52)
^{62}Zn		61.93433	9.22 h	β^+ /3/1.63		0.66/7.	0+		ann.rad./
				EC/93/					0.0408/25
									0.5967/26.
									(0.20-1.526)/
^{63}Zn		62.933215	38.5 m	β^+ /93/3.367	1.02/	3/2-	-0.28164	+0.29	ann.rad./
				EC/7/	1.40/				0.66962(5)/8.4
					1.71/				0.96206(5)/6.6
					2.36/84.				(0.24-3.1)
^{64}Zn	48.63(60)	63.929146				0+			
^{65}Zn		64.929245	243.8 d	β^+ /98/1.3514	0.325/	5/2-	+0.7690	-0.023	ann.rad./
				EC/1.5/				1.116/50.8	
^{66}Zn	27.90(27)	65.926036				0+			
^{67}Zn	4.10(13)	66.927131				5/2-	+0.8755	+0.15	
^{68}Zn	18.75(51)	67.924847				0+			
^{69m}Zn			13.76 h	I.T./99+/0.439			9/2+		0.4390(2)/95.
^{69}Zn		68.926553	56. m	β^- /0.906	0.905/99.9	1/2-			0.318/
^{70}Zn	0.62(3)	69.925325				0+			
^{71m}Zn			3.97 h	β^- /	1.45/	9/2+			0.3864/93.
									0.4874/62.
									0.6203/57.
									(0.099-2.489)
^{71}Zn		70.92773	2.4 m	β^- /2.81		1/2-			0.5116(1)/30.
									0.9103(1)/7.5
									(0.12-2.29)
^{72}Zn		71.92686	46.5 h	β^- /0.46	0.25/14.	0+			0.0164(3)/8.
					0.30/86.				0.1447(1)/83.
									0.1915(2)/9.4
^{73m}Zn			6. s		I.T./0.196	(7/2+)			0.042
^{73}Zn		72.92978	24. s	β^- /4.29	4.7/	(1/2-)			0.216(1)/100.
									0.496-0.911
^{74}Zn		73.92946	1.60 m	β^- /2.3	2.1/				0.0565/
									0.1401/
									(0.05-0.35)
^{75}Zn		74.9329	10.2 s	β^- /6.0					0.229/
^{76}Zn		75.9334	5.7 s	β^- /4.2	3.6/				0.119/
^{77m}Zn			1.0 s	β^- /		(1/2-)			0.772
^{77}Zn		76.9371	2.1 s	β^- /7.3	4.8/				0.189/
^{78m}Zn			>0.03 ms						1.070
^{78}Zn		77.9386	1.5 s	β^- /6.4					0.225/
^{79}Zn		78.9421	1.0 s	β^- /8.6					0.702/
^{80}Zn		79.9444	0.54 s	β^- /7.3					0.713/
									0.2248/
^{81}Zn		80.9505	0.29 s	β^- /11.9					
^{82}Zn		81.9548	>0.15 μs						
^{83}Zn			>0.15 μs						

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
$_{31}$Ga		69.723(1)							
^{56}Ga		55.9949							
^{57}Ga		56.9829							
^{58}Ga		57.9742							
^{59}Ga		58.9634							
^{60}Ga		59.9571							
^{61}Ga		60.9492	0.15 s	β^+ /9.0		3/2$^-$			
^{62}Ga		61.94418	0.116 s	β^+ /9.17	8.3/	0+			ann.rad./
				EC/					
^{63}Ga		62.9391	32. s	β^+ /5.5	4.5/				ann.rad./
				EC/					0.6271(2)/10.
									0.6370(2)/11.
									1.0652(4)/45.
^{64m}Ga			0.022 ms						0.0429
^{64}Ga		63.936838	2.63 m	β^+ /7.165		2.79/	0+		ann.rad./
					6.05/				0.80785(1)/14.
									0.99152(1)/43.
									1.38727(1)/12.
									3.3659(1)/13.
^{65}Ga		64.9394	15.2 m	β^+ /86/3.255		0.82/10.	3/2-		ann.rad./
				EC/	1.39/19.				0.1151(2)/55.
					2.113/56.				0.1530(2)/96.
					2.237/15.				0.2069(2)/39.
									(0.06-2.4)
^{66}Ga		65.931592	9.5 h	β^+ /56/5.175		0.74/1.	0+		ann.rad./
				EC/43/	1.84/54.				1.03935(8)/38.
					4.153/51.				2.7523(1)/23.
									(0.28-5.01)
^{67}Ga		66.928205	3.260 d	EC/1.001		3/2-	+1.8507	0.20	0.09332/37.
									0.18459/20.
									0.30024/17.
									(0.091-0.89)
^{68}Ga		67.927983	1.130 h	β^+ /90/2.921	1.83/	1+	0.01175	0.028	ann.rad./
				EC/10/					1.0774(1)/3.
									(0.57-2.33)/
^{69}Ga	60.108(9)	68.925581				3/2-	+2.01659	+0.17	
^{70}Ga		69.926027	21.1 m	EC/0.2/0.655		1+			0.1755(5)/0.15
				β^- /99.8/1.656		1.65/99.			1.042(5)/0.48
^{71}Ga	39.892(9)	70.924707				3/2-	+2.56227	+0.11	
^{72}Ga		71.926372	14.10 h	β^- /4.001	0.64/40.	3-	-0.13224	+0.5	0.62986(5)/24.
					1.51/9.				2.2016(2)/26.
					2.52/8.				2.5077(2)/12.8
					3.15/11.				(0.11-3.3)/
^{73}Ga		72.92517	74.87 h	β^- /1.59		3/2-			0.05344(5)/10.
									0.29732(5)/47.
									(0.01-1.00)/
^{74m}Ga			10. s	I.T./		1+			0.0565(1)/75.
^{74}Ga		73.92694	8.1 m	β^- /5.4	2.6/	3-			0.5959/92.
									2.354/45.
									(0.23-3.99)
^{75}Ga		74.92650	2.10 m	β^- /3.39	3.3/	3/2-			0.2529/
									0.5746/
									(0.12-2.10)
^{76}Ga		75.9289	29. s	β^- /7.0		3-			0.5629/66.
									0.5455/26.
									(0.34-4.25)
^{77}Ga		76.9293	13.0 s	β^- /5.3	5.2/				0.469/
									0.459/

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{78}Ga		77.9317	5.09 s	β^- /8.2		3+			0.619/77.
									1.187/20.
^{79}Ga		78.9329	2.85 s	β^- /7.0	4.6/				0.465/
^{80}Ga		79.9366	1.68 s	β^- /10.4	10./				0.659/
^{81}Ga		80.9377	1.22 s	β^- /8.3	5.1/				0.217/
^{82}Ga		81.9432	0.599 s	β^- /12.6					1.348/
^{83}Ga		82.9469	0.308 s	β^- /≈ 11.5					
^{84}Ga		83.952	≈0.085 s		β^- /14				
^{85}Ga			>0.15 μs						
^{86}Ga			>0.15 μs						
$_{32}$Ge		72.61(2)							
^{58}Ge		57.9910							
^{59}Ge		58.9817							
^{60}Ge		59.9702							
^{61}Ge		60.9638	0.04 s	β^+ /13.6					
^{63}Ge		62.9496	0.10 s	β^- /9.8					
^{64}Ge		63.9416	1.06 m	β^+ /4.4	3.0/	0+			ann.rad./
				EC/					0.1282(2)/11.
				β^+,p					0.4270(3)/37.
									0.6671(3)/17.
^{65}Ge		64.9394	31. s	β^+ /6.2	0.82/10.				ann.rad./
				EC/	1.39/19.				0.0620/27.
				EC,p	2.113/56.				0.6497/33.
					2.237/15.				0.8091/21.
									(0.19-3.28)
^{66}Ge		65.93385	2.26 h	β^+ /27/2.10			0+		ann.rad./
				EC/73/					0.0438/29.
									0.3819/28.
									(0.022-1.77)
^{67}Ge		66.932738	19.0 m	β^+ /96/4.225		1.6/	1/2-		ann.rad./
				EC/4/	2.3/				0.1670/84.
					3.15/				(0.25-3.73)
^{68}Ge		67.92810	270.8 d	EC/0.11		0+			Ga k x-ray/39.
^{69}Ge		68.927973	1.63 d	β^+ /36/2.2273	0.70/	5/2-	0.735	0.02	ann.rad./
				EC/64/	1.2/				0.574/13.
									1.1068/36.
									(0.2-2.04)
^{70}Ge	20.84(87)	69.924250				0+			
^{71m}Ge			20.4 ms		I.T./0.0234	9/2+			0.1749
^{71}Ge		70.924954	11.2 d	EC/0.229		1/2-	+0.547		
^{72}Ge	27.54(34)	71.922076				0+			
^{73}Ge	7.73(5)	72.923460				9/2+	-0.879467	-0.17	
^{74}Ge	36.28(73)	73.921178				0+			
^{75m}Ge			48. s	I.T./		7/2+			0.13968(3)/39.
^{75}Ge		74.922860	1.380 h	β^- /1.177	1.19/	1/2-	+0.510		0.26461(5)/11.
									0.41931(5)/0.2
^{76}Ge	7.61(38)	75.921403	≈1(10^{21}y		$\beta^-\beta^-$		0+		
^{77m}Ge			53. s	I.T./20/		1/2-			1.605/0.22
				β^- /80/2.861		2.9/			1.676/0.16
									0.195-1.482
^{77}Ge		76.923549	11.25 h	β^- /2.702	0.71/23.	7/2+			0.2110/29.
					1.38/35.				0.2155/27.
					2.19/42.				0.2644/51.
									(0.15-2.35)
^{78}Ge		77.922853	1.45 h	β^- /0.95	0.70/	0+			0.2773(5)/96.
									0.2939(5)/4.
^{79m}Ge			39. s	β^- /IT		7/2+			
^{79}Ge		78.9254	19.1 s	β^- /4.2	4.0/20.	1/2-			0.1096/21.
					4.3/80.				(0.10-2.59)

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									0.5427(4)/15.
^{80}Ge		79.92545	29.5 s	β⁻ /2.67	2.4/	0+			0.1104(4)/6.
									0.2656(4)/25.
^{81m}Ge			≈7.6 s		β⁻ /	3.75/	1/2+		0.3362(4)/
									0.7935(4)/
^{81}Ge		80.9288	≈7.6 s		β⁻ /6.2	3.44/	9/2+		0.1976(4)/21.
									0.3362(4)/100.
^{82}Ge		81.9296	4.6 s	β⁻ /4.7		0+			1.093/
^{83}Ge		82.9345	1.9 s	β⁻ /8.9					
^{84}Ge		83.9373	0.98 s	β⁻ /7.7					
^{85}Ge		84.943	0.54 s	β⁻ /10.					
^{86}Ge		85.946	>0.15 μs						
^{87}Ge			>0.15 μs						
^{88}Ge			>0.15 μs						
^{89}Ge			>0.15 μs						
$_{33}$As		74.92160(2)							
^{60}As		59.993							
^{61}As		60.981							
^{62}As		61.9732							
^{63}As		62.9637							
^{64}As		63.9576	>1.2 μs						
^{65}As		64.9495	0.19 s	β⁺ /9.4					
^{66m2}As			1.9 μs						
^{66m1}As			0.018 ms						
^{66}As		65.94410	95.8 ms	β⁺ /9.55					
^{67}As		66.9392	42. s	β⁺ /6.0	5.0/	5/2-			0.121/
				EC/					0.123/
									0.244/
^{68}As		67.9368	2.53 m	β⁺ /8.1		3+			ann.rad./
									0.652/32.
									0.762/33.
									1.016/77.
									(0.61-3.55)
^{69}As		68.93228	15.2 m	β⁺ /98/4.01		2.95/	5/2-	1.6	ann.rad./
				EC/2/					0.0868(5)/1.5
									0.1458(3)/2.4
^{70}As		69.93093	52.6 m	β⁺ /84/6.22	1.44/	4+	+2.1061	+0.09	ann.rad./
				EC/16/2.14					1.0395(7)/82.
				/2.89					(0.17-4.4)/
^{71}As		70.927114	2.72 d	β⁺ /32/2.013		5/2-	+1.6735	-0.02	ann.rad./
				EC/68/					0.1749(2)/84.
									1.0957(2)/4.2
^{72}As		71.926753	26.0 h	β⁺ /77/4.356	0.669/5.	2-	-2.1566	-0.08	ann.rad./
					1.884/12.				0.83395(5)/80.
					2.498/62.				1.0507(1)/9.6
					3.339/19.				(0.1-4.0)
^{73}As		72.923825	80.3 d	EC/0.341		3/2-			0.0133/0.1
									0.0534/10.5
									Se k x-ray/90.
^{74}As		73.923829	17.78 d	β⁺ /31/2.562		0.94/26.	2-	-1.597	ann.rad./
				EC/37/	1.53/3.				0.59588(1)/60.
				β⁻ /1.353	0.71/16.				0.6084(1)/0.6
					1.35/16.				0.6348(1)/15.
^{75m}As			0.017 s						
^{75}As	100.	74.921597				3/2-	+1.43947	+0.31	
^{76}As		75.922394	26.3 h	β⁻ /2.962	0.54/3.	2-	-0.903		0.5591(1)/45.
					1.785/8.				0.65703(5)/6.2
					2.410/36.				1.21602(1)/3.4
					2.97/51.				(0.3-2.67)

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{77}As		76.920648	38.8 h	β^- /0.683	0.70/98.	3/2-	+1.295		0.2391(2)/1.6
									0.2500(3)/0.4
								0.5208/0.43	
^{78}As		77.92183	1.512 h	β^- /4.21	3.00/12.	2-			0.6136(3)/54.
					3.70/17.				0.6954(3)/18.
					4.42/37.				1.3088(3)/10.
^{79m}As			1.21 μs			9/2+			0.542/IT
									0.231
^{79}As		78.92095	9.0 m	β^- /2.28	1.80/95.	3/2-			0.0955(5)/16.
									0.3645(5)/1.9
^{80}As		79.92258	16. s	β^- /5.64	3.38/	1+			0.6662(2)/42.
									(2.5-3.0)
^{81}As		80.92213	33. s	β^- /3.856		3/2-			0.4676(2)/20.
									0.4911(2)/8.
^{82m}As			13.7 s	β^- /	3.6/	5-			0.6544(1)/72.
									0.8186(4)/27.
									1.7313(2)/27.
									1.8954(2)/38.
^{82}As		81.9246	19. s	β^- /7.4	7.2/80.	1+			0.6544(1)/15.
^{83}As		82.9250	13.4 s	β^- /5.5					0.7345/100.
									1.1131/34.
									2.0767/28.
^{84m}As			0.6 s	β^-					
^{84}As		83.9291	4. s	β^-, n/7.2		1-			0.6671(2)/21.
									1.4439(5)/49.
									(0.325-5.150)
^{85}As		84.9318	2.03 s	β^-, n/8.9		3/2-			0.667(1)/42.
									1.4551(2)/100.
^{86}As		85.9362	0.95 s	β^-, n/11.4					0.704/
^{87}As		86.9396	0.49 s	β^-, n/10.					0.704/
^{88}As		87.945	>0.15 μs						
^{89}As		88.949	>0.15 μs						
^{90}As			>0.15 μs						
^{91}As			>0.15 μs						
^{92}As			>0.15 μs						
$_{34}$Se		78.96(3)							
^{65}Se		64.965	0.011 s	β^+ /60/14.					
				β^+, p	3.55/				
^{66}Se		65.9552							
^{67}Se		66.9501	0.06 s	β^+ /10.2					ann.rad./
				β^+ ,(p)/					0.352
^{68}Se		67.9419	36. s	β^+ /4.7					ann.rad./
									(0.050-0.426)
^{69}Se		68.93956	27.4 s	β^+ /6.78	5.006/				ann.rad./
				EC/					0.0664(4)/27.
									0.0982(4)/63.
^{70}Se		69.9335	41.1 m	β^+ /2.4		0+			ann.rad
									0.04951(5)/35.
									0.4262(2)/29.
^{71}Se		70.9319	4.7 m	β^+ /4.4	3.4/36.	5/2-			ann.rad
				EC/					0.1472(3)/47.
									0.8309(3)/13.
									1.0960(3)/10.
^{72}Se		71.92711	8.5 d	EC/0.34		0+			0.0460(2)/57.
^{73m}Se			40. m	I.T./73/0.0257		0.85	3/2-		ann.rad.
				β^+ /27/2.77		1.45/			0.0257(2)/27.
					1.70/				0.2538(1)/2.5
^{73}Se		72.92678	7.1 h	β^+ /65/2.74		0.80/	9/2+	0.86	ann.rad
				EC/35/	1.32/95.				0.0670(1)/72.

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
					1.68/1.				0.3609(1)/97.
									(0.6-1.5)
^{74}Se	0.89(4)	73.922477				0+			
^{75}Se		74.922524	119.78 d	EC/0.864		5/2+	0.67	1.0 0.13600/55	
							0.26465/58		
									(0.024-0.821)
^{76}Se	9.37(29)	75.919214				0+			
^{77m}Se			17.4 s	I.T./		7/2+			0.1619(2)/52.
^{77}Se	7.63(16)	76.919915				1/2-	+0.53506		
^{78}Se	23.77(28)	77.917310				0+			
^{79m}Se			3.92 m	I.T./					0.09573(3)/9.5
^{79}Se		78.918500	1.1x10^{6} y	β^-/0.151		7/2+	-1.018	+0.8	
^{80}Se	49.61(41)	79.916522				0+			
^{81m}Se			57.3 m	I.T./99/0.1031			7/2+		0.1031(3)/9.7
									0.2602(2)/0.06
								0.2760/0.06	
^{81}Se		80.917993	18.5 m	β^-/1.585	1.6/98.	1/2-		0.2759/0.85	
								0.2901/0.75	
								0.8283/0.32	
^{82}Se	8.73(22)	81.916700	≈1(10^{20} y		$\beta^-\beta^-$		0+		
^{83m}Se			1.17 m	β^- /3.96	2.88/	1/2-			0.35666(6)/17.
					3.92/				0.9879(1)/15.
									1.0305(1)/21.
									2.0514(2)/11.
									(0.19-3.1)
^{83}Se		82.919119	22.3 m	β^- /3.668	0.93/	9/2+			0.22516(6)/33.
					1.51/				0.35666(6)/69.
									0.51004(8)/45.
									(0.21-2.42)
^{84}Se		83.91847	3.3 m	β^- /1.83	1.41/100.	0+			0.4088(5)/100.
^{85}Se		84.92225	32. s	β^- /6.18	5.9/	5/2+			0.3450(1)/22.
									0.6094(1)/41.
^{86}Se		85.92428	15. s	β^- /5.10		5/2+			2.0124(1)/24.
									2.4433(8)/100.
									2.6619(1)/49.
^{87}Se		86.92853	5.4 s	β^- /7.28					0.468(1)/100.
				n/					1.4979(1)/23.
^{88}Se		87.93143	1.5 s	β^- ,n/6.85					0.5346/
^{89}Se		88.9360	0.41s	β^- ,n/9.0					
^{90}Se		89.9394	>0.15 μs						
^{91}Se		90.945	0.27 s	β^- ,n/8.					
^{92}Se		91.949	>0.15 μs						
^{93}Se			>0.15 μs						
^{94}Se			>0.15 μs						
$_{35}$Br		79.904(1)							
^{67}Br		66.9648							
^{68}Br		67.958	<1.2 μs						
^{69}Br		68.9502	<0.024 μs		β^+ /9.6				
^{70}Br		69.9446	79. ms	β^+ /10.0	/0.75				
^{71}Br		70.9392	21. s	β^+ /6.9					
^{72}Br		71.9365	1.31 m	β^+ /8.7		3	≈0.55		0.4547-1.3167
^{73}Br		72.9318	3.4 m	β^+ /4.7	3.7/	3/2-			ann.rad
								0.065-0.700	
^{74m}Br			46. m	β^+ /	4.5/	4-	1.82		ann.rad
									0.6348
									0.7285
									(0.2 - 4.38)
^{74}Br		73.92989	25.4 m	β^+ /6.91					ann.rad
									0.6341

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									0.6348
									(0.2-4.7)
^{75}Br		74.92578	1.62	β^+ /76/3.03			3/2-	+0.75	ann.rad
									0.28650
									(0.1-1.56)
^{76m}Br			1.4 s	I.T./5.05		4+			0.104548
									0.05711
^{76}Br		75.92454	16.0 h	β^+ /57 /4.96	1.9/	1-	0.54821	0.270	ann.rad
					3.68/				0.55911
									1.85368
									(0.4-4.6)
^{77m}Br			4.3 m	I.T./0.1059		9/2+			0.1059
^{77}Br		76.921380	2.376 d	EC/99 /1.365		3/2-	0.973	+0.53	ann.rad.
									0.23898
									0.52069
									(0.08-1.2)
^{78}Br		77.921146	6.45 m	β^+ /92/3.574		1.2/	1+	0.13	ann.rad.
				EC/8 /	2.5/				0.61363
									(0.7-3.0)
^{79m}Br			4.86 s	I.T./0.207		9/2+			0.2072
^{79}Br	50.69(7)	78.918338				3/2-	+2.106400	+0.331	
^{80m}Br			4.42 h	I.T./0.04885		5-	+1.3177	+0.75	Br k x-ray
									0.03705/39.1
									0.04885/0.3
^{80}Br		79.918530	17.66 m	β^- /92 /2.004	1.38 β^- /7.6	1+	0.5140	0.196	ann.rad.
				EC/5.7/1.8706	1.99 β^- /82				0.6169/6.7
				β^+ /2.6/	0.85 β^+ /2.8				(0.64-1.45)
^{81}Br	49.31(7)	80.916291				3/2-	+2.270562	+0.276	
^{82m}Br			6.1 m	I.T./98/0.046		2-			0.046/0.24
				β^- /2 /3.139					(0.62-2.66)
^{82}Br		81.916805	1.471 d	β^- /3.093	0.444/	5-	+1.6270	0.751	0.5544/71
									0.61905/43
									0.77649/84
									(0.013-1.96)
^{83}Br		82.915181	2.40 h	β^- /0.972	0.395/1	3/2-			0.52964
					0.925/99				(0.12-0.68)
^{84m}Br			6.0 m	β^- /4.97	2.2/100	(6-)			0.4240/100
									0.8817/98
									1.4637/101
^{84}Br		83.91651	31.8 m	β^- /4.65	2.70/11	2-	2.		0.8816/41
					3.81/20				1.8976/13
					4.63/34				(0.23-4.12)
^{85}Br		84.91561	2.87 m	β^- /2.87	2.57	3/2-			0.80241/2.56
									0.92463/1.6
									(0.09-2.4)
^{86}Br		85.91880	55.5 s	β^- /7.63	3.3	(2-)			1.56460/64
					7.4				2.75106/21
									(0.5-6.8)
^{87}Br		86.92072	55.6 s	β^- /6.85	6.1/	3/2-			1.41983
				n/					1.4762
									(0.2-6.1)
^{88m}Br			5.1 μs						
^{88}Br		87.92407	16.3 s	β^- /8.96		1-			0.7649
				n/					0.7753
									0.8021
									(0.1-6.99)
^{89}Br		88.92640	4.35 s	β^- /8.16		3/2-			0.7753

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
				n/					1.0978
^{90}Br		89.9306	1.91 s	β^- /10.4	8.3/	2-			0.6555
				n/	9.8/				0.7071
									1.3626
^{91}Br		90.9339	0.54 s	β^- /90 /9.80					0.263
				β^- n/10 /					0.803
^{92}Br		91.9392	0.31 s	β^- /12.20					0.740
				β^- n/					
^{93}Br		92.9431	0.10 s	β^- n/11.1					
^{94}Br		93.9487	0.07 s	β^- n/					
^{95}Br			>0.15 μs						
^{96}Br			>0.15 μs						
^{97}Br			>0.15 μs						
$_{36}$Kr		83.80(1)							
^{69}Kr		68.9653	0.03 s	β^+,(p)	4.07/				
^{70}Kr		69.9560	>1.2 μs						
^{71}Kr		70.9505	100. ms	β^+ ,EC/10.1					(0.198-0.207)
^{72}Kr		71.9419	17. s	β^+ /5.0		0+			ann.rad
				EC/					0.3100/29
									0.4150/36
									(0.12-0.58)
^{73}Kr		72.9389	28. s	β^+ /6.7		5/2-			ann.rad.
				EC/					0.1781/66
				β^+ ,p/	/0.25				(0.06-0.86)
^{74}Kr		73.9333	11.5 m	β^+ /3.1		0+			ann.rad.
				EC/					0.08970/31
									0.2030/20
									(0.010-1.06)
^{75}Kr		74.93104	4.3 m	β^+ /4.90	3.2/	5/2+	- 0.531	+ 1.1	ann.rad.
				EC/					0.1325/68
									0.1547/21
									(0.02-1.7)
^{76}Kr		75.92595	14.8 h	EC/1.31		0+			Br k x-ray
									0.270/21
									0.3158/39
									(0.03-1.07)
^{77}Kr		76.92467	1.24 h	β^+ /80 /3.06		5/2+	- 0.583	+ 0.9	ann.rad.
				EC/20 /	1.55/				0.1297/80
					1.70/				0.1465/38
					1.87/				(0.02-2.3)
^{78}Kr	0.35(1)	77.92039	>0.9(10^{20} y		$\beta^-\beta^-$		0+		
^{79m}Kr			53. s	I.T./0.1299		7/2+	- 0.786	+ 0.40	Kr x-ray
^{79}Kr		78.920083	1.455 d	β^+ /7 /1.626			1/2-	+ 0.536	ann.rad.
				EC/93 /					0.2613/13
									0.39756/19
									0.6061/8
									(0.04-1.3)
^{80}Kr	2.28(6)	79.916379				0+			
^{81m}Kr			13.1 s	I.T./0.1904		1/2-	+ 0.586		0.1904
^{81}Kr		80.916593	2.1x10^{5} y	EC/0.2807		7/2+	- 0.908	+ 0.63	Br k x-ray
									0.2760
^{82}Kr	11.58(14)	81.913485				0+			
^{83m}Kr			1.86 h	I.T./0.0416		1/2-	+ 0.591		Kr k x-ray
									0.00940
									0.03216
^{83}Kr	11.49(6)	82.914137				9/2+	-0.970699	+0.253	
^{84}Kr	57.00(4)	83.911508				0+			
^{85m}Kr			4.48 h	β^- /79 /	0.83/79	1/2-	+ 0.633		0.30487
				I.T./21 /0.305					0.15118

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Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{85}Kr		84.912530	10.73 y	β^- /0.687	0.15/0.4	9/2+	1.005	+0.43	0.51399
^{86}Kr	17.30(22)	85.910615				0+			
^{87}Kr		86.913359	1.27 h	β^- /3.887	1.33/8	5/2+	-1.023	- 0.30	0.40258/49.6
					3.49/43				2.5548/9.2
					3.89/30				(0.13-3.31)
^{88}Kr		87.91445	2.84 h	β^- /2.91		0+			0.19632/26.
									2.392/34.6
									(0.03-2.8)
^{89}Kr		88.91764	3.15 m	β^- /4.99	3.8/	5/2+	- 0.330	+ 0.16	0.19746
					4.6/				0.2209/19.9
					4.9/				0.5858/16.4
									1.4728/6.8
									(0.2-4.7)
^{90}Kr		89.91953	32.3 s	β^- /4.39	2.6/77	0+			0.12182/32.9
					2.8/6				0.5395/28.6
									1.1187/36.2
									(0.1 - 4.2)
^{91}Kr		90.9234	8.6 s	β^- /6.4	4.33/	5/2+	- 0.583	+ 0.30	0.10878/43.5
					4.59/				0.50658/19.
									(0.2-4.4)
^{92}Kr		91.92611	1.84 s	β^- /5.99					0.1424/66.
				n/					(0.14 - 3.7)
^{93}Kr		92.9312	1.29 s	β^- /8.6	7.1/	1/2+	- 0.413		0.1820
				n/					0.2534/42.
									0.32309/24.6
									(0.057-4.03)
^{94}Kr		93.9343	0.21 s	β^- /7.3					0.2196/67
									0.6293/100.
							- 0.410		(0.098-0.985)
^{95}Kr		94.9397	0.78 s	β^- /9.7					
^{96}Kr		95.9431	> 50 ms						
^{97}Kr		96.9486	< 0.1 s	β^-					
^{98}Kr			>0.15 μs						
^{99}Kr			>0.15 μs						
^{100}Kr			>0.15 μs						
$_{37}$Rb		85.4678(3)							
^{71}Rb		70.9653							
^{72}Rb		71.9591	<1.2 μs						
^{73}Rb		72.9504	<0.03 μs						
^{74}Rb		73.9445	65. ms	β^+ /10.4					
^{75}Rb		74.93857	19. s	β^+ /7.02	2.31/				ann. rad.
									0.179
^{76}Rb		75.93508	39. s	β^+ /8.50	4.7/	1-	-0.372623	+0.4	ann.rad.
									0.4240/92.
									(0.064-1.68)
^{77}Rb		76.93041	3.8 m	β^+ /5.34	3.86/	3/2-	+0.654468	+0.70	ann.rad.
									0.0665/59
									(0.04 - 2.82)
^{78m}Rb			5.7 m	I.T./0.1034		4-	+2.549	+0.81	ann.rad.
				β^+ /	3.4				0.4553/81.
				EC/					(0.103-4.01)
^{78}Rb		77.92814	17.7 m	β^+ /7.22		0+			ann.rad.
				EC/					0.4553/63.
									(0.42-5.57)
^{79}Rb		78.92400	23. m	β^+ /84 /3.65		5/2+	+0.3358	-0.10	ann.rad.
				EC/16 /					0.68812/23.
									(0.017-3.02)
^{80}Rb		79.92252	34. s	β^+ /5.72	4.1/22	1+	-0.0836	+0.35	ann.rad.
					4.7/74				0.6167/25.

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{81m}Rb			30.5 m	I.T./0.85	1.4	9/2+	+5.598	-0.74	ann.rad.
				β^+,EC/					(0.085-1.9)
^{81}Rb		80.91900	4.57 h	β^+/27 /2.24	1.05/	3/2-	+2.060	+0.40	ann.rad./
				EC/73					0.19030/64.
									(0.05 - 1.9)
^{82m}Rb			6.47 h	β^+/26 /	0.80/	5-	+1.5100	+1.0	ann.rad./
				EC/74 /					0.5544/63.
									0.7765/85.
									(0.092 - 2.3)
^{82}Rb		81.91821	1.258 m	β^+/96 /4.40	3.3/	1+	+0.554508	+0.19	ann.rad./
				EC/4 /					0.7665/13.
									(0.47 - 3.96)
^{83}Rb		82.91511	86.2 d	EC/0.91		5/2-	+1.425	+0.20	Kr x-ray
									0.5205/46.
									(0.03-0.80)
^{84m}Rb			20.3 m	I.T./0.216		6-	+0.2129	+0.6	0.2163/34.
									0.2482/63.
									0.4645/32.
^{84}Rb		83.914387	32.9 d	β^+/22 /2.681	0.780/11	2-	-1.32412	-0.015	ann.rad./
				EC/75 /	1.658/11				0.8817/68.
				β^-/3 /0.894		0.893/			(1.02-1.9)
^{85}Rb	72.17(2)	84.911792				5/2-	+1.353	+0.23	
^{86m}Rb			1.018 m	I.T./0.5560		6-	+1.815	+0.37	0.556/98.
^{86}Rb		85.911170	18.65 d	β^-/1.775	1.774/8.8	2-	-1.6920	+0.19	1.0768/8.8
^{87}Rb	27.83(2)	86.909186	4.88x10^{10}y	β^-/0.283	0.273/100	3/2-	+2.7512	+0.13	
^{88}Rb		87.911323	17.7 m	β^-/5.316	5.31	2-	0.508		0.8980/14.
									1.8360/21.
									(0.34-4.85)
^{89}Rb		88.91229	15.4 m	β^-/4.50	1.26/38	3/2-	+2.304	+0.14	1.032/58.
					1.9/5				1.248/42.
					2.2/34				2.1960/13
					4.49/18				(0.12-4.09)
^{90m}Rb			4.3 m	β^-/4.50	1.7/	4-	+1.616	+0.20	0.1069(IT)
					6.5/				0.8317/94
									(0.20-5.00)
^{90}Rb		89.91481	2.6 m	β^-/6.59	6.6	1-			0.8317/28.
									(0.31-5.60)
^{91}Rb		90.91649	58.0 s	β^-/5.861	5.9	3/2-	+2.182	+0.15	0.0936/34.
									(0.35-4.70)
^{92}Rb		91.91968	4.48 s	β^-/8.11	8.1/94	1-			0.8148/8.
									(0.1-6.1)
^{93}Rb		92.92195	5.85 s	β^-/7.46	7.4/	5/2	+1.410	+0.18	0.2134/4.8
				n/1					0.4326/12.5
									0.9861/4.9
									(0.16-5.41)
^{94}Rb		93.92643	2.71 s	β^-/10.31	9.5/	3	+1.498	+0.16	0.8369/87.
				n/10					1.5775/32.
									(0.12-6.35)
^{95}Rb		94.92929	0.377 s	β^-/9.30	8.6/	5/2	+1.334	+0.21	0.352/65.
				n/8					0.680/22.
									(0.20-2.27)
^{96m}Rb			1.7 μs						0.2999
									0.4612
									0.2400
									0.093-0.369
^{96}Rb		95.93427	0.199 s	β^-/11.76	10.8/	2+	+1.466	+0.25	0.815/76.
				n/13/					(0.20-5.42)
^{97}Rb		96.93733	0.169 s	β^-/10.42	10.0	3/2	+1.841	+0.58	0.167/100.
				n/27/					0.585/79.

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									0.599/56.
									1.258/52.
									(0.14-2.08)
^{98}Rb		97.94174	0.107 s	β^-/12.34	0.144/				
				n/13					(0.07-3.68)
^{99}Rb		98.9453	59. ms	β^-/11.3					
^{100}Rb		99.9499	53. ms	β^- /13.5					
^{101}Rb		100.9532	0.03 s	β^- /11.8					
^{102}Rb		101.9592	0.09 s	β^-					
$_{36}$Sr		87.62(1)							
^{73}Sr		72.966	> 25 ms						
^{74}Sr		73.9563	>1.2 μs						
^{75}Sr		74.9499	≈ 0.07 s						
^{76}Sr		75.9416	8.9 s	β^+ /6.1					
^{77}Sr		76.9378	9.0 s	β^+ /6.9	5.6		-0.35	+1.4	0.147
^{78}Sr		77.93218	2.7 m	β^+ /3.76					(0.047-0.793)
^{79}Sr		78.92971	2.1 m	β^+ /5.32	4.1	3/2-	-0.474	+0.74	ann.rad./
									0.039/28.
									0.105/22.
									(0.135-0.612)
^{80}Sr		79.92453	1.77 h	β^+ /1.87		0+			ann.rad./
									0.174/10.
									0.589/39.
									(0.24-0.55)
^{81}Sr		80.92322	22.3 m	β^+ /87 /3.93		2.43/	1/2-	+0.544	ann.rad./
				EC/13 /	2.68/				0.148/31.
									0.1534/35
									(0.06-1.7)
^{82}Sr		81.91840	25.36 d	EC/0.18					Rb x-ray
^{83m}Sr			5.0 s	I.T./0.2591		1/2-	+0.582		0.2591/87.5
^{83}Sr		82.91756	1.350 d	β^+/24 /2.28	0.465/	7/2+	-0.898	+0.79	ann.rad./
				EC/76/	0.803/				0.3816/12.
					1.227/				0.3816
									0.7627/30.
									(0.094-2.15)
^{84}Sr	0.56(1)	83.913426				0+			
^{85m}Sr			1.127 h	I.T./87 /0.2387		1/2-	+0.601		0.2318/84.
				EC/13					(0.15-0.24)
^{85}Sr		84.912936	64.85 d	EC/1.065		9/2+	-1.001	+0.30	0.51399/99.3
^{86}Sr	9.86(1)	85.909265				0+			
^{87m}Sr			2.81 h	I.T./0.3884		1/2-	+0.63		0.3884(IT)
^{87}Sr	7.00(1)	86.908882				9/2+	-1.09360	+0.34	
^{88}Sr	82.58(1)	87.905617				0+			
^{89}Sr		88.907455	50.52 d	β^-/1.497	1.492/100	5/2+	-1.149	-0.3	0.9092
^{90}Sr		89.907738	29.1 y	β^-/0.546	0.546/100	0+			
^{91}Sr		90.91020	9.5 h	β^-/2.70	0.61/7	5/2+	-0.887	+0.044	0.5556/61.
					1.09/33				0.7498/24.
					1.36/29				1.0243/33.
					2.66/26				(0.12-2.4)
^{92}Sr		91.91098	2.71 h	β^-/1.91	0.55/96	0+			1.3831/90.
					1.5/3				(0.24-1.1)
^{93}Sr		92.91394	7.4 m	β^-/4.08	2.2/10	5/2+	-0.794	+0.26	0.5903/
					2.6/25				0.7104
					3.2/65				0.87573
									0.8883/
									(0.17-3.97)
^{94}Sr		93.91537	1.25 m	β^-/3.511	2.1/	0+			0.6219
					3.3/				0.7043
									0.7241

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									0.8064
									1.4283
^{95}Sr		94.91931	25.1 s	β^-/6.08		1/2+	-0.5379		0.6859
					6.1/50				0.8269
									2.7173
									2.9332
^{96}Sr		95.92165	1.06 s	β^-/5.37	4.2/	0+			0.1222
									0.5305
									0.8094
									0.9318
^{97}Sr		96.92615	0.42 s	β^-/7.47	5.3	(1/2+)	-0.500		0.2164
									0.3071
									0.6522
									0.9538
									1.2580
									1.9050
^{98}Sr		97.92845	0.65 s	β^-/5.83	5.1				0.0365
									0.1190
									0.4286
									0.4447
									0.5636
^{99}Sr		98.9333	0.27 s	β^-/8.0			-0.26	0.8	
^{100}Sr		99.9354	0.201 s	β^-/7.1					
^{101}Sr		100.9405	0.115 s	β^-/9.5					
^{102}Sr		101.9430	68. ms	β^-/8.8					
^{103}Sr		102.9490	>0.15 μs						
^{104}Sr		103.952	>0.15 μs						
^{105}Sr			>0.15 μs						
$_{39}$Y		88.90585(2)							
^{77}Y		76.9496	> 0.5 _s						
^{78m}Y			0.06 s						
^{78}Y		77.9435	5.8 s	β^+/10.5		(5+)			0.279/100
									0.504/90
									0.713/40
^{79}Y		78.9374	15. s	β^+/7.1					(0.152-1.106)
^{80m}Y			4.7 s						0.2285
^{80}Y		79.9320	30. s	β^+/7.0	5.5	(4)			ann.rad./
					5.0/				0.3858/100
									0.5951/42
									0.756-1.396
^{81}Y		80.9291	1.21 m	β^+/5.5	3.7/				ann.rad./
					4.2/				0.428
									0.469
^{82}Y		81.9268	9.5 s	β^+/7.8	6.3/	1+			ann.rad./
									0.5736
									0.6017
									0.7375
^{83m}Y			2.85 m	β^+/95/4.6		2.9	1/2-		ann.rad./
				EC/5 /					0.2591
									0.4218
									0.4945
^{83}Y		82.92235	7.1 m	β^+/4.47	3.3	9/2+			ann.rad./
				EC/					0.0355
									0.4899
									0.8821
									(0.03 - 3.4)
^{84m}Y			4.6 s	β^+/		1+			ann.rad./
				EC/					0.7930
^{84}Y		83.9203	40. m	β^+/6.4	1.64/47	5-			ann.rad./

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
				EC/	2.24/25				0.4628
					2.64/21				0.6606
					3.15/7				0.7931
									0.9744
									1.0398
									(0.2 - 3.3)
^{85m}Y			4.9 h	β^+/70 /		9/2+	6.2		ann.rad./
				EC/30 /					0.2317
									0.5356
									0.7673
									2.1238
									(0.1 - 3.1)
^{85}Y		84.91643	2.6 h	β^+/55 /3.26		1.54/	1/2-		ann.rad./
				EC/45 /					0.2317
									0.5045
									0.9140
									(0.07 - 1.4)
^{86m}Y			48. m	I.T./99 /		8+	4.8		ann.rad./
				β^+/					0.0102(IT)
				EC/					0.2080
									(0.09 - 1.1)
^{86}Y		85.91489	14.74 h	β^+/5.24		4-	<0.6		ann.rad./
				EC/					0.3070
									0.6277
									1.0766
									1.1531
									1.9207
									(0.1 - 3.8)
^{87m}Y			13. h	I.T./98 /		9/2+	6.1		0.3807
				β^+/0.7 /	1.15/0.7				
				EC/					
^{87}Y		86.910880	3.35 d	EC/99+/1.862	0.78/	1/2-			0.3880
									0.4870
^{88}Y		87.909506	106.6 d	EC/99+ /3.623	0.76/	4-			ann.rad./
				β^+/0.2 /					0.89802
									1.83601
									2.73404
									3.2190
^{89m}Y			15.7 s	I.T./0.909		9/2+			0.9092(IT)
^{89}Y	100.	88.905849				1/2-	-0.13742		
^{90m}Y			3.24 h	I.T./99+ /0.68204		7+	5.1		0.2025
				β^-/0.002/					0.4794
									0.6820
^{90}Y		89.907152	2.67 d	β^-/2.282	2.28/	2-	-1.630	-0.155	
^{91m}Y			49.7 m	I.T./0.555		9/2+	5.96		0.5556(IT)
^{91}Y		90.907301	58.5 d	β^-/1.544	1.545/	1/2-	0.1641		1.208
^{92}Y		91.90893	3.54 h	β^-/3.63	3.64/	2-			0.4485
									0.5611
									0.9345
									1.4054
									(0.4 - 3.3)
^{93m}Y			0.82 s	I.T./0.759		9/2+			0.1686(IT)
									0.5902
^{93}Y		92.90956	10.2 h	β^-/2.87	2.88/90	1/2-			0.2669
									0.9471
									1.9178
^{94m}Y			1.4 μs						0.4322
									0.7699
									1.2024

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Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{94}Y		93.91160	18.7 m	β^-/4.919	4.92/	2-			0.3816
									0.9188
									1.1389
									(0.3 - 4.1)
^{95}Y		94.91279	10.3 m	β^-/4.42		1/2-			0.4324
									0.9542
									2.1760
									3.5770
^{96m}Y			9.6 s	β^-/		(3+)			0.1467
									0.6174
									0.9150
									1.1071
									1.7507
^{96}Y		95.91588	6.2 s	β^- /7.09	7.12/	0-			1.594
^{97m}Y			1.21 s	β^- /7.4	4.8/	9/2+			0.1614
					6.0/				0.9700
									1.1030
^{97}Y		96.91813	3.76 s	β^- /6.69	6.7	1/2-			0.2969
									1.9960
									3.2876
									3.4013
^{98m}Y			2.1 s	β^- /9.8	5.5/	(4-)			0.2415
									0.6205
									0.6473
									1.2228
									1.8016
^{98}Y		97.92224	0.59 s	β^- /8.83	8.7/	1+			0.2131
									1.2228
									1.5907
									2.9413
									4.4501
^{99m}Y			0.011 ms						
^{99}Y		98.92463	1.47 s	β^- /7.57		1/2-			0.1218/43.8
				n	/2.5/				0.5362
									0.7242
									1.0130
^{100m}Y			0.94 s	β^-,n /		3+			
^{100}Y		99.9278	0.73 s	β^-,n /9.3	n/1.8/	1+			
^{101}Y		100.9303	0.43 s	β^-,n /8.6	n/1.5/	(5/2)			
^{102}Y		101.9336	0.36 s	β^-,n /9.9	n/4.0/				
^{103}Y		102.9369	0.23 s	β^-,n	n/8.3/				
^{104}Y		103.9414	0.18 s						
^{105}Y		104.9451	>0.15 μs						
^{106}Y		105.950	>0.15 μs						
^{107}Y			>0.15 μs						
^{108}Y			>0.15 μs						
$_{40}$Zr		91.224(2)							
^{79}Zr		78.949	0.06 s						
^{80}Zr		79.9406	4. s	β^+ /8.0					0.290
									0.538
^{81}Zr		80.9368	5. s	β^+ /7.2	6.1	(3/2-)			
^{82}Zr		81.9311	32. s	β^+ /4.0	3.				ann.rad./
^{83m}Zr			7. s	β^+ /7.0		(7/2+)			ann.rad./
^{83}Zr		82.9287	44. s	β^+ /5.9	4.8	(1/2-)			ann.rad./
				EC					0.0556
									0.1050
									0.2560
									0.474
									1.525

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{84}Zr		83.9233	26. m	β^+ /2.7		0+			ann.rad./
				EC/					0.0449
									0.1125
									0.3729
									0.667
^{85m}Zr			10.9 s	I.T./0.2922		1/2-			ann.rad./
				β^+ ,EC/					0.2922(IT)
									0.4165
^{85}Zr		84.9215	7.9 m	β^+ /4.7	3.1	7/2+			ann.rad./
				EC/					0.2663
									0.4163
									0.4543
^{86}Zr		85.91647	16.5 h	EC/1.47		0+			0.0280
									0.243
									0.612
^{87m}Zr			14.0 s	I.T./0.3362		1/2-			0.1352(IT)
									0.2010
^{87}Zr		86.91482	1.73 h	β^+ /3.67		2.26	9/2+		ann.rad./
				EC/					0.3811
									1.228
^{88}Zr		87.91023	83.4 d	EC/0.67		0+			0.3929
^{89m}Zr			4.18 m	I.T./94 /0.5877		1/2-			ann.rad./
				β^+ /1.5 /					0.5877(IT)
				EC/4.7 /					1.507
^{89}Zr		88.908889	3.27 d	β^+ /23 /2.832		0.9/	9/2+	-1.07	ann.rad./
				EC/77 /					0.9092
^{90m}Zr			0.809 s	I.T./		5-	6.3		0.1326
									2.1862
									2.3189(IT)
^{90}Zr	51.45(40)	89.904702				0+			
^{91}Zr	11.22(5)	90.905643				5/2+	-1.30362	-0.21	
^{92}Zr	17.15(8)	91.905039				0+			
^{93}Zr		92.906474	1.5x10^{6}y	β^- /0.091			5/2+		0.0304
^{94}Zr	17.38(28)	93.906314	> 10^{17} y	$\beta^-\beta^-$			0+		
^{95}Zr		94.908041	64.02 d	β^- /1.125	0.366/55	5/2+	1.13	+0.29	0.7242
					0.400/44				0.7567
^{96}Zr	2.80(9)	95.908275	>2(10^{19} y	$\beta^-\beta^-$			0+		
^{97}Zr		96.910950	16.8 h	β^- /2.658		1.91/	1/2-		0.7434
^{98}Zr		97.91276	30.7 s	β^- /2.26	2.2/100	0+			
^{99}Zr		98.91651	2.2 s	β^- /4.56	3.9/	1/2+			0.4692/55.2
					3.5/				0.5459/48
									0.028-1.321
^{100}Zr		99.91776	7.1 s	β^- /3.34		0+			0.4006
									0.5043
^{101}Zr		100.92114	2.1 s	β^- /5.49	6.2/	3/2-			0.1194
									0.2057
									0.2089
^{102}Zr		101.92298	2.9 s	β^- /4.61					
^{103}Zr		102.9266	1.3 s	β^- /7.0					
^{104}Zr		103.9288	1.2 s	β^- /5.9					
^{105}Zr		104.9331	≈1. s	β^- /8.5					
^{106}Zr		105.9359	>0.24 μs						
^{107}Zr		106.941	>0.24 μs						
^{108}Zr		107.944	>0.15 μs						
^{109}Zr			>0.15 μs						
^{110}Zr			>0.15 μs						
$_{41}$Nb		92.90638(2)							
^{81}Nb		80.949	< 0.08 _s						
^{82}Nb		81.9431	50 ms	β^+ /11.					

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{83}Nb		82.9367		β^+ /7.5					
^{84}Nb		83.9336	12. s	β^+ ,EC/9.6			(3+)		
^{85}Nb		84.9279	2.3 m	β^+ /6.0					
^{86m}Nb			56. s	β^+					
^{86}Nb		85.9250	1.46 m	β^+ /8.0					ann.rad./
									0.751
									1.003
^{87m}Nb			3.7 m	β^+ /		1/2-			ann.rad./
				EC/					0.1352
									0.2010
^{87}Nb		86.92036	2.6 m	β^+ 5.2/		(9/2+)			ann.rad./
				EC/					0.2010
									0.4706
									0.6165
									1.0665
									1.8842
^{88m}Nb			7.7 m	β^+ /		4-			ann.rad./
				EC/					0.2625
									0.3996
									1.0569
									1.0825
^{88}Nb		87.9183	14.3 m	β^+ /7.6	3.2/	8+			ann.rad./
				EC/					1.0570
									1.0828
									(0.07 - 2.5)
^{89m}Nb			2.0 h	β^+ /	3.3/	9/2+			0.5880/10(D)
				EC/					(0.17 - 4.0)
^{89}Nb		88.91349	1.10 h	β^+ /74 /4.29		2.8/	1/2-	+6.216	ann.rad./
				EC/26 /					0.5074
									0.5880
									0.7696
									1.2775
^{90m}Nb			18.8 s	I.T./0.1246		4-			0.002
									0.1225
^{90}Nb		89.911263	14.6 h	β53 /6.111 0.86/5		8+	4.961		ann.rad./
				EC/47 /	1.5/92				0.1412
									1.1292
									2.1862
									2.3189
									(0.1 - 3.3)
^{91m}Nb			62. d	I.T./97 /		1/2-			0.1045(IT)
				EC/3 /					1.2050
^{91}Nb		90.906989	$7x10^2$y	EC/1.253		9/2+			Mo k x-ray
^{92m}Nb			10.13 d	EC/99+ /		2+	6.114		0.9126
									0.9345
									1.8475
^{92}Nb		91.907192	$3.7x10^7$y	EC/2.006		7+			0.5611
									0.9345
^{93m}Nb			16.1 y	I.T./0.0304		1/2-			Nb x-ray
									0.0304
^{93}Nb	100.	92.906376				9/2+	+6.1705	-0.32	
^{94m}Nb			6.26 m	I.T./99+ /2.086		3+			Nb k x-ray
				β^- /0.5 /					0.0409
									0.87109
^{94}Nb		93.907282	$2.4x10^4$y	β^- /2.045		0.47/	6+		0.70263
									0.87109
^{95m}Nb			3.61 d	I.T./97.5 / 0.2357		1/2-			0.2040
				β^- /2.5 /					0.2356
^{95}Nb		94.906834	34.97 d	β^- /0.926		0.160/	9/2+	6.141	0.76578

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{96}Nb		95.908099	23.4 h	β^- /3.187		0.5/10	6+	4.976	0.7782
					0.75/90				0.2191-1.498
^{97m}Nb			58.1 s	I.T./0.7434	0.734/98	1/2-			0.7434
^{97}Nb		96.908096	1.23 h	β^- /1.934		1.27/98	9/2+	6.15	0.4809
									0.6579
^{98m}Nb			51. m	β^- /4.67		5+			0.7874
									0.1726-1.89
^{98}Nb		97.91033	2.9 s	β^- /4.59	4.6/	1+			0.6451
									0.7874
									1.0243
^{99m}Nb			2.6 m	β^- /	3.2/	1/2-			0.0978/100
									(0.138-3.010)
^{99}Nb		98.91162	15.0 s	β^- /3.64	3.5/100	9/2+			0.0977
									0.1378/3.1
^{100m2}Nb			0.013 ms						
^{100m1}Nb			3.0 s	β^- /6.74	5.8				Nb k x-ray
									0.159
									0.6364
									1.0637
^{100}Nb		99.91418	1.5 s	β^- /6.25	6.2/				0.5354
					5.3/				0.6001-1.566
^{101}Nb		100.91525	7.1 s	β^- /4.57	4.3/				0.1105-0.810
^{102m}Nb			4.3 s	β^- /					
^{102}Nb		101.91804	1.3 s	β^- /7.21	7.2/				0.2960-2.184
^{103}Nb		102.91914	1.5 s	β^- /5.53	5.3/	5/2+			
^{104m}Nb			0.9 s	β^-,n/	n/0.06				
^{104}Nb		103.9225	4.8 s	β^-,n/8.1	n/0.05				
^{105}Nb		104.9239	3.0 s	β^-,n/6.5	n/1.7				
^{106}Nb		105.9282	1.0 s	β^-,n/9.3	n/4.5				
^{107}Nb		106.9303	0.30 s	β^-,n/7.9	n/6.0				
^{108}Nb		107.9350	0.19 s	β ,n/	n/6.2				(0.193-0.590)
^{109}Nb		108.9376	0.19 s	β ,n/	n/31				
^{110}Nb		109.943	0.17 s	β ,n/	n/40				
^{111}Nb			>0.15 μs						
^{112}Nb			>0.15 μs						
^{113}Nb			>0.15 μs						
$_{42}$Mo		95.94(1)							
^{83}Mo		82.949							
^{84}Mo		83.9401	>0.15 μs		β^+ /6.		(1/2-)		
^{85}Mo		84.9366	3.2 s	β^+/8.1					
^{86}Mo		85.9302	20. s	β^+ /4.8					
^{87}Mo		86.9273	14. s	EC, β^+/6.5					(0.752-1.004)
^{88}Mo		87.92195	8.0 m	β^+ /3.4		0+	+0.5		ann.rad./
				EC					0.0800
									0.1399
									0.1707
^{89m}Mo			0.19 s	I.T./0.118		1/2-			0.118(IT)
									0.268
^{89}Mo		88.91948	2.2 m	β^+ /5.58			9/2+		ann.rad./
				EC/					0.659
									0.803
									1.155
									1.272
^{90}Mo		89.91394	5.7 h	β^+ /25 /2.489 1.085/		0+			ann.rad./
				EC/75 /					0.04274
									0.12237
									0.25734
^{91m}Mo			1.08 m	I.T./50 /0.653			1/2-		ann.rad./

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
				β^+ ,EC/50 /		2.5/			0.6529
					2.8/				1.2081
					4.0/				1.5080
									2.2407
^{91}Mo		90.91175	15.5 m	β^+ /94 /4.43		3.44/94	9/2-		ann.rad./
				EC/6 /					1.6373
									2.6321
									3.0286
									(0.1 - 4.2)
^{92}Mo	14.84(35)	91.906810				0+			
^{93m}Mo			6.9 h	I.T./99+ /2.425		21/2+	+9.21		0.26306(IT)
									0.68461
									1.47711
^{93}Mo		92.906811	3.5x10^{3}y	EC/0.405		5/2+			0.0304
^{94}Mo	9.25(12)	93.905087				0+			
^{95}Mo	15.92(13)	94.905841				5/2+	-0.9142	-0.02	
^{96}Mo	16.68(2)	95.904678				0+			
^{97}Mo	9.55(8)	96.906020				5/2+	-0.9335	+0.26	
^{98}Mo	24.13(31)	97.905407				0+			
^{99}Mo		98.907711	2.7476 d	β^- /1.357		0.45/14	1/2+	0.375	0.144048
					0.84/2				0.18109
					1.21/84				0.36644
									0.73947
^{100}Mo	9.63(23)	99.90748	≈ 1(10^{19} y		$\beta^-\beta^-$		0+		
^{101}Mo		100.91035	14.6 m	β^- /2.82	2.23/	1/2+			0.0063
					0.7/				0.19193
									0.5909
									(0.0809-2.405)
^{102}Mo		101.91030	11.3 m	β^- /1.01	1.2/	0+			0.1493/89.
									0.2116/100.
									0.2243/32.
^{103}Mo		102.91320	1.13 m	β^- /3.8		3/2+			0.1028(2)/
									0.1440(2)
									0.2511(2)
^{104}Mo		103.91376	1.00 m	β^- /2.16		0+			0.0686(1)/100.
									0.4239(4)/21.
^{105}Mo		104.9170	36. s	β^- /4.95		3/2+			0.0642/
									0.0856/
									0.2495/
^{106}Mo		105.91814	8.4 s	β^- /3.52		0+			0.1894(2)/22.
									0.3644(2)/6.
									0.3723(2)/12.
^{107}Mo		106.9217	3.5 s	β^- /6.2					
^{108}Mo		107.9236	1.1 s	β^- /5.1					(0.028-0.636)
^{109}Mo		108.9278	0.5 s	β^- /7.2					
^{110}Mo		109.9297	0.30 s	β^- /5.7					Tc k x-ray
									0.142
									(0.039-0.599)
^{111}Mo		110.9345	>0.15 μs						
^{112}Mo		111.937	>0.15 μs						
^{113}Mo		112.942	>0.15 μs						
^{114}Mo			>0.15 μs						
^{115}Mo			>0.15 μs						
^{116}Mo			>0.15 μs						
^{117}Mo			>0.15 μs						
$_{43}$Tc									
^{85}Tc		84.949	< 0.1 ms						
^{86}Tc		85.9430	0.05 s	β^+ /11.9					
^{87}Tc		86.9365	>0.15 μs		β^+ /8.6				

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{88}Tc		87.9328	5.8 s	β^+ /10.1					
^{89m}Tc			13. s						
^{89}Tc		88.9275	13. s	β^+ /7.5					
^{90m}Tc			49.2 s	β^+	5.3/	6+			ann.rad./
									0.9479/
									1.0542/
^{90}Tc		89.9235	8.3 s	β^+ /8.9	7.0/15	1+			ann.rad./
					7.9/95.				0.9479/
^{91m}Tc			3.3 m	β^+		1/2+			ann.rad./170.
				EC					0.8110(5)/5.
									1.6052(1)/7.8
									1.6339(1)/9.1
									1.9023(1)/6.
									2.4509(1)/13.5
^{91}Tc		90.9184	3.14 m	β^+ /6.2	5.2	9/2+			ann.rad./200.
^{92}Tc		91.91526	4.4 m	β^+ /7.87	4.1	8+			ann.rad./200.
				EC					0.0850/
									0.1475
									0.3293
									0.7731
									1.5096
^{93m}Tc			43. m	I.T./13		1/2-			0.3924(IT)
				EC/20					0.9437
									2.6445
^{93}Tc		92.910248	2.73 h	β^+ /13/3.201		0.81	9/2+	6.26	ann.rad./
				EC/87/					1.3629
									1.4771
									1.5203
									(0.1 - 3.0)
^{94m}Tc			52. m	β^+ /72/4.33		2+			ann.rad./
				EC/28/					0.8710
									1.8686
^{94}Tc		93.909655	4.88 h	β^+ /11/4.256			7+	5.08	ann.rad./
				EC/89/					0.4491
									0.7026
									0.8496
									0.8710
^{95m}Tc			61. d	I.T./4/		1/2-			ann.rad./
				β^+ /0.3	0.5/				0.0389(IT)
				EC/96	0.7/				0.2041
									0.5821
									0.5821
									0.8351
^{95}Tc		94.90766	20.0 h	EC/100/1.691		9/2+	5.89		0.7657
									1.0738
^{96m}Tc			52. m	I.T./90/		4+			0.0342(IT)
				β^+ ,EC/2/					0.7782
									1.2002
^{96}Tc		95.90787	4.3 d	EC/2.973		7+	+5.04		Mo k x-ray
									0.7782
									0.8125
									0.8498
									1.12168
^{97m}Tc			91. d	I.T./0.0965		1/2-			Tc k x-ray
				EC	/3.9				0.0965
^{97}Tc		96.906364	4.2x10^6 y	EC/100/0.320		9/2+			Mo k x-ray
^{98}Tc		97.907215	≈6.6x10^6 y		β^- /1.80	0.40/100	6+		0.65241
									0.74535
^{99m}Tc			6.01 h	I.T./100/0.142			1/2-		Tc k x-ray

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									0.14049
									0.14261
^{99}Tc		98.906254	2.13x10^5 y	β^- /0.294	0.293/100	9/2+	+5.6847	-0.129	
^{100}Tc		99.907657	15.8 s	β^- /3.202	2.2/	1+			0.5396
				EC /1.8(10)$^{-3}$/0.17		2.9/			0.5908
					3.3				1.5122
									(0.3 - 2.6)
^{101}Tc		100.90731	14.2 m	β^- /1.61	1.32/	9/2+			0.1272
									0.1841
									0.3068
									0.5451
									(0.073-0.969)
^{102m}Tc			4.4 m	I.T./2/4.8	1.8/				0.4184
				β^- /98/					0.4752
									0.6281
									0.6302
									1.0464
									1.1033
									1.6163
									2.2447
^{102}Tc		101.90921	5.3 s	β^- /4.53	3.4/	1+			0.4686
					4.2				0.4751
					2.2/				1.1055
^{103}Tc		102.90918	54. s	β^- /2.66	2.0/	5/2+			0.1361
					2.2/				0.1743
									0.2104
									0.3464
									0.5629
									(0.13 - 1.0)
^{104m}Tc			0.005 ms						
^{104}Tc		103.91144	18.2 m	β^- /5.60	5.3/	(3+)			0.3483
									0.3580
									0.5305
									0.5351
									0.8844
									0.8931
									1.6768
									(0.3 - 3.7)
^{105}Tc		104.91166	7.6 m	β^- /3.6	3.4/	5/2+			0.1079
									0.1432
									0.3215
^{106}Tc		105.91436	36. s	β^- /6.55		2+			0.2703
									0.5222
									1.9694
									2.2393
									2.7893
^{107}Tc		106.9151	21.2 s	β^- /4.8					0.1027
									0.1063
									0.1770
									0.4587
^{108}Tc		107.9185	5.1 s	β^- /7.72		(3)			0.2422
									0.4656
									0.7078
									0.7326
									1.5835
^{109}Tc		108.9200	1.4 s	β^- /6.3	p/0.08				
^{110}Tc		109.9234	0.83 s	β^- /8.8	p/0.04				0.2407
^{111}Tc		110.9250	0.30 s	β^-.n /7.0	n/0.85				0.150/92.7
									0.063-1.435

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Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{112}Tc		111.9292	0.26 s	β,n	n/2.6				
^{113}Tc		112.931	0.15 s	β^-,n/8.	/2.1				0.0985/100
									0.0658-1.520
^{114}Tc		113.936	0.15 s	β^-,n	/1.3				
^{115}Tc		114.938	>0.15 μs						
^{116}Tc			>0.15 μs						
^{117}Tc			>0.15 μs						
^{118}Tc			>0.15 μs						
$_{44}$Ru		101.07(2)							
^{87}Ru		86.949	>1.5 μs						
^{88}Ru		87.9404	>0.15 μs				0^+		
^{89}Ru		88.936	1.2 s	β^+.p/8.					
^{90}Ru		89.9298	11. s	β^+ /5.9		0^+			ann.rad./
									0.155 - 1.551
^{91}Ru		90.9264	9. s	β^+ ,EC/7.4			9/2+		ann.rad./
^{92}Ru		91.9201	3.7 m	β^+ /53/4.5			0+		ann.rad./
				EC/47/					0.1346
									0.2138
									0.2593
^{93m}Ru			10.8 s	I.T./21/		1/2-			ann.rad./
				β^+ ,EC/79/		5.3/			0.7344
									1.1112
									1.3962
									2.0931
^{93}Ru		92.9171	1.0 m	β^+ /6.3		9/2+			ann.rad./
				EC/					0.6807
									1.4349
									(0.5- 4.2)weak
^{94}Ru		93.91137	52. m	EC/100/1.59		0^+			0.3672
									0.5247
									0.8922
^{95}Ru		94.91042	1.64 h	EC/85/2.57	1.20/	5/2+	0.86		ann.rad./
				β^+ /15/	0.91/				0.2904
									0.3364
									0.6268
^{96}Ru	5.52(20)	95.90760				0+			
^{97}Ru		96.90756	2.89 d	EC/1.12		5/2+	-0.78		Tc k x-ray
									0.2157
									0.3245
									0.4606
^{98}Ru	1.88(9)	97.90529				0+			
^{99}Ru	12.74(26)	98.905939				5/2+	-0.6413	+0.079	
^{100}Ru	12.60(19)	99.904219				0+			
^{101}Ru	17.05(7)	100.905582				5/2+	-0.7188	+0.46	
^{102}Ru	31.57(31)	101.904349				0+			
^{103}Ru		102.906323	39.27 d	β^- /0.763	0.223	3/2+	0.206	+0.62	0.05329
									0.29498
									0.4438
									0.49708
									0.55704
									0.61033
									(0.04 - 1.6)
^{104}Ru	18.66(44)	103.905430				0+			
^{105}Ru		104.907750	4.44 h	β^- /1.917	1.11/22	3/2+	-0.3		0.12968
					1.134/13				0.1491
					1.187/49				0.2629
									0.31664
									0.46943
									0.67634

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									0.72420
									(0.1 - 1.8)
^{106}Ru		105.90733	1.020 y	β^- /0.0394		0.0394/100	0+		
^{107}Ru		106.9099	3.8 m	β^- /2.9	2.1/				0.1939
					3.2/				0.3741
									0.4625
									0.8488
^{108}Ru		107.9102	4.5 m	β^- /1.4	1.2/	0^+			0.0923
									0.1651
									0.4339
									0.4975
									0.6189
^{109}Ru		108.91320	34.5 s	β^- /4.2					0.1164
									0.3584
^{110}Ru		109.9140	15. s	β^- /2.81					0.1121
									0.3737
									0.4397
									0.7967
^{111}Ru		110.9176	1.5 s	β^- /5.5					
^{112}Ru		111.9188	4.5 s	β^- /4.5					
^{113}Ru		112.9225	2.7 s	β^- /7.					
^{114}Ru		113.9239	0.57 s	β^- /6.1					0.127/24
									(0.053-0.180)
^{115}Ru		114.928	≈0.74 s		β^- /8.				
^{116}Ru		115.930	>0.15 μs						
^{117}Ru		116.935	>0.15 μs						
^{118}Ru		117.937	>0.15 μs						
^{119}Ru			>0.15 μs						
^{120}Ru			>0.15 μs						
$_{45}$Rh		102.90550(2)							
^{89}Rh		88.9494	>0.15 μs						
^{90}Rh		89.9429	>0.15 μs						
^{91}Rh		90.9366	>0.15 μs						
^{92}Rh		91.9320	>0.15 μs		β^+ /11.1				
^{93}Rh		92.9257	>0.15 μs		β^+ /8.1				(0.138-1.493)
^{94m}Rh			25.8 s	β^+ /		8+			ann.rad./
									0.1264
									0.3117
									0.7562
									1.0752
									1.4307
^{94}Rh		93.9217	1.18 m	β^+ /9.6	6.4/	3+			ann.rad./
									0.1461
									0.3117
									0.7562
									1.4307
^{95m}Rh			1.96 m	I.T./88/		1/2+			ann.rad./
				β^+ ,EC/12/					0.5433(IT)
									0.7837
^{95}Rh		94.9159	5.0 m	β^+ /5.1	3.2	9/2+			ann.rad./
									0.2293
									0.4103
									0.6610
									0.9416
									1.3520
									(0.2 - 3.8)
^{96m}Rh			1.51 m	I.T./60 /0.052			2+		ann.rad./
				β^+ ,EC/40/		4.70/			Tc,Ru x-rays
									0.8326

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									1.0985
									1.6921
									(0.4 - 3.3)
^{96}Rh		95.91452	9.6 m	β^+/6.45	3.3/	5+			ann.rad./
				EC/					0.4299
									0.6315
									0.6853
									0.7418
									0.8326
									(0.2 - 3.4)
^{97m}Rh			46.m	I.T./5 /	2.6/	1/2-			ann.rad./
				β^+,EC/95 /					0.1886
									0.4215
									2.2452
^{97}Rh		96.91134	31.0m	β^+ /3.52	2.1/	9/2+			ann.rad./
									0.1886
									0.3892
									0.4515
									0.8398
									0.8788
									(0.2 - 3.5)
^{98m}Rh			3.5 m	β^+ /		5+			ann.rad./
									0.6154
									0.6524
									0.7452
^{98}Rh		97.91072	8.7 m	β^+ /90 /5.06		3.4/	2+		ann.rad./
									0.6524
									0.7623
^{99m}Rh			4.7 h	β^+ /8 /	.74/	9/2+	5.67		ann.rad./
				EC/92 /					0.2766/
									0.3408
									0.6178
									1.2612
^{99}Rh		98.90820	16. d	β^+/4 /2.10		0.54/	1/2-		ann.rad./
				EC/97 /	0.68/				0.0894/
									0.3530
									0.5277
									(0.1 - 2.0)
^{100m}Rh			4.7 m	I.T./99 /		5+			ann.rad./
				β^+ /0.4 /					0.0748/
									0.2647(IT)
^{100}Rh		99.90812	20.8 h	β^+ /3.63		2.62/	1-		0.4462
				EC/	2.07/				0.5396
									0.5882
									0.8225
									1.5534
									2.3761
^{101m}Rh			4.35 d	EC/92 /		9/2+	+5.51		Rh k x-ray
				I.T./8 /0.1573					0.1272/
									0.3069
									0.5451
^{101}Rh		100.90616	3.3 y	EC/0.54		1/2-			Ru k x-ray
									0.1272
									0.1980
									0.3252
^{102m}Rh			3.74 y	EC/2.323		6^+	4.04		0.4751
				IT/0.0419					0.6313
									0.6975
									0.7668

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									1.0466
									1.1032
^{102}Rh		101.906842	207. d	EC/62			0.5		ann.rad./
				β^- /19/					0.4686
				β^+ /14/					0.4751
									0.5566
									0.6280
									1.1032
									(0.4 - 1.6)
^{103m}Rh			56.12 m	IT		7/2+	4.54		
^{103}Rh	100.	102.905504				1/2-	-0.0884		
^{104m}Rh			4.36 m	I.T./99+ /		5+			Rh k x-ray
				β^-	1.3/				0.0514
									0.0971
									0.5558
^{104}Rh		103.906655	42.3 s	β^-/99+/2.441		1.88/2	1+		0.3581
				EC/0.4/1.141	2.44/98				0.5558
									1.2370
									(0.35 - 1.8)
^{105m}Rh			43. s	I.T./1.296		1/2-			Rh k x-ray
									0.1296
^{105}Rh		104.905692	35.4 h	β^- /0.567		0.247/30	7/2+	+4.45	0.2801
					0.567/70				0.3061
									0.3189
^{106m}Rh			2.18 h	β^- /	0.92/	6+			0.2217
									0.4510
									0.5119
									0.6162
									0.7173
									0.7484
									1.0458
									1.5277
^{106}Rh		105.90729	29.9 s	β^- /3.54	2.4/2	1+	+2.58		0.51186/
					3.0/12				0.61612
					3.54/79				0.62187
									(0.05 - 3.04)
^{107}Rh		106.90675	21.7 m	β^- /1.51	1.20/65	7/2+			0.2776
					1.5/17				0.3028
									0.3925
^{108m}Rh			6.0 m	β^- /	1.57/				0.4339
									0.4973
									0.6189
^{108}Rh		107.9087	17. s	β^- /4.5		1+			0.4046
									0.4339
									0.4973
									0.5811
									0.6146
									0.9014
									0.9471
^{109}Rh		108.90874	1.34 m	β^- /2.59	2.25/	7/2+			0.1134
									0.1780
									0.2914
									0.3254
									0.3268
									0.4261
									(0.1 - 1.6)
^{110m}Rh			29. s	β^- /	[.6/				0.3737
									0.4397
									0.7967

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{110}Rh		109.9110	3.1 s	β^- /5.4	5.5/	1+			0.3737
									0.4400
									0.5463
									0.6877
									0.8381
									0.9045
^{111}Rh		110.9117	11. s	β^- /3.7					0.275
^{112m}Rh			6.8 s	β^- /					
^{112}Rh		111.9140	3.5 s	β^- /6.2		1+			0.3489
^{113}Rh		112.9154	0.9 s	β^- /4.9					0.1285
^{114m}Rh			1.8 s	β^- /					
^{114}Rh		113.9173	1.8 s	β^- /6.5		1+			
^{115}Rh		114.9201	0.99 s	β^- /6.0					
^{116m}Rh			0.9 s	β^- /					0.3405
^{116}Rh		115.9228	0.7 s	β^- /8.0		1+			
^{117}Rh		116.925	0.44 s	β^- /7.					0.0346
									0.1317
^{118}Rh		117.929	>0.15 μs						
^{119}Rh		118.931	>0.15 μs						
^{120}Rh		119.936	>0.15 μs						
^{121}Rh		120.938	>0.15 μs						
^{122}Rh									
$_{46}$Pd		106.42(1)							
^{91}Pd		90.949	>1.5 μs						
^{92}Pd		91.9404	>0.15 μs						
^{93}Pd		92.9359	0.9 s	β^+,p					0.240/81
									0.382-0.864
^{94}Pd		93.9288	9. s	EC,β^+ /≈ 6.6					0.5582
									(0.0546-0.798)
^{95m}Pd		94.92684	13.4 s	EC,β^+ /10.2			21/2+		
^{95}Pd									
^{96}Pd		95.9182	2.03 m	EC,β^+ /3.5		1.15/			0.1248
									0.4995
^{97}Pd		96.9165	3.1 m	β^+ ,EC/4.8		3.5/	5/2+		ann.rad./
									0.2653
									0.4752
									0.7927
									(0.2 - 3.4)
^{98}Pd		97.91273	17.7 m	β^+ /1.87			0+		ann.rad./
				EC/					0.0677
									0.1125
									0.6630
									0.8379
^{99}Pd		98.91181	21.4 m	β^+ /49 /3.37		2.18/	5/2+		ann.rad./
				EC/51 /					0.1360
									0.2636
									0.6734
									(0.2 - 2.85)
^{100}Pd		99.90851	3.7 d	EC/0.36		0+			0.03271
									0.0748
									0.0840
^{101}Pd		100.90829	8.4 h	β^+ /5 /1.980		0.776/	5/2+	-0.66	ann.rad./
				EC/95 /					0.0244
									0.2963
									0.5904
^{102}Pd	1.02(1)	101.905607				0+			
^{103}Pd		102.906087	16.99 d	EC/0.543		5/2+			Rh k x-ray
									0.03975
									0.3575

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Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									0.4971
^{104}Pd	11.14(8)	103.904034				0+			
^{105}Pd	22.33(8)	104.905083				5/2+	-0.642	+0.66	
^{106}Pd	27.33(3)	105.903484				0+			
^{107m}Pd			20.9 s	I.T./0.2149		11/2-			Pd k x-ray
									0.2149(IT)
^{107}Pd		106.90513	$6.5x10^6$y	β^- /0.033		0.03/	5/2+		
^{108}Pd	26.46(9)	107.903895				0+			
^{109m}Pd			4.75 m	I.T./0.1889		11/2-			Pd x-ray
									0.1889(IT)
^{109}Pd		108.905954	13.5 h	β^- /1.116		1.028	5/2+		0.0880
									(0.08 - 1.0)
^{110}Pd	11.72(9)	109.905153				0+			
^{111m}Pd			5.5 h	I.T./73 /0.172			11/2-		0.0704
				β^- /27 /	0.35				0.1722
					0.77				0.3912
									(0.1 - 1.97)
^{111}Pd		110.90764	23.4 m	β^- /2.19	2.2/95	5/2+			0.0598
									0.2454
									0.5800
									0.6504
									1.3885
									1.4590
^{112}Pd		111.90731	21.04 h	β^- /0.29	0.28/	0+			0.018
^{113m}Pd			1.48 m	β^- /		5/2+			0.0959
^{113}Pd		112.91015	1.64 m	β^- /3.34					0.0958
									0.4824
									0.6436
									0.7394
^{114}Pd		113.91037	2.48 m	β^- /1.45		0+			0.1266
									0.2320
									0.5582
									0.5760
^{115}Pd		114.9137	47. s	β^- /4.58					0.1255
									0.2554
									0.3428
^{116}Pd		115.9142	12.7 s	β^- /2.61					0.1015
									0.1147
									0.1778
^{117}Pd		116.9178	4.4 s	β^- /5.7					0.2473
								0.077-0.403	
^{118}Pd		117.9189	2.4 s	β^- /4.1					0.1254
								0.028-0.596	
^{119}Pd		118.9227	0.9 s	β^- /6.5					0.2566
								0.070-0.326	
^{120}Pd		119.9240	0.5 s	β^- /5.0					0.1581
								0.053-0.595	
^{121}Pd		120.9282	>0.24 μs						
^{122}Pd		121.9298	>0.24 μs						
^{123}Pd		122.934	>0.15 μs						
^{124}Pd									
$_{47}$Ag		107.8682(2)							
^{93}Ag									
^{94}Ag		93.9428	0.42 s	β^+, p/					
^{95}Ag		94.9355	2.0 s	β^+, p/					(0.539-2.025)
^{96}Ag		95.9307	5.1 s	β^+ /11.6					ann.rad./
				EC/					0.1248
									0.4995
									(0.1066-1.416)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{97}Ag		96.9240	19. s	β+ /7.0					ann.rad./
				EC/					0.6862
									1.2941
									(0.352-3.294)
^{98}Ag		97.9218	47. s	β+ /8.4		5+			ann.rad./
				EC/					0.5711
									0.6786
									0.8631
									(0.153-1.185)
^{99m}Ag			11. s	I.T./100/		1/2-			Ag k x-ray
									0.1636(IT)
									0.3426
^{99}Ag		98.9176	2.07 m	β+ /87 /5.4			9/2+		ann.rad./
				EC/13 /					0.2199
									0.2645
									0.8056
									0.8323
									(0.2 - 3.5)
^{100m}Ag			2.3 m	β+ /		2+			ann.rad./
				EC/					0.6657
									1.6941
^{100}Ag		99.9161	2.0m	β+/7.1	4.7/	5+			ann.rad./
				EC/					0.2807
									0.4503
									0.6657
									0.7508
									0.7732
^{101m}Ag			3.1 s	I.T./0.23		1/2-			Ag k x-ray
									0.0981
									0.176(IT)
^{101}Ag		100.9128	11.1 m	β+ /69 /4.2		2.7/	9/2+	5.7	ann.rad./
				EC/31 /					0.2610
					2.18/				0.2747
					2.73/				0.3269
					3.38/				0.4392
									0.6673
									1.1739
									(0.2 - 3.1)
^{102m}Ag			7.8 m	β+ /38 /	3.4	2+	+4.14		ann.rad./
				EC/13 /					0.5567
				I.T./49 /					0.9777
									1.8347
									2.0545
									2.1594
									3.2386
^{102}Ag		101.91197	13.0 m	β+ /78 /5.92		2.26/	5+	4.6	ann.rad./
				EC/22 /					0.5567
									0.7194
									0.8354
									1.2571
									1.5816
									1.7446
^{103m}Ag			5.7 s	I.T./0.134		1/2-			Ag k x-ray
									0.1344
^{103}Ag		102.90897	1.10 h	β+ /28 /2.69		1.7	7/2+	+4.47	ann.rad./
				EC/72 /	1.3				0.1187
									0.1482
^{104m}Ag			33. m	β+ /64/	2.71/	2+	+3.7		ann.rad./
				EC/36/					0.5558

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
				I.T./0.07/					0.7657
									(0.5 - 3.4)
^{104}Ag		103.90863	69. m	β^+ /16 /4.28		0.99/	5+	3.92	ann.rad./
				EC/84 /					0.5558
									0.9259
									0.9416
									(0.18 - 2.27)
^{105m}Ag			7.2 m	I.T./98/0.0255			7/2+	+4.41	Ag x-ray
				EC/2 /					0.3063
									0.3192
									(0.1 - 1.0)
^{105}Ag		104.90653	41.3 d	EC/1.35		1/2-	0.1014		0.0640
									0.2804
									0.3445
									0.4434
^{106m}Ag			8.4 d	EC/		6+	3.71	+1.1	Pd k x-ray
									0.4510
									0.5118
									0.7173
									1.0458
^{106}Ag		105.90667	24.0 m	β^+ /59 /2.965		/1.96	1+	+2.85	ann.rad./
				EC/41 /					0.5119
^{107m}Ag			44.2 s	I.T./0.093		7/2+	+4.40	1.0	Ag x-ray
									0.0931
^{107}Ag	51.839(8)	106.905093				1/2-	-0.11357		
^{108m}Ag			418.y	EC/92 /		6+	3.580	+1.3	Ag k x-ray
				I.T./8 /0.079					Pd k x-ray
									0.43392
									0.61427
									0.72290
^{108}Ag		107.905954	2.39 m	β^- /97/1.65		1.02/1.7	1+	+2.6884	ann.rad./
				EC/2/	1.65/96				0.43392
				β^- /1/1.92		0.88/0.3			0.61885
									0.63298
^{109m}Ag			39.8 s	I.T./0.088		7/2+	+4.40	+1.0	Ag k x-ray
									0.0880
^{109}Ag	48.161(8)	108.904756				1/2-	-0.13069		
^{110m}Ag			249.8 d	β^- /99 /	0.087	6+	+3.60	+1.4	0.65774
				I.T./1 /0.1164		0.530			0.76393
									0.88467
									0.93748
									1.38427
									(0.447-1.56)
^{110}Ag		109.906111	24.6 s	β^- /2.892	2.22/5	1+	+2.7271	0.2	0.65774
					2.89/95				0.8154
									1.1257
^{111m}Ag			1.08 m	IT/99/0.0598		7/2+			Ag k x-ray
				β^- /1/					0.0598
									0.2454
^{111}Ag		110.905295	7.47 d	β^- /1.037	1.035/	1/2-	-0.146		0.2454
									0.3421
^{112}Ag		111.90701	3.13 h	β^- /3.96	3.94/	2-	0.0547		0.6067
					3.4				0.6174
									1.3877
									(0.4 - 2.9)
^{113m}Ag			1.14 m	I.T./80 /0.043			7/2+		0.1422
				β^- /20 /	1.5				0.2983
									0.3161
									0.3923

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{113}Ag		112.90657	5.3 h	β^- /2.02	2.01/	1/2-	0.159		0.2588
									0.2986
^{114}Ag		113.90881	4.6 s	β^- /5.08	4.9/	1+			0.5582
									0.5760
									1.9946
^{115m}Ag			18.7 s	β^- /		7/2+			0.1134
									0.1315
									0.2288
									0.3887
^{115}Ag		114.90876	20. m	β^- /3.10		1/2-			0.1316
									0.2128
									0.2291
									0.4727
									(0.13 - 2.49)
^{116m}Ag			10.5 s	I.T./2 /	3.2/	5+			0.1027
				β^- /98 /	2.9				0.2549
									0.5134
									0.7055
									1.0289
^{116}Ag		115.91137	2.68 m	β^- /6.16	5.3	2-			0.5134
									0.6993
									2.4779
^{117m}Ag			5.3 s	β^- /	3.2/	7/2+			0.1354
									0.2981
									0.3868
^{117}Ag		116.91171	1.22 m	β^- /4.18	2.3	1/2-			0.1354
									0.1571
									0.3377
^{118m}Ag			2.8 s	β^- /59 /					0.1277
				I.T./41 /0.1277					0.4878
									0.6771
									0.7709
									1.0586
^{118}Ag		117.9145	4.0 s	β^- /7.1					0.4878
									0.6771
									3.2259
^{119}Ag		118.9157	2.1 s	β^- /5.35		7/2+			0.0674
									0.3662
									0.3991
									0.6264
^{120m}Ag			0.32 s	β^- /					0.2030
				I.T./					0.5059
									0.6978
									0.8300
									0.9258
^{120}Ag		119.9188	1.23 s	β^- /8.2					0.5059
									0.6978
									0.8171
									1.3231
^{121}Ag		120.9198	0.78 s	β^- /6.4					0.1150
									0.3148
									0.3537
									0.3696
									0.5007
									1.5105
									(0.11 - 2.5)
^{122m}Ag			1. s	β^- /					
^{122}Ag		121.9233	0.44 s	β^- /9.2					
^{123}Ag		122.9249	0.31 s	β^- /7.4					

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
^{124}Ag		123.9285	0.22 s	β^- /10.1					
^{125}Ag		124.9305	0.17 s	β^-					
^{126}Ag		125.9345	0.11 s	β^-					
^{127}Ag		126.9369	0.11 s	β^-					
^{128}Ag			58 ms	β^-					
^{129}Ag			0.05 s	β^-,n					
$_{48}$Cd		112.411(8)							
^{96}Cd		95.9398							
^{97}Cd		96.9349	3. s	β^+,(p)					
^{98}Cd		97.9276	9.2 s	β^+ /5.4					
				(p)	/0.025				
^{99}Cd		98.9250	16. s	β^+ ,EC/6.9					ann.rad./
^{100}Cd		99.9203	1.1 m	β^+ ,EC/3.9					ann.rad./
									(0.090-1.043)
^{101}Cd		100.9187	1.2 m	β^+ /83 /5.5		4.5	5/2+		In k x-ray
				EC/17 /					0.0985
									1.7225
									0.31 - 2.84)
^{102}Cd		101.91474	5.8 m	β^+ /27 /2.59			0+		ann.rad./
				EC/73					0.0974
									0.4810
									1.0366
									1.3598
^{103}Cd		102.91342	7.5 m	β^+ /33 /4.14	5/2+	-0.81	-0.8		ann.rad./
				EC/67 /					Ag k x-ray
									1.0799
									1.4487
									1.4618
									(0.1 - 2.8)
^{104}Cd		103.90985	58. m	EC/1.14		0+			Ag k x-ray
									0.0835
									0.7093
^{105}Cd		104.90947	55.5 m	β^+ /26 /2.739	1.69/	5/2+	-0.7393	+0.43	Ag k x-ray
				EC/74 /					0.3469
									0.6072
									0.9618
									1.3025
									(0.25 - 2.4)
^{106}Cd	1.25(6)	105.90646	>2.6x10^{17} y		β^+,EC		0+		
^{107}Cd		106.90661	6.52 h	EC/99+ /1.417		5/2+	-0.615055	+0.68	Ag k x-ray
				β^+ /					0.0931
									0.8289
^{108}Cd	0.89(3)	107.90418				0+			
^{109}Cd		108.904985	462.0 d	EC/0.214		5/2+	-0.827846	+0.69	Ag k x-ray
									0.08804
^{110}Cd	12.49(18)	109.903006				0+			
^{111m}Cd			48.5 m	I.T./		11/2-			Cd k x-ray
									0.1508(IT)
									0.2454
^{111}Cd	12.80(12)	110.904182				1/2+	-0.594886		
^{112}Cd	24.13(21)	111.902758				0+			
^{113m}Cd			14.1 y	β^- /99.9 /0.59	0.59/99.9	11/2-	-1.087	-0.71	0.2637
^{113}Cd	12.22(12)	112.904401	7.7x10^{15}y	β^-		1/2+	-0.622301		
^{114}Cd	28.73(42)	113.903359				0+			
^{115m}Cd			44.6 d	β^- /1.629	0.68/1.6	11/2-	-1.042	-0.54	0.48450
					1.62/97				0.93381
									1.29064
^{115}Cd		114.905431	2.228 d	β^- /1.446	0.593/42	1/2+	-0.648426		0.23141

TABLE OF ISOTOPES (CONTINUED)

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
					1.11/58				0.26085
									0.33624
									0.49227
									0.52780
^{116}Cd	7.49(18)	115.904756	2.3(10^{19} y	$\beta^-\beta^-$			0+		
^{117m}Cd			3.4 h	β^- /2.66	0.72/	11/2-			0.1586
									0.5529
									0.37 - 2.42
^{117}Cd		116.907219	2.49 h	β^- /2.52	0.67/51	1/2+			0.2209
					2.2/10				0.2733
									0.3445
									1.3033
^{118}Cd		117.90692	50.3 m	β^- /0.52		0+			
^{119m}Cd			2.20 m	β^- /		11/2-			0.1056
									0.7208
									1.0250
									2.0213
^{119}Cd		118.90992	2.69 m	β^- /3.8	≈ 3.5/	1/2+			0.1340
									0.2929
									0.3429
^{120}Cd		119.90985	50.8 s	β^- /1.76	1.5/	0+			
^{121m}Cd			8. s	β^- /		11/2-			0.1008
									0.9878
									1.0209
									1.1815
									2.0594
^{121}Cd		120.9131	13.5 s	β^- /4.9		(3/2+)			0.2102
									0.3242
									0.3492
									1.0403
^{122}Cd		121.9135	5.3 s	β^- /3.0		0+			
^{123m}Cd			1.9 s	β^- /					
^{123}Cd		122.91770	2.09 s	β^- /6.12		3+			
^{124}Cd		123.9177	1.24 s	β^- /4.17		0+			0.0365
									0.0628
									0.1799
^{125m}Cd			0.66 s	β^- /					
^{125}Cd		124.92129	0.68 s	β^- /7.16		3/+			
^{126}Cd		125.9224	0.52 s	β^- /5.49		0+			0.2601
^{127}Cd		126.9264	0.4 s	β^- /8.5		3/+			
^{128}Cd		127.9278	0.28 s	β^- /7.1		0+			0.247
^{129}Cd		128.9323	0.27 s	β^- /5.9					0.281
^{130}Cd		129.9340	0.20 s	β^- /		0+			
^{131}Cd			68 ms	p/	/3.5				
^{132}Cd			0.10 ms	p/	/60				
$_{49}$In		114.818(3)							
^{98}In		97.9422	>1.5 µs						
^{99}In		98.9346	>0.15 µs		β^+ /8.9				
^{100}In		99.9316	6. s	β^+,(p)/10.5					
^{101}In		100.9266	15. s	β^+ /7.3					
^{102}In		101.9243	22. s	EC/8.9		(5)			0.1566
									0.7767
									(0.397-0.923)
^{103m}In			34. s						
^{103}In		102.91991	1.1 m	β^+ ,EC/6.05		4.2	9/2+		ann.rad./
				EC	/45				0.1879
									(0.157-3.98)
^{104m}In			16. s	IT/0.0935					
^{104}In		103.9183	1.84 m	β^+ ,EC/7.9	4.8	5+	+4.44	+0.7	ann.rad./

Elem. Energy or Isot.	Natural Abundance (%)	Atomic Mass or Weight	Half-Life	Decay Mode/Energy (/MeV)	Particle Energy /Intensity (MeV/%)	Spin (h/2π)	Nuclear Magnetic Mom. (nm)	Elect. Quadr. Mom. (b)	γ-ray/ Intensity (MeV/%)
									0.6580
									0.8341
									0.8781
^{105m}In			43. s	I.T.		1/2-			In k x-ray
									0.6740
^{105}In		104.91467	5.1 m	β^+ ,EC/4.85	3.7	9/2+	+5.675	+0.83	0.1310
									0.2600
									0.6038
^{106m}In			5.3 m	β^+ /85 /	4.90	3+			ann.rad./
				EC/15 /					0.6326
									0.8611
									1.7164
^{106}In		105.91346	6.2 m	β^+ /65 /6.52	2.6	7+	+4.92	+0.97	ann.rad./
				EC/35 /					0.2259
									0.6327
									0.8611
									0.9978
									1.0091
^{107m}In			51. s	I.T./0.6786		1/2-			In k x-ray
									0.6785
^{107}In		106.91029	32.4 m	β^+ /35 /3.43	2.20/	9/2+	+5.59	+0.81	ann.rad./
				E.C/65 /					Cd k x-ray
									0.2050
									0.3209
									0.5055
									(0.2 - 2.99)
^{108m}In			57. m	β^+ /53 /	1.3	6+	+4.94	+0.47	ann.rad./
				EC/47 /					Cd k x-ray
									0.6329
									1.9863
									3.4522
^{108}In		107.90971	40. m	β^+ /33 /5.15	3.49/	3+	+4.56	+1.01	ann.rad./
				EC/67 /					Cd k x-ray
									0.2429
									0.6331
									0.8756
^{109m}In			1.3 m	I.T./0.650		1/2-			In k x-ray
									0.6498
^{109}In		108.90715	4.2 h	β^+ /8 /2.02	0.79/	9/2+	+5.54	+0.84	ann.rad./
				EC/92 /					Cd k x-ray
									0.2035
									0.6235
^{110m}In			4.9 h	EC/		7+	+4.72	+1.00	Cd k x-ray
									0.6577
									0.8847
									0.9375
									(0.1 - 1.98)
^{110}In		109.90717	1.15 h	β^+ /62 /3.88	2.22/	2+	+4.37	+0.35	ann.rad./
				EC/38 /					Cd k x-ray
									0.6577
									(0.6 - 3.6)
^{111m}In			7.7 m	I.T./0.537		1/2-	+5.53		In k x-ray
									0.537
^{111}In		110.90511	2.8049 d	EC/0.866		9/2+	+5.50	+0.80	Cd k x-ray
									0.1712
									0.2453
^{112m}In			20.8 m	I.T./0.155		4+			In k x-ray
									0.1555
^{112}In		111.90553	14.4 m	β^+ /22 /2.586		1+	+2.82	+0.09	ann.rad./

NEUTRON SCATTERING AND ABSORPTION PROPERTIES*
(Revised 1996)

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This Table presents an evaluated set of values for the experimental quantities, which characterize the properties for scattering and absorption of neutrons. The neutron cross section is given for room temperature neutrons, 20.43° C, corresponds to a thermal neutron energy of 0.0253 electron volts (eV) or a neutron velocity of 2200 meters/second. The neutron resonance integral is defined over the energy range from 0.5 eV to 0.1 x 10^6 eV, or 0.1 MeV. Bound neutron scattering lengths and neutron cross sections averaged over a maxwellian spectrum at 30 keV for astrophysical applications are also presented. A list of the major references used is given below. The literature cutoff date is December 1996. Uncertainties are given in parentheses. Parentheses with two or more numbers indicate values to the excited state(s) and to the ground state of the product nucleus. Discussions with Frank Feiner and Harold Knox of KAPL on thermal cross sections and resonance integrals and the assistance of Felicia Kramer in assembling this file are gratefully acknowledged.

TABLE LAYOUT

Column No.	Column Title	Description
1	Isotope or Element	For elements, the atomic number and chemical symbol are listed. For nuclides, the mass number and chemical symbol are listed. Isomers are indicated by the addition of m, m1, or m2.
2	Isotopic Abundance	in atom percent.
3	Half-life	Half-life in decimal notation. μs = microseconds; ms = milliseconds; s = seconds; m = minute; h = hours; d = days; and y = years.
4	Thermal Neutron Cross Section	Cross sections for neutron capture reactions in barns (10^{-24} cm^2) or in millibarns (mb). Proton, alpha production and fission reactions are designated by σ_p, σ_a, σ_f, respectively. Separate values are listed for isomeric production.
5	Neutron Resonance Integral	Resonance integrals for neutron capture reactions in barns (10^{-24} cm^2) or millibarns (mb). Proton, alpha production and fission reactions are designated by RI_p, RI_a, RI_f, respectively. Separate values are listed for isomeric production.
6	Neutron Scattering Length	Bound Coherent scattering length for neutron scattering reactions in units of femtometer (fm), which is equal to fermis (10^{-13} cm).
7	Maxwellian Averaged Cross Section	Astrophysical Cross Sections, averaged over a stellar neutron maxwellian spectrum characterized by a thermal energy of 30 keV, expressed in barns (10^{-24} cm^2), millibarns (mb) or microbarns (μb).

GENERAL NUCLEAR DATA REFERENCES

The following references represent the major sources of the neutron data presented:

1. Mughabghab, S.F.; Divadeenam, M.; Holden, N.E.; Neutron Cross Sections, Vol. I *Neutron Resonance Parameters and Thermal Cross Sections* Part A Z=1-60. Academic Press Inc., New York, New York (1981); Mughabghab, S.F.; Part B, Z-61-100. Academic Press Inc., Orlando, Florida (1984).

2. Parrington, J.R.; Knox, H.D.; Breneman, S.L.; Baum, E.M.; Feiner, F.: *Chart of the Nuclides, 15th Edition*, Knolls Atomic Power Laboratory (Oct. 1996).

3. Holden, N.E.; *Fifty Years with Nuclear Fission* Conference, Wash., D.C., Gaithersburg, Md. April 26-29, 1989, p. 946. American Nuclear Society, LaGrange Park, Illinois (1989).

4. Holden, N.E.; *Review of Thermal Neutron Cross Sections and Isotopic Composition of the Elements*, BNL-NCS-42224 (March 1989) and Holden, N.E.; *Thermal Neutron Cross Sections for the 1991 Table of the Isotopes*, BNL-45255 (Feb. 1991).

5. Tuli, J.K.; *Nuclear Wallet Cards*, Brookhaven National Laboratory (July 1995).

6. Holden, N.E.; *Half-lives of Selected Nuclides*, Pure & Applied Chemistry 62, 941 (1990).

7. Koester, L; Rauch, H.; Seymann, E.; *Neutron Scattering Lengths: A Survey of Experimental Data and Methods*, Atomic Data Nuclear Data Tables 49, 65 (1991).

8. Sears, V.F.; *Neutron Scattering Lengths and Cross Sections*, Neutron News 3, (3), 26 (1992).

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Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
$_{1}$H			0.332(2)	0.149(1)	- 3.739(1)	
^{1}H	99.985(1)		0.332(2)	0.149(1)	- 3.741(1)	0.25(2) mb*
^{2}H	0.015(1)		0.51(1)mb	0.23(2) mb	6.671(4)	
^{3}H		12.32 y	< 6. μb		4.79(3)	
$_{2}$He			< 0.05		3.26(3)	
^{3}He	1.37x10^{-6}		σ_p=5.33(1)x10^{3}	RI$_p$=2.39(1)x10^{3}	5.74(7)	
			0.05(1) mb			8.(1) μb*
^{4}He	≈ 100.				3.26(3)	
$_{3}$Li			71.(2)	32.(1)	- 1.90(2)	
^{6}Li	7.5(2)		σ_α=9.4(1)x10^{2}	RI$_\alpha$=422.(4)	2.0(1)	
			39.(5) mb	17.(2) mb		
^{7}Li	92.5(2)		45.(5) mb	20.(2) mb	- 2.22(2)	39(6) μb
$_{4}$Be			8.8(4) mb	3.9(2) mb	7.79(1)	
^{7}Be *		53.28 d	σ_p=3.9(1)x10^{4}	RI$_p$=1.75(5)x10^{4}	σ_p 16(4)	
			σ_α ≈ 0.1			
^{9}Be	100.		8.8(4) mb	3.9(2) mb	7.79(1)	
^{10}Be		1.52x10^{6} y	<1. mb			
$_{5}$B			7.6(1)x10^{2}	343.(5)	5.30(4)	
^{10}B	19.9(2)		σ_α=38.4(1)x10^{2}	RI$_\alpha$=17.3(1)x10^{2}	- 0.1(3)	
			0.3(1)	0.13(4)		
			σ_p=7.(1) mb			
			σ_t=8.(2) mb			
^{11}B	80.1(2)		5.(3) mb	2(1) mb	6.65(4)	
$_{6}$C			3.5(1) mb	1.6(1) mb	6.646(1)	
^{12}C	98.89(1)		3.5(1) mb	1.6(1) mb	6.651(2)	16(1) μb*
^{13}C	1.11(1)		1.4(1) mb	1.7(2) mb	6.19(9)	0.2(1) mb
^{14}C		5715. y	<1. μb			1.5(4) μb*
$_{7}$N			1.9(1)	0.85(5)	9.36(2)	
^{14}N	99.634(9)		σ_p=1.83(7)	RI$_p$=0.82(3)	9.37(2)	σ_p 1.8(2) mb*
			0.080(1)	0.034(1)		0.04(7) mb
^{15}N	0.366(9)		0.04(1) mb	0.11(3) mb	6.44(3)	4.9(5) μb*
$_{8}$O			0.29(1) mb	0.40(4) mb	5.805(4)	
^{16}O	99.76(1)		0.19(1) mb	0.36(4) mb	5.805(5)	34(4) μb
^{17}O	0.04		σ_α=0.24(1)	0.11(1)	5.8(2)	σ_α 3.9(5) mb*
			0.54(7) mb	0.39(5) mb		
^{18}O	0.20(1)		0.16(1) mb	0.81(4) mb	5.84(7)	7.2(6) μb*

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
$_{9}$F			9.5(7) mb	21.(3) mb	5.65(1)	
^{19}F	100.		9.5(7) mb	21.(3) mb	5.65(1)	6.(1) mb
$_{10}$Ne			42(5) mb	19(3) mb	4.566(6)	
^{20}Ne	90.48(3)		39(5) mb	18(3) mb	4.631(6)	0.12(1) mb
^{21}Ne	0.27(1)		0.7(1),σ_{α}<1.5	0.31(5)	6.7(2)	≈ 1.6 mb
^{22}Ne	9.25(3)		51(5) mb	23(3) mb	3.87(1)	60.(5) μb*
$_{11}$Na			0.53(2)	0.32(2)	3.63(2)	2.3(2) mb
^{22}Na		2.605 y	σ_p=2.8(3)x10^4	< 2x10^5		
			σ_{α}=2.6(4)x10^2	1.2(2) x 10^2		
^{23}Na	100.		σ_m=0.43(3)	RI$_m$=0.30(6)	3.63(2)	
$_{12}$Mg			66(6) mb	38.(5) mb	5.375(4)	
^{24}Mg	78.99(3)		0.053(6)	32.(4) mb	5.7(2)	4.2(2) mb
^{25}Mg	10.00(1)		.20(1)	98.(15) mb	3.6(2)	6.5(3) mb
^{26}Mg	11.01(2)		.038(1)	25.(2) mb	4.9(2)	66.(3) μb
^{27}Mg		9.45 m	0.07(2)	0.03(1)		
$_{13}$Al			0.230(2)	0.17(1)	3.45(1)	
^{26}Al			σ_p ≈ 2.1			0.14(2)
^{27}Al	100.		0.230(2)	0.17(1)	3.45(1)	3.8(3) mb
$_{14}$Si			0.166(9)	0.12(2)	4.15(1)	
^{28}Si	92.21(2)		0.17(1)	0.11(2)	4.11(1)	1.8(2) mb
^{29}Si	4.69(2)		0.12(1)	0.08(2)	4.7(1)	7.9(9) mb
^{30}Si	3.10(1)		0.107(4)	0.62(6)	4.61(1)	6.4(6) mb
^{31}Si		2.62 h	73.(6) mb	33.(3) mb		
$_{15}$P			0.17(1)	0.08(1)	5.13(1)	
^{31}P	100.		0.17(1)	0.08(1)	5.13(1)	1.7(1) mb
$_{16}$S			0.54(2)	0.24(2)	2.847(1)	
^{32}S	95.02(9)		0.55(5)	0.25(2)	2.804(2)	4.7(2) mb
			σ_{α} < 0.5 mb			
^{33}S	0.75(4)		0.46(3)	0.21(2)	4.7(2)	7.4(15) mb
			σ_{α} = 0.12(1)	RI$_{\alpha}$ = 0.05(1)		
			σ_p = 2 mb			σ_{α} = 0.18(1)
^{34}S	4.21(8)		0.30(2)	0.13	3.48(3)	2.9(9) mb
^{36}S	0.02(1)		0.23(2)	0.26(3)		0.17(1) mb
$_{17}$Cl			33.6(3)	15.(2)	9.58(1)	
^{35}Cl	75.77(7)		43.7(4);σ_p=0.44(1)	20.(2);RI$_p$=0.2	11.7(1)	10.(3) mb
			σ_{α} ≈ 0.08 mb			σ_p 1.7(2) mb

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
^{36}Cl		3.01x10^{5} y	σ_p=46.(2) mb	RI_p=0.02		σ_p 91.(8) mb
			<10.			
			σ_α = 0.59(7) mb			σ_α 0.9(2) mb
^{37}Cl	24.23(7)		(0.05 + 0.38)	(0.04+0.26)	3.1(1)	2.15(8) mb
$_{18}$Ar			0.66(3)	0.42(5)	1.91(1)	
^{36}Ar	0.337(3)		5(1);σ_p<1.5 mb	2.(1)	24.9(1)	
			σ_α 6(1) mb			
^{37}Ar		35.0 d	σ_α=2.0(3)x10^{3}	RI_α=900.		
			σ_p = 69(14)	RI_p=31.		
^{38}Ar	0.063(1)		0.8(2)	0.4(1)	3.5(35)	
^{39}Ar		268. y	6.(2)x10^{2}			
^{40}Ar	99.600(3)		0.64(3)	0.41(5)	1.83(1)	2.3(2)mb
^{41}Ar		1.82 h	0.5(1)	0.2(1)		
$_{19}$K			2.1(1)	1.0(1)	3.67(2)	
^{39}K	93.2581(44)		2.1(2)	0.9(1)	3.74(2)	11.8(4)mb
			σ_α = 4.3(5) mb			
			σ_p < 0.05 mb			
^{40}K	0.0117(1)	1.26x10^{9} y	30.(8)	13.(4)		σ_p .7(1)mb
			σ_p=4.4(4)	2.0(2)		σ_α 40(6)mb
			σ_α = 0.42(8)			
^{41}K	6.7302(44)		1.46(3)	1.4(2)	2.69(8)	22.0(7)mb
$_{20}$Ca			0.43(2)	0.23(2)	4.70(2)	
^{40}Ca	96.941(18)		0.41(3)	0.22(4)	4.80(2)	6.7(7)mb
			σ_α 0.13(4) mb			
^{41}Ca		1.02x10^{5} y	≈ 4.			
			σ_α = 0.19			
^{42}Ca	0.647(9)		0.65(10)	0.39(4)	3.4(1)	16.(2)mb
^{43}Ca	0.135(6)		6.(1)	3.9(2)	- 1.56(9)	51.(6)mb
^{44}Ca	2.086(12)		0.8(2)	0.56(1)	1.42(6)	9.(1)mb
^{45}Ca		162.7 d	≈ 15.			
^{46}Ca	0.004(3)		0.70(3)	0.9(1)	3.6(2)	5.7(5)mb
^{48}Ca	0.187(4)		1.1(1)	0.5(1)	0.39(9)	1.0(2)mb
$_{21}$Sc			27.2(2)	12.(1)	12.3(1)	
^{45}Sc	100.		(10.+17.)	(5.6+6.4)	12.3(1)	90.(6)mb
^{46}Sc		83.81 d	8.(1)	3.6(5)		
$_{22}$Ti			6.1(1)	2.8(2)	- 3.438(2)	
^{46}Ti	8.25(3)		0.6(2)	0.4(1)	4.93(6)	27.(3)mb
^{47}Ti	7.44(2)		1.6(2)	1.6(2)	3.63(1)	64.(8)mb
^{48}Ti	73.72(3)		7.9(9)	3.6(2)	- 6.09(2)	31.(5)mb
^{49}Ti	5.41(2)		1.9(5)	1.2(2)	1.04(5)	22.(2)mb
^{50}Ti	5.18(2)		0.179(3)	0.12(2)	6.18(8)	4.0(5)mb

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
$_{23}$V			5.0(2)	2.8(1)	- 0.382(1)	
^{50}V	0.250(4)	>1.4x10^{17} y	21(4)	50.(20)	7.6(6)	
			σ_p = 0.7(4) mb			
^{51}V	99.750(4)		4.9(1)	2.7(2)	- 0.402(2)	42.(3)mb
$_{24}$Cr			3.0(2)	1.7(1)	3.635(7)	
^{50}Cr	4.345(13)		15.(1)	8.(1)	- 4.5(1)	52.(1)mb
^{51}Cr		27.70 d	< 10.			
^{52}Cr	83.79(2)		0.8(1)	0.6(2)	4.91(2)	8.8(4)mb
^{53}Cr	9.50(2)		18.(2)	9(1)	- 4.2(1)	0.06(1)
^{54}Cr	2.365(7)		0.36(4)	0.25(5)	4.6(1)	7.(2)mb
$_{25}$Mn			13.3(1)	14.0(3)	- 3.75(2)	
^{53}Mn		3.7x10^{6} y	70.(10)	32.(5)		
^{54}Mn		312.2 d	< 10.			
^{55}Mn	100.		13.3(1)	14.0(3)	- 3.75(2)	40.(2)mb
$_{26}$Fe			2.6(1)	1.4(2)	9.45(2)	
^{54}Fe	5.85(4)		2.7(5)	1.3(2)	4.2(1)	29.(2)mb
			σ_α = 10 μb	RI$_\alpha$ = 1.1(1) mb		
^{55}Fe		2.73 y	13.(2)	6.(1)		
			σ_α = 0.03			
^{56}Fe	91.75(4)		2.6(2)	1.4(2)	9.93(3)	13.5(5)mb
^{57}Fe	2.12(1)		2.5(5)	1.6(2)	2.3(1)	35.(4)mb
^{58}Fe	0.28(1)		1.3(1)	1.3(2)	15.(7)	13.(2)mb
^{59}Fe		44.51 d	13.(3)	6.(1)		
$_{27}$Co			37.19(8)	74.(2)	2.49(2)	
^{58m}Co		9.1 h	1.4(1)x10^{5}	2.5(10)x10^{5}		
^{58}Co		70.88 d	1.9(2)x10^{3}	7.(1)x10^{3}		
^{59}Co	100.		(20.7+16.5)	(39.+35.)	2.49(2)	38.(4)mb
^{60m}Co		10.47 m	58.(3)	230.(50)		
^{60}Co		5.271 y	2.0(2)	4.3(10)		
^{28}Ni			4.5(2)	2.3(2)	10.3(1)	
^{58}Ni	68.077(9)		4.6(4)	2.3(2)	14.4(1)	42.(3)mb
			σ_α < 0.03 mb			
^{59}Ni		≈7.6x10^{4} y	σabs=92.(4)	RIabs=1.4(1)x10^{2}		
			σ_α = 14(2)			
			σ_p = 2(1)			
^{60}Ni	26.223(8)		2.9(3)	1.5(2)	2.8(1)	27.(2)mb
^{61}Ni	1.140(1)		2.5(5)	1.5(4)	7.60(6)	82.(1)mb
			σ_α = 0.03 mb			
^{62}Ni	3.634(2)		15.(1)	6.8(3)	- 8.7(2)	36.(4)mb
^{63}Ni		100. y	20(5)	9.(2)	26.(8)mb	
^{64}Ni	0.926(1)		1.6(1)	1.(2)	- 0.37(7)	10.(1)mb
^{65}Ni		2.517 h	22.(2)	10.(1)		
$_{29}$Cu			3.8(1)	4.1(4)	7.718(4)	

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
^{63}Cu	69.17(3)		4.5(2)	5.(1)	6.43(15)	0.09(1)
^{64}Cu		12.701 h	≈ 270.			
^{65}Cu	30.83(3)		2.17(3)	2.2(1)	10.61(19)	53(5)mb
^{66}Cu		5.09 m	1.4(1)x10^{2}	60.(20)		
$_{30}$Zn			1.1(2)	2.8(4)	5.680(5)	
^{64}Zn	48.6(6)		0.74(5)	1.4(3)	5.23(4)	59(5)mb
			σ_p < 12 μb			
			σ_α = 11(3) μb			
^{65}Zn		243.8 d	66.(8)	30.(4)		
			σ_α = 2.0(2)			
^{66}Zn	27.9(3)		0.9(3)	1.8(2)	5.98(5)	35(3)mb
			σ_α < 0.02 mb			
^{67}Zn	4.1(1)		6.9(1.4)	25.(5)	7.58(8)	0.15(2)
			σ_α = 0.4 mb			
^{68}Zn	18.8(5)		(0.072 + 0.8)	(0.2 + 2.9)	6.04(3)	19(2)mb
			σ_α <0.02 mb			
^{70}Zn	0.6(3)		(8.1+83.) mb	0.9(2)		
$_{31}$Ga			2.9(1)	22.(3)	7.288(2)	
^{69}Ga	60.11(3)		1.68(7)	16.(2)	7.88(4)	0.15(1)
^{71}Ga	39.89(3)		4.7(2);σ_m=0.15(5)	31.(3)	6.40(3)	0.12(1)
$_{32}$Ge			2.2(1)	6.(2)	8.19(2)	
^{70}Ge	21.23(4)		(0.3 + 2.7)	2.3(1)	10.0(1)	86(5)mb
^{72}Ge	27.66(3)		0.9(2)	0.8(3)	8.5(1)	0.06(2)
^{73}Ge	7.73(1)		15.(1)	66.(20)	5.02(4)	0.28(8)
^{74}Ge	35.94(2)		(0.14 + 0.28)	(0.4+0.5)	7.6(1)	54(6)mb
^{76}Ge	7.44(2)		(0.09 + 0.06)	(1.3+0.6)	8.2(15)	16(1)mb
$_{33}$As			4.0(4)	61.(5)	6.58(1)	
^{75}As	100.		4.0(4)	61.(5)	6.58(1)	0.46(2)
$_{34}$Se			12.(1)	14.(3)	7.970(9)	
^{74}Se	0.89(4)		50.(2)	520(50)	0.8(3)	
^{75}Se		119.78 d	3.3(10)x10^{2}			
^{76}Se	9.37(29)		(22. + 63.)	(9.+31.)	12.2(1)	164(8)mb
^{77}Se	7.63(16)		42.(4),σ_α=0.97(3)μb	30.(5)	8.25(8)	
^{78}Se	23.77(28)		σ_m=0.38(2)	RI_m=4.3(4)	8.24(9)	0.08
^{80}Se	49.61(41)		(0.06+0.35)	(0.36+1.0)	7.48(3)	44.(3)mb
^{82}Se	8.73(22)		(39.+ 5.2) mb	39.(4)mb	6.34(8)	
$_{35}$Br			6.8(2)	92.(8)	6.79(2)	
^{76}Br		16.0 h	224.(42)			
^{79}Br	50.69(7)		(2.5+8.3)	(36.+96)	6.79(7)	0.74(3)
^{81}Br	49.31(7)		(2.4+0.24)	51.(5)	6.78(7)	0.24(1)
$_{36}$Kr			24.(1)	39.(6)	7.81(2)	

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
^{78}Kr	0.35(1)		(0.17+6.)	20.(1)		0.34(4)
^{80}Kr	2.28(6)		(4.6+7.)	57.(6)		0.24(1)
^{82}Kr	11.58(14)		(14.+7.)	130.(13)		79(6)mb
^{83}Kr	11.50(6)		183.(30)	183.(20)	0.24(2)	
^{84}Kr	56.99(4)		σ_m=0.09;σ_m+g=0.11	2.4(3)	(17+17)mb	
^{85}Kr		10.73 y	1.7(2)	1.8(10)		0.07(2)
^{86}Kr	17.30(22)		3.(2)mb	≈1. mb	8.1(3)	3.5(3)mb
$_{37}$Rb			0.39(4)	6.(3)	7.08(2)	
^{84}Rb		32.9 d	σ_p=12.(2)			
^{85}Rb	72.17(2)		(0.06+0.38)	(0.7+7.)	7.0(1)	240(9)mb
^{86}Rb		18.65 d	<20.			
^{87}Rb	27.83(2)	4.88×10^{10} y	0.10(1)	2.3(4)	7.3(1)	18.0(5)mb
^{88}Rb		17.7 m	1.2(3)	0.5(1)		
$_{38}$Sr			1.2(1)	10.(1)	7.02(2)	
^{84}Sr	0.56(1)		(0.6+0.2)	(9.+1.)		
^{86}Sr	9.86(1)		σ_m=0.81(4)	RI_m=4.(1)	5.68(5)	(48+22)mb
^{87}Sr	7.00(1)		16.(3)	118.(30)	7.41(7)	97.(5)mb
^{88}Sr	82.58(1)		5.8(4)mb	0.07(3)	7.16(6)	6.1(2)mb
^{89}Sr		50.52 d	0.42(4)	0.2		
^{90}Sr		29.1 y	9.7(7)mb	4. mb		
$_{39}$Y			1.25(5)	1.0(1)	7.75(2)	
^{89}Y	100.		(0.001+1.25)	(0.006+1.0)	7.75(2)	19.(1)mb
^{90}Y		2.67 d	<6.5			
^{91}Y		58.5 d	1.4(3)	0.6(1)		
$_{40}$Zr			0.19(1);σ_α<0.1mb	0.95(9)	7.16(3)	
^{90}Zr	51.45(40)		≈0.014	0.2(1)	6.4(1)	21.(2)mb
^{91}Zr	11.22(5)		1.2(3)	5.(2)	8.8(1)	60.(8)mb
^{92}Zr	17.15(8)		0.2(1)	0.6(2)	7.5(2)	33.(4)mb
^{93}Zr		1.5×10^{6} y	<4.	16.(5)		0.10(1)
^{94}Zr	17.38(28)		0.049(6)	0.25(3)	8.3(2)	26.(1)mb
^{96}Zr	2.80(9)		0.020(3)	5.0(5)	5.5(1)	10.0(3)mb
$_{41}$Nb			1.11(1);σ_α<0.1mb	8.5(6)	7.14(3)	
^{93}Nb	100.		1.1;σ_m=0.86	(6.3+2.2)	7.14(3)	266.(5)mb
^{94}Nb		2.4×10^{4} y	σ_m+g=15.(1) σ_m=0.6(1)	126.(13)		
^{95}Nb		34.97 d	<7.	<200.		
$_{42}$Mo			2.5(1),σ_α<0.1mb	26.(5)	6.72(2)	
^{92}Mo	14.84(35)		0.06,σ_m=0.2μb	≈0.8	6.93(8)	
^{94}Mo	9.25(12)		0.02	≈0.8	6.82(7)	
^{95}Mo	15.92(13)		13.4(3),σ_α=30.(4)μb	109.(5)	6.93(6)	0.29(1)
^{96}Mo	16.68(2)		0.5	17.(3)	6.22(6)	112.(5)mb

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
^{97}Mo	9.55(8)		2.5(2),σ_α=0.4(2)μb	14.(3)	7.26(8)	0.34(1)
^{98}Mo	24.13(31)		0.14(1)	7.2(7)	6.60(7)	99.(5)mb
^{100}Mo	9.63(23)		0.19(1)	3.6(3)	6.75(7)	
$_{43}$Tc						
^{98}Tc		4.2x10^{6} y	σ_m = 0.9(2)			
^{99}Tc		2.13x10^{5} y	23.(2)	4.0(4)x10^{2}	6.8(3)	0.78(4)
$_{44}$Ru			2.6 (1)	48.(5)	7.03(3)	
^{96}Ru	5.52(20)		0.23(4)	7.(2)		
^{98}Ru	1.86(9)		< 8.			
^{99}Ru	12.74(26)		4.(1)	195.(20)		
^{100}Ru	12.60(19)		5.8(6)	11.(2)		0.21(1)
^{101}Ru	17.05(7)		5.(1),σ_α<0.15μb	1.1(3)x10^{2}		1.00(4)
^{102}Ru	31.57(31)		1.2(1)	4.3(5)		0.19(1)
^{103}Ru		39.27 d	<20.	≈30.		
^{104}Ru	18.66(44)		0.49(2)	6.(2)		0.16(1)
^{105}Ru		4.44 h	0.29(3)	0.13(1)		
^{106}Ru		1.020 y	0.15(4)	2.0(6)		
$_{45}$Rh			145.(2)	1.2(1)x10^{3}	5.88(4)	
^{103}Rh	100.		(11.+ 134.)	(0.08+1.1)x10^{3}	5.88(4)	0.81(1)
^{104m}Rh		4.36 m	800.(100)			
^{104}Rh		42.3 s	40.(30)			
^{105}Rh		35.4 h	1.1(3)x10^{4}	1.7(4)x10^{4}		
$_{46}$Pd			7.(1)	82.(8)	5.91(6)	
^{102}Pd	1.02(1)		3.2(10)	10.(2)		
^{104}Pd	11.14(11)			16.(2)		
^{105}Pd	22.33(13)		22.(2),σ_α=0.5(2)μb	60.(20)	5.5(3)	1.20(6)
^{106}Pd	27.33(6)		(0.013+0.28)	(0.2+5.5)	6.4(4)	0.25(3)
^{107}Pd		6.5x10^{6} y	1.8(2)	108.(4)		1.34(6)
^{108}Pd	26.46(15)		(0.19+8.5)	(2.+240.)	4.1(3)	0.20(2)
^{110}Pd	11.72(16)		(0.033+0.7)	(0.7+8.)		0.15(2)
$_{47}$Ag			62.(1)	767.(60)	5.922(7)	
^{107}Ag	51.839(8)		(0.37+35.)	(1.2+105.)	7.56(1)	0.80(2)
^{109}Ag	48.161(8)		(4.2 + 87.)	(0.7+14.1)x10^{2}	4.17(1)	0.78(2)
^{110m}Ag		249.8 d	82.(11)	20.(4))		
^{111}Ag		7.47 d	3.(2)	105.(20)		
$_{48}$Cd			2.52(5)x10^{3}	73.(8)	4.87(5)	
^{106}Cd	1.25(6)		0.20(3)	4.(1)		0.56(6)
^{108}Cd	0.89(3)		1.	14.(3)	5.4(1)	0.41(7)
^{109}Cd		462.0 d	≈180.,σ_α<0.05	6.7(12)x10^{3}		
^{110}Cd	12.49(18)		(0.06+11.)	(6.+34.)	5.9(1)	0.25(3)
^{111}Cd	12.80(12)		3.5(20)	51.(6)	6.5(1)	1.06(13)
^{112}Cd	24.13(21)		(0.012+2.2)	15.	6.4(1)	0.23(3)
^{113}Cd	12.22(12)	9x10^{15} y	2.06(4)x10^{4},σ_α<1.μb	390.(40)	- 8.0(2)	0.73(8)

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
^{114}Cd	28.73(42)		(0.04+0.29)	16.(7)	7.5(1)	0.16(3)
^{116}Cd	7.49(18)		(26.+52.)mb	1.2	6.3(1)	0.09(1)
$_{49}$In			197.(4)	3.3(2)x10^{3}	4.07(2)	
^{113}In	4.29(5)		(3.1+5.0+3.9)	(220.+90)	5.39(6)	0.79(7)
^{115}In	95.71(5)	4.4x10^{14} y	(88.+73.+44.)	(1.5+1.2+0.7)x10^{3}	4.01(2)	0.74(7)
$_{50}$Sn			0.61(3)	8.(2)	6.225(2)	
^{112}Sn	0.97(1)		(0.15+0.40)	(8.+19.)		0.20(5)
^{113}Sn		115.1 d	≈ 9.	210.(50)		
^{114}Sn	0.66(1)		≈ 0.12	5.(1)	6.2(3)	134.(3) mb
^{115}Sn	0.34(1)		σ_α=0.06 mb	29.(6)		0.34(1)
^{116}Sn	14.54(9)		(0.006+0.14)	(0.5+11.)	5.93(5)	91.(2)mb
^{117}Sn	7.68(7)		1.1(1)	16.(5)	6.48(5)	319.(7)mb
^{118}Sn	24.22(9)		σ_m=4. mb	4.7(5)	6.07(5)	62.(1)mb
^{119}Sn	8.58(4)		2.(1)	2.9(5)	6.12(5)	0.25(5)
^{120}Sn	32.59(9)		(0.001+0.13)	1.2(3)	6.49(5)	(0.5+36)mb
^{122}Sn	4.63(3)		(0.15+0.001)	0.81(4)	5.74(5)	
^{124}Sn	5.79(5)		(0.13+0.005)	RI_m=8.0(2)	5.97(5)	
$_{51}$Sb			5.2(2)	169.(20)	5.57(3)	
^{121}Sb	57.21(5)		(0.4+5.6)	(13.+192.)	5.71(6)	0.53(2)
^{123}Sb	42.79(5)		(0.02+0.04+4.0)	(1.+119.)	5.38(7)	0.30(1)
^{124}Sb		60.20 d	17.(3)	≈8.		
$_{52}$Te			4.2(1)	47.(3)	5.80(3)	
^{120}Te	0.096(2)		(0.25+2.0)	≈1.	5.3(5)	
^{122}Te	2.603(4)		2.4(5)	80.(20)	3.8(2)	295.(3)mb
^{123}Te	0.908(2)	1.3x10^{13} y	370.(40),σ_α=0.05mb	4.5(3)x10^{3}	- 0.05	0.83(1)
^{124}Te	4.816(6)		(0.05+7.)	5.2(7)	8.0(1)	155.(2)mb
^{125}Te	7.139(6)		1.6(2)	21.(4)	5.02(8)	431.(4)mb
^{126}Te	18.952(11)		(0.12+0.8)	8.2(6)	5.56(7)	81.(1)mb
^{128}Te	31.687(11)		(0.016+0.20)	(0.08+1.5)	5.89(7)	
^{130}Te	33.799(10)	2.5x10^{21} y	(0.03+0.20)	(0.08+0.34)	6.02(7)	
$_{53}$I			6.15(10)	148.(7)	5.28(2)	
^{125}I		59.4 d	900.(100)	1.4(2)x10^{4}		
^{127}I	100.		6.15(10)	148.(7)	5.28(2)	0.64(3)
^{128}I		25.00 m	22.(4)	≈10.		
^{129}I		1.7x10^{7} y	(20.7+10.3)	36.(4)		0.44(2)
^{130}I		12.36 h	18.(3)	≈8.		
^{131}I		8.040 d	≈ 0.7	8.(4)		
$_{54}$Xe			25.(1)	263.(50)	4.92(3)	
^{124}Xe	0.09(1)		(28.+137.)	(0.6+3.0)x10^{3}		
^{125}Xe		17.1 h	σ_α≤<0.03			
^{126}Xe	0.09(1)		(0.45+3.)	(8.+52.)		
^{127}Xe		36.4 d	σ_α≤0.01			

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
^{128}Xe	1.92(3)		σ_m=0.48	RI_m=38.(10)		0.35(11)
^{129}Xe	26.44(24)		22.(5)	250.(50)		0.76(7)
^{130}Xe	4.08(2)		σ_m=0.45	RI_m=16.(4)		0.18(5)
^{131}Xe	21.18(3)		90.(10)	9.(1)x10^2		0.45(8)
^{132}Xe	26.89(6)		(0.05+0.4)	(0.9+3.7)		65.(5)mb
^{133}Xe		5.243 d	190.(90)			
^{134}Xe	10.44(10)		(0.003 + 0.26)	0.40(4)		20.(2)mb
^{135}Xe		9.10 h	2.65(11)x10^6	7.6(5)x10^3		
^{136}Xe	8.87(16)		0.26(2)	0.7(2)		0.9(1)mb
$_{55}$Cs			30.4(8)	422.(50)	5.42(2)	
^{132}Cs		6.48 d	σ_α< 0.15			
^{133}Cs	100.		(2.7+27.7)	(32.+390.)	5.42(2)	0.51(2)
^{134}Cs		2.065 y	140.(10)	54.(9)		
^{135}Cs		2.3x10^6 y	8.9(5)	90.(20)		
^{137}Cs		30.2 y	0.25(1)	0.36(7)		
$_{56}$Ba			1.3(2)	10.(2)	5.07(3)	
^{130}Ba	0.106(1)		(1.+8.)	(25.+200.)	- 3.6(6)	
^{132}Ba	0.101(1)		(0.84+9.7)	(4.7+24.)	7.8(3)	
^{133}Ba		10.53 y	4.(1)	85.(30)		
^{134}Ba	2.417(18)		(0.1+1.3)	(5.6+18.)	5.7(1)	0.18(6)
^{135}Ba	6.592(12)		(0.014+5.8)	(0.47+131.)	4.7(1)	0.30(6)
^{136}Ba	7.854(24)		(0.010+0.44)	(0.1+1.5)	4.91(8)	62.(2)mb
^{137}Ba	11.232(24)		5.(1)	4.(1)	6.8(1)	0.05(1)
^{138}Ba	71.698(42)		0.41(2)	0.4(1)	4.84(8)	4.1(2)mb
^{139}Ba		1.396 h	5.(1)	2.2(5)		
^{140}Ba		12.75 d	1.6(3)	14.(1)		
$_{57}$La			9.2(2)	12.(1)	8.24(4)	
^{138}La	0.090(1)	1.06x10^{11} y	57.(6)	4.1(9)x10^2		
^{139}La	99.910(1)		9.2(2)	12.(1)	8.24(4)	38.(3)mb
^{140}La		1.678 d	2.7(3)	69.(4)		
$_{58}$Ce			0.64(4)	0.71(6)	4.84(2)	
^{136}Ce	0.185(2)		(1.0+6.5)	58.(12)	5.80(9)	(28+272)mb
^{138}Ce	0.251(2)		(0.018+1.)	(1.5+5.2)	6.70(9)	179.(5)mb
^{140}Ce	88.450(18)		0.58(4)	0.50(5)	4.84(9)	11.0(4)mb
^{141}Ce		32.50 d	29.(3)	13.(2)		
^{142}Ce	11.114(17)		0.97(3)	1.3(3)	4.75(9)	28.(1)mb
^{143}Ce		1.38 d	6.1(7)	2.7(3)		
^{144}Ce		284.6 d	1.0(1)	2.6(3)		
$_{59}$Pr			11.5(4)	14.(3)	4.58(5)	
^{141}Pr	100.		(4.+7.5)	14.(3)	4.58(5)	0.12(2)
^{142}Pr		19.12 h	20.(3)	9.(1)		
^{143}Pr		13.57 d	90.(10)	190.(25)		
$_{60}$Nd			51.(2)	49.(5)	7.69(5)	

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
^{142}Nd	27.2(5)		19.(1)	34.(11)	7.7(3)	46.(4)mb
^{143}Nd	12.2(2)		330.(10),σ_α=17.mb	128.(30)		0.24(1)
^{144}Nd	23.8(3)	2.1x10^{15} y	3.6(3)	3.9(5)	2.8(3)	0.11(1)
^{145}Nd	8.30(1)		47.(6),σ_α=12.μb	260.(40)		0.49(10)
^{146}Nd	17.2(3)		1.5(2)	3.0(4)	8.7(2)	0.16(4)
^{147}Nd		10.98 d	440.(150)	200.		
^{148}Nd	5.7(1)		2.4(1)	13.(2)	5.7(3)	0.19(4)
^{150}Nd	5.6(2)		1.0(1)	14.(2)	5.3(2)	
$_{61}$Pm						
^{146}Pm		5.53 y	8.4(1.7)x10^{3}			
^{147}Pm		2.6234 y	(84.+96.)	(1000.+1280.)	12.6(4)	
^{148m}Pm		41.3 d	10600.(800)			
^{148}Pm		5.37 d	≈ 10^{3}	2.6(2.4)x10^{3}		
^{149}Pm		2.212 d	1400.(200)			
^{151}Pm		1.183 d	≈ 150.			
$_{62}$Sm			5.6(1)x10^{3}	1.4(2)x10^{3}		
^{144}Sm	3.08(7)		1.6(1)	2.4(3)		
^{145}Sm		340. d	280.(20)	600.(90)		
^{147}Sm	14.99(17)	1.06x10^{11} y	56.(4),σ_α=0.6mb	710.(50)	14.(3)	0.97(1)
^{148}Sm	11.24(10)	7x10^{15} y	2.4(6)	27.(14)		241.(2)mb
^{149}Sm	13.82(7)	10^{16} y	40100.(600),σ_α=31.mb	3100.(500)		1.82(2)
^{150}Sm	7.38(1)		102.(5)	290.(30)	14.(3)	422.(4)mb
^{151}Sm		90. y	15200.(300)	3520.(60)		
^{152}Sm	26.74(14)		206.(15)	3000.(300)	- 5.0(6)	473.(4)mb
^{153}Sm		1.929 d	420.(180)			
^{154}Sm	22.75(27)		7.5(3)	32.(6)	9.(1)	
$_{63}$Eu			4570.(100)	3.8(5)x10^{3}	5.3(3)	
^{151}Eu	47.81(6)		(4.+3150.+6000.) σ_α=8.7(3)μb	(2000.+4000.)		4.4(2)
^{152m1}Eu		9.30 h	68000.(15000)	< 100000.		
^{152}Eu		13.5 y	11000.(2000)	1600.(200)		
^{153}Eu	52.19(6)		300.(20),σ_α<1.μb	1800.(400)	8.2(1)	3.2(3)
^{154}Eu		8.59 y	1500.(300)	1600.(200)		4.4(7)
^{155}Eu		4.76 y	3900.(200)	16000.(2000)		
$_{64}$Gd			48.8(6)x10^{3}	400.(10)	9.5(2)	
^{152}Gd	0.20(1)		700.(200),σ_α<7.mb	700.(200)		1.05(7)
^{153}Gd		241.6 d	20000.(10000),σ_α=0.03			
^{154}Gd	2.18(3)		(0.06+60.)	230.(50)		0.88(3)
^{155}Gd	14.80(12)		61.(1)x10^{3},σ_α=.08mb	1540.(100)		2.72(9)
^{156}Gd	20.47(9)		≈2.0	104.(15)	6.3(4)	0.64(6)
^{157}Gd	15.65(2)		2.54(3)x10^{5},σ_α<0.05	800.(100)		1.36(4)
^{158}Gd	24.84(7)		2.3(3)	73.(7)	9.(2)	0.22(2)
^{160}Gd	21.86(19)		1.5(7)	6.(1)	9.15(5)	
^{161}Gd		3.66 m	2.0(6)x10^{4}			
$_{65}$Tb			23.2(5)	420.(50)	7.38(3)	

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
^{159}Tb	100.		23.2(5)	420.(50)	7.38(3)	1.75(10)
^{160}Tb		72.3 d	570.(110)			
$_{66}$Dy			9.5(2)x10^{2}	1.5(2)x10^{3}	16.9(3)	
^{156}Dy	0.06(1)		33.(3),σ_{α}<9mb	1000.(100)		
^{158}Dy	0.10(1)		43.(6),σ_{α}<6mb	120.(10)	6.1(5)	
^{159}Dy		144. d	8.(2)x10^{3}			
^{160}Dy	2.34(8)		60.(10),σ_{α}<0.3mb	1100.(200)	6.7(4)	0.77(4)
^{161}Dy	18.91(24)		600.(50),σ_{α}<1μb	1100.(100)	10.3(4)	2.01(6)
^{162}Dy	25.51(26)		170.(20)	2755.(300)	- 1.4(5)	0.47(5)
^{163}Dy	24.90(16)		120.(10),σ_{α}<20μb	1600.(400)	5.0(4)	1.14(4)
^{164}Dy	28.18(36)		(1.7+1.0)x10^{3}	(420.+100.)	49.4(2)	0.27(3)
^{165m}Dy		1.26 m	2.0(6)x10^{3}			
^{165}Dy		2.33 h	3.5(3)x10^{3}	2.2(3)x10^{4}		
$_{67}$Ho			61.(2)	670.(40)	8.01(8)	
^{165}Ho	100.		(3.1+58.),σ_{α}<20μb	(?+670.)	8.01(8)	1.32(7)
^{166}Ho		1.2x10^{3} y	9140.(650)	1140.(90)		
$_{68}$Er			169.(20)	730.(10)	7.79(2)	
^{162}Er	0.14(1)		19.(3),σ_{α}<11mb	480.(50)	8.8(2)	
^{164}Er	1.61(3)		13.(3),σ_{α}<1.2mb	105.(10)	8.2(2)	0.71(6)
^{166}Er	33.61(35)		(15.+5.),σ_{α}<70μb	96.(12)	10.6(2)	0.61(6)
^{167}Er	22.93(17)		700.(200),σ_{α}=3μb	2970.(70)	3.0(3)	1.5(2)
^{168}Er	26.78(26)		2.0(6),σ_{α}=0.09mb	37.(5)	7.4(4)	0.37(4)
^{170}Er	14.93(27)		6.(1)	26.(4)	9.6(5)	0.22(3)
^{171}Er		7.52 h	370.(40)	170.(20)		
$_{69}$Tm			106.(5)	1.5(2)x10^{3}	7.07(3)	
^{169}Tm	100		(8.+98.)	1.5(2)x10^{3}	7.07(3)	1.13(6)
^{170}Tm		128.6 d	100.(20)	460.(50)		
^{171}Tm		1.92 y	≈ 160.	118.(6)		
$_{70}$Yb				52.(10)	1.7(2)x10^{2}	12.43(3)
^{168}Yb	0.13(1)		2.4(2)x103,σ_{α}<0.1mb	2.0(5)x10^{4}	-4.07(2)	
^{169}Yb		32.03 d	3.6(3)x10^{3}	5200.(500)		
^{170}Yb	3.04(15)		12.(2),σ_{α}<10μb	320.(30)	6.8(1)	0.74(3)
^{171}Yb	14.3(6)		53.(5),σ_{α}<1.5μb	315.(30)	9.7(1)	1.41(5)
^{172}Yb	21.8(7)		≈ 1.3,σ_{α}<1μb	25.(3)	9.4(1)	0.41(3)
^{173}Yb	16.13(3)		16.(2),σ_{α}<1μb	380.(30)	9.56(7)	0.87(7)
^{174}Yb	31.8(9)		(46.+74.),σ_{α}<0.02mb	(13.+47.)	19.3(1)	0.18(2)
^{176}Yb	12.8(4)		3.1(2),σ_{α}<1μb	8.(2)	8.7(1)	
$_{71}$Lu			78.(7)	8.3(7)x10^{2}	7.21(3)	
^{175}Lu	97.41(2)		(16.+8.)	(550.+270.)	7.24(3)	1.18(4)
^{176}Lu	2.59(2)	3.8x10^{10} y	(2.+2100.)	(3.+1100.)	6.1(2)	1.54(6)
^{177m}Lu		160.7 d	3.2(3)	1.4(2)		
^{177}Lu		6.75 d	1000.(300)			

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
$_{72}$Hf			106.(3)	19.7(5)x10^{2}	7.8(1)	
^{174}Hf	0.162(3)	2.0x10^{15} y	600.(50)	400.(50)	11.(1)	
^{176}Hf	5.206(5)		23.(4)	700.(100)	6.6(2)	0.46(2)
^{177}Hf	18.606(13)		(1.+375.),σ_α<20μb	7170.(200)		1.37(6)
^{178}Hf	27.297(4)		(53.+32.)	(340.+1500.)	5.9(2)	0.31(1)
^{179}Hf	13.629(6)		(0.43+46.)	(6.8+620.)	7.5(2)	0.99(3)
^{180}Hf	35.100(7)		13.(1),σ_α<13μb	32.(2)	13.2(3)	175.(5)mb
^{181}Hf		42.4 d	30.(25)			
$_{73}$Ta			20.(1)	650(20.)	6.91(7)	
^{180m}Ta	0.012(2)	> 1.2x10^{15} y	≈ 560.	1350.(100)		
^{181}Ta	99.998(2)		(0.012 + 20),σ_α<1μb	(0.4+650.)	6.91(7)	0.77(2)
^{182}Ta		114.43 d	8200.(600)	900.(90)		
$_{74}$W			18.(1)	3.6(3)x10^{2}	4.86(2)	
^{180}W	0.12(1)		≈ 4.	210.(30)		
^{182}W	26.50(16)		20.(1)	600.(90)	6.97(4)	274.(8)mb
^{183}W	14.31(4)		10.5(3)	340.(50)	6.53(4)	0.52(2)
^{184}W	30.64(2)		(0.002 + 2.0)	15.(2)	7.48(6)	0.23(1)
^{185}W		74.8 d	≈ 3.3	300.(50)		
^{186}W	28.43(19)		37.(2)	510.(50)	- 0.72(4)	176.(5)mb
^{187}W		23.9 h	70.(10)	2760.(550)		
$_{75}$Re			90.(4)	8.4(2)x10^{2}	9.2(3)	
^{185}Re	37.40(2)		(0.33+110.)	1700.(50)	9.0(3)	1.54(6)
^{187}Re	62.60(2)	4.4x10^{10} y	(2.+72.)	(9.+310.)	9.3(3)	1.16(6)
$_{76}$Os			17.(1)	1.5(1)x10^{2}	10.7(2)	
^{184}Os	0.020(3)		3.3(3)x10^{3},σ_α<10mb	1.4(1)x10^{3}		
^{186}Os	1.58(2)	2.x10^{15} y	≈ 80.,σ_α<0.1mb	280.(40)	12(2)	0.42(2)
^{187}Os	1.6(4)		2.(1)x10^{2},σ_α<0.1mb	500.(70)		0.87(3)
^{188}Os	13.3(1)		≈ 5.,σ_α<30μb	150.(20)	7.6(3)	0.40(2)
^{189}Os	16.1(1)		(0.00026+40),σ_α<10μb	(0.013+670.)	10.7(3)	1.17(5)
^{190}Os	26.4(2)		(9.+4.),σ_α<20μb	(22.+8.)	11.0(3)	0.30(5)
^{191}Os		15.4 d	3.8(6)x10^{2}			
^{192}Os	41.0(3)		3.(1),σ_α<10μb	6.(1)	11.5(4)	0.31(5)
^{193}Os		30.5 h	40.(10)			
$_{77}$Ir			4.2(1)x10^{2}	2.8(4)x10^{3}	10.6(3)	
^{191}Ir	37.3(2)		(660.+260.)	(1000.+4200.)		1.35(7)
^{192}Ir		73.83 d	1450.(250)	4800.(700)		
^{193}Ir	62.7(2)		(6.+110.)	1400.(200)		0.86(4)
^{194}Ir		19.3 h	1.5(3)x10^{3}			
$_{78}$Pt			10.(1)	1.3(1)x10^{2}	9.60(1)	
^{190}Pt	0.014(1)	6.5x10^{11} y	1.5(1)x10^{2},σ_α<8mb	70.(10)	9(1)	

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
^{192}Pt	0.782(7)		(2.0+6.),σ_α<0.2mb	115.(20)	9.9(5)	0.20(6)
^{194}Pt	32.97(10)		(0.1+1.1),σ_α< 5μb	(4.+?)	10.55(8)	0.37(8)
^{195}Pt	33.832(10)		28.(1),σ_α< 5μb	365.(50)	8.8(1)	0.9(2)
^{196}Pt	25.242(41)		(0.045+0.55)	7.(2)	9.89(8)	0.20(2)
^{198}Pt	7.16(6)		(0.027+3.6)	(0.5+56.)	7.8(1)	
^{199}Pt		30.8 m	≈ 16.			
$_{79}$Au			98.7(1)	1.55(3)x10^3	7.63(6)	
^{197}Au	100.		98.7(1)	1.55(3)x10^3	7.63(6)	582.(9)mb
^{198}Au		2.694 d	26.5(15)x10^3	≈ 4.x10^4		
^{199}Au		3.14 d	≈ 30.			
$_{80}$Hg			3.7(1)x10^2	87.(5)	12.69(2)	
^{196}Hg	0.15(1)		(105.+3000.)	(53.+410.)	30.(1)	
^{198}Hg	9.97(20)		(0.017+2.)	(1.7+70.)		0.17(2)
^{199}Hg	16.87(22)		2.1(2)x10^3	435(20)	16.9(4)	0.37(2)
^{200}Hg	23.10(19)		< 60.	2.1(5)		0.12(1)
^{201}Hg	13.18(9)		< 60.	30.(3)		0.26(1)
^{202}Hg	29.86(26)		4.9(5)	4.5(2)		74.(6)mb
^{204}Hg	6.87(15)		0.4(1)	0.8(2)		42.(4)mb
$_{81}$Tl			3.3(1)	12.5(8)	8.776(5)	
^{203}Tl	29.52(1)		11.(1),σ_α<0.3mb	41.(2)	7.0(2)	124.(8)mb
^{204}Tl		3.78 y	22.(2)	90.(20)		
^{205}Tl	70.48(1)		0.11(2)	0.6(2)	9.52(7)	54.(4)mb
$_{82}$Pb			0.172(2)	0.14(4)	9.402(2)	
^{204}Pb	1.4(1)		0.68(7)	2.0(2)	10.6(20)	90.(6)mb
^{205}Pb		1.51x10^7 y	≈ 5.			
^{206}Pb	24.1(1)		0.030(1)	0.10(1)	9.23(5)	14.(1)mb
^{207}Pb	22.1(1)		0.70(1)	0.38(1)	9.28(4)	8.4(4)mb
^{208}Pb	52.4(1)		0.49(3)mb,σ_α<8μb	2.0(2) mb	9.50(6)	0.36(2)mb
^{210}Pb		22.6 y	< 0.5			
$_{83}$Bi			0.034(1)	0.19(2)	8.532(2)	
^{209}Bi	100.		(11+23)mb,σ_α<0.3μb	0.19(2)	8.532(2)	3.1(3)mb
^{210m}Bi		3.0x10^6 y	54(4)mb	0.20(3)		
$_{84}$Po						
^{210}Po		138.38 d	σ_m<0.5mb,σ_α< 2.mb σ_g<30.mb,σ_f< 0.1			
$_{85}$At						
$_{86}$Rn						
^{220}Rn		55.6 s	<0.2			
^{222}Rn		3.8235 d	0.74(5)			

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
$_{88}$Ra						
^{223}Ra		11.435d	$1.3(2)x10^{2}$,σ_f<0.7			
^{224}Ra		3.66 d	12.0(5)			
^{226}Ra		1599. y	≈ 13.,σ_f< 7.μb	280.(50)	10.(1)	
^{228}Ra		5.76 y	36.(5),σ_f<2.			
$_{89}$Ac						
^{227}Ac		21.77 y	$8.8(7)x10^{2}$,σ_f<.35 mb	$1.5(4)x10^{3}$		
$_{90}$Th			7.4	85.(3)	10.31(3)	
^{227}Th		18.72 d	σ_f=$2.0(2)x10^{2}$			
^{228}Th		1.913 y	$1.2(2)x10^{2}$,σ_f<0.3	1014.(400)		
^{229}Th		$7.9x10^{3}$ y	≈ 60.	$1.0(2)x10^{3}$		
			σ_f=30(3)	RI_f=466.(75)		
^{230}Th		$7.54x10^{4}$ y	23.4(5)	$1.0(1)x10^{3}$		
			σ_f<0.5mb			
^{232}Th	100.	$1.4x10^{10}$y	7.37(4)	85.(3)	10.31(3)	
			σ_f=3.(1) μb			
			σ_α<1. μb			
^{233}Th		22.3 m	$1.5(1)x10^{3}$	$4.(1)x10^{2}$		
			σ_f=15.(2)			
^{234}Th		24.10 d	1.8(5)			
			σ_f<0.01			
$_{91}$Pa						
^{230}Pa		17.4 d	$1.5(3)x10^{3}$			
^{231}Pa		$3.25x10^{4}$ y	$2.0(1)x10^{2}$	750.(80)	9.1(3)	
			σ_f=20.(1) mb	RI_f=0.05(1)		
^{232}Pa		1.31 d	$4.6(10)x10^{2}$	300.(70)		
			σ_f=$7.(1)x10^{2}$			
^{233}Pa		27.0 d	39.(2)	(460.+440)		
			σ_m=20.(4)			
			σ_g=19.(3)			
			σ_f< 0.1			
$_{92}$U			3.4(3);σ_f=4.2(1)	280.(20),RI_f=2.0	8.417(5)	
^{230}U		20.8 d	σ_f≈ 25.			
^{231}U		4.2 d	σ_f≈ 250.			
^{232}U		68.9 y	73.(2)	280.(15)		
			σ_f=74.(8)	RI_f=350.(30)		
^{233}U		$1.59x10^{5}$ y	47.(2)	137.(6)	10.1(2)	
			σ_f=$5.3(1)x10^{2}$	RI_f=760.(17)		
			σ_α<0.2 mb			
^{234}U	0.0055(5)	$2.45x10^{5}$ y	96.(2)	660.(70)	12.(4)	
			σ_f< 5. mb	RI_f=6.5		

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
^{235}U	0.720(1)	$7.04x10^8$ y	95.(5)	144.(6)	10.47(4)	
			σ_f=586.(2)	RI_f=275(5)		
			σ_α< 0.1 mb			
^{236}U		$2.34x10^7$ y	5.1(3)	360.(15)		
			σ_f=0.04	RI_f=4.38(50)		
^{237}U		6.75 d	≈ 10^2	1200.(200)		
			σ_f< 0.35			
^{238}U	99.2745(15)	$4.46x10^9$ y	2.7(1)	277.(3)	8.402(5)	
			σ_f≈3.μb	1.54(15) mb		
			σ_α=1.4(5) μb			
^{239}U		23.5 m	22.(2)			
			σ_f=15.(3)			
$_{93}Np$						
^{234}Np		4.4 d	σ_f=9.(3)$x10^2$			
^{235}Np		1.085 y	1.6(1)$x10^2$			
^{236m}Np		22.5 h	σ_f=2.7(2)$x10^3$	700.(400)		
^{236}Np		$1.55x10^5$ y	σ_f=2.6(5)$x10^3$	1030.(100)		
^{237}Np		$2.14x10^6$ y	160.(10)	8.(2)$x10^2$	10.6(1)	
			σ_f=20.(1)mb	RI_f=0.32		
^{238}Np		2.117 d	σ_f=2.1(1)$x10^3$	9.(1)$x10^2$		
^{239}Np		2.355 d	(32.+19.)			
			σ_f<1.			
$_{94}Pu$						
^{236}Pu		2.87 y	σ_f=1.6(3)$x10^2$	1000.(60)		
^{237}Pu		45.7 d	σ_f=2.3(3)$x10^3$			
^{238}Pu		87.74 y	5.1(2)$x10^2$	1.6(2)$x10^2$	14.1(5)	
			σ_f=17.(1)	RI_f=33.(5)		
^{239}Pu		2.411 x 10^4y	2.7(1)$x10^2$	2.0(2)$x10^2$	7.7(1)	
			σ_f=752.(3)	3.0(1)$x10^2$		
			σ_α≤0.3 mb			
^{240}Pu		6537. y	2.9(1)$x10^2$	8.4(3)$x10^3$	3.5(1)	
			σ_f≈44.mb	RI_f=2.4		
^{241}Pu		14.4 y	3.7(1)$x10^2$,σ_α<0.2mb	1.6(1)$x10^2$		
			σ_f=1.01(1)$x10^3$	5.7(4)$x10^2$		
^{242}Pu		3.76 x 10^5 y	19.(1)	1.1(1)$x10^3$	8.1(1)	
			σ_f<0.2	RI_f=0.23		
^{243}Pu		4.956 h	<100.			
			σ_f=2.0(2)$x10^2$			
^{244}Pu		$8.2x10^7$ y	1.7(1)	41.(3)		
^{245}Pu		10.5 h	1.5(3)$x10^2$	220(40)		
$_{95}Am$						
^{241}Am		432.2 y	(0.5+5.7)$x10^2$	(2.0+12.3)$x10^2$		
			σ_f=3.1(2)	14.(1)		
^{242m}Am		141. y	1.7(4)$x10^3$	≈ 200.		
			σ_f=7.0(3)$x10^3$	RI_f=1.8(1)$x10^3$		
^{242}Am		16.02 h	σ_f=2.1(2)$x10^3$	RI_f=< 300.		
^{243}Am		$7.37x10^3$y	(75.+5.)	(17.1+1.0)$x10^2$	8.3(2)	
			σ_f=74.(4) mb	RI_f=0.056		

Elem. or Isot.	Natural Abundance (%)	Half-life	Thermal Neut. Cross Section (barns)	Resonance Integral (barns)	Coh. Scat. Length (fm)	σ(30KEV) Maxw. Avg. (barns)
^{244m}Am		≈ 26. m	σ_f=1.6(3)x10^3			
^{244}Am		10.1 h	σ_f=2.2(3)x10^3			
$_{96}$Cm						
^{242}Cm		162.8 d	≈ 20.	120.(50)		
			σ_f≈ 5.			
^{243}Cm		28.5 y	1.3(1)x10^2	214.(20)		
			σ_f=6.2(2)x10^2	RI_f=1.6(1)x10^3		
^{244}Cm		18.11 y	15.(1)	640.(50)	9.5(3)	
			σ_f=1.1(2)	RI_f=10.8(8)		
^{245}Cm		8.5x10^3 y	3.5(2)x10^2	110(10)		
			σ_f=2.1(1)x10^3	RI_f=8.(1)x10^2		
^{246}Cm		4.78x10^3y	1.2(2)	120.(10)	9.3(2)	
			σ_f=0.16(7)	13.(2)		
^{247}Cm		1.56x10^7y	60.(30)	5.(1)x10^2		
			σ_f=82.(5)	7.3(7)x10^2		
^{248}Cm		3.4x10^5 y	2.6(3)	270.(30)	7.7(2)	
			σ_f=0.36(7)	13.(2)		
^{249}Cm		64.15 m	≈1.6			
^{250}Cm		≈ 9.7x10^3 y	≈80.			
$_{97}$Bk						
^{249}Bk		320. d	7.(1)x10^2	9.(1)x10^2		
			σ_f≈0.1			
^{250}Bk		3.217 h	σ_f=1.0(2)x10^3			
$_{98}$Cf						
^{249}Cf		351. y	5.0(3)x10^2	7.7(4)x10^2		
			σ_f=1.7(1)x10^3	RI_f=2.1(3)x10^3		
^{250}Cf		13.1 y	2.0(2)x10^3	12.(2)x10^3		
			σ_f=110.(90)	RI_f=160.(40)		
^{251}Cf		9.0x10^2 y	2.9(2)x10^3	1.6(1)x10^3		
			σ_f=4.5(5)x10^3	RI_f=5.5(3)x10^3		
^{252}Cf		2.65 y	20.(2)	43.(3)		
			σ_f=32.(4)	RI_f=1.1(3)x10^2		
^{253}Cf		17.8 d	18.(2)	8.(1)		
			σ_f=1.3(2)x10^3			
^{254}Cf		60.5 d	4.5(10)	2.		
$_{99}$Es						
^{253}Es		20.47 d	(180.+5.8)	(37.5+1.1)x10^2		
^{254m}Es		1.64 d	σ_f=1.8(1)x10^3			
^{254}Es		276. d	28.(3)	18.(2)		
			σ_f=1.8(2)x10^3	RI_f=1.2(3)x10^3		
^{255}Es		40. d	≈ 55.			
$_{100}$Fm						
^{255}Fm		20.1 h	26.(3)	14.(2)		
			σ_f=3.3(2)x10^3			
^{257}Fm		100.5 d	σ_f=3.0(2)x10^3			

COSMIC RADIATION

A.G. Gregory and R.W. Clay

The Nature of Cosmic Rays

Primary cosmic radiation, in the form of high energy nuclear particles, electrons and photons from outside the solar system and from the Sun, continually bombards our atmosphere. Secondary radiation, resulting from the interaction of the primary cosmic rays with atmospheric gas, is present at sea-level and throughout the atmosphere.

The secondary radiation is collimated by absorption and scattering in the atmosphere and consists of a number of components associated with different particle species. High energy primary particles can produce large numbers of secondary particles forming an extensive air shower. Thus, a number of particles may then be detected simultaneously at sea-level.

Primary particle energies accessible in the vicinity of the earth range from ~10^8 eV to ~10^{20} eV. At the lower energies, the limit is determined by the inability of charged particles to traverse the heliosphere to us through the outward-moving solar wind. The upper energy limit is set by the practicality of building detectors to record particles with the extremely low fluxes found at those energies (J.G. Wilson, 1976; O.C. Allkofer, 1975a).

Primary Cosmic Rays

Primary Particle Energy Spectrum

Figure 1 shows the spectrum of primary particle energies. This includes all particle species. In differential form it is roughly a power law of intensity versus energy with an index of ~ –3. There appears to be a knee (a steepening) at a little above 10^{15} eV and an ankle (a flattening) above ~10^{18} eV. Figure 2 emphasizes the features in the spectrum at the highest energies through multiplying the flux with a strongly rising power law of energy. This figure should be used with caution as errors for the two axes are not now independent.

Data on the high energy cosmic ray spectrum are uncertain largely because of limited event statistics due to the very low flux which might best be measured in particles per square kilometer per century. The highest energy event recorded to 1995 had an energy of 3×10^{20} eV (D.J. Bird et al., 1993).

It is expected that the highest energy cosmic rays will interact with the 2.7 K cosmic microwave background through photoproduction or photodisintegration. These interactions will appreciably reduce the observed flux of cosmic rays with energies above 5×10^{19} eV if they travel further than ~150 million light years. This process is known as the Greisen-Zatsepin-Kuz'min (GZK) cut off (P. Sokolsky, 1989).

At energies below ~10^{13} eV, solar system magnetic fields and plasma can modulate the primary component and Figure 3 shows the extent of this modulation between solar maximum and minimum (E. Juliusson, 1975; J. Linsley, 1981).

Primary Particle Energy Density

If the above spectrum is corrected for solar effects, the energy density above a particle energy of 10^9 eV outside the solar system is found to be ~5×10^5 eV m^{-3}. As the threshold energy is increased, the energy density decreases rapidly, being 2×10^4 eV m^{-3} above 10^{12} eV and 10^2 eV m^{-3} above 10^{15} eV. The energy density at lower energies outside the heliosphere is unknown but may be substantially greater if the particle rest mass energy is included together with the kinetic energy (A. W. Wolfendale, 1979).

Primary Particle Isotropy

This is measured as an anisotropy $(I_{max} - I_{min})/(I_{max} + I_{min}) \times 100\%$, where I, the intensity (m^{-2}s^{-1}sr^{-1}), is usually measured with an angular resolution of a few degrees.

The measured anisotropy is small and energy dependent. It is roughly constant in amplitude at between 0.05 and 0.1% (with a phase of 0 to 6 hours in right ascension) for energies between 10^{11} eV and 10^{14} eV and appears to increase at higher energies roughly as $0.4 \times (\text{Energy(eV)}/10^{16})^{0.5}$% up to ~$10^{18}$ eV. The latter rise may well be an artifact of the progressively more limited statistics as the flux drops rapidly with energy. It appears possible that a real anisotropy has been observed at the highest energies (above a few times 10^{19} eV) with a directional preference for the supergalactic plane (this plane reflects the directions of galaxies within about 100 million light years) (A.W. Wolfendale, 1979; R.W. Clay, 1987; T. Stanev et al., 1995).

Primary Particle Composition

The composition of low energy cosmic rays is close to universal nuclear abundances except where propagation effects are present. For example, Li, Be, and B which are spallation products, are over-abundant by about six orders of magnitude.

Composition at 10^{11} eV per nucleus

Charge	1	2	(3–5)	(6–8)	(10–14)	(16–24)	(26–28)	≥30
% Composition (10% uncertainty)	50	25	1	12	7	4	4	0.1

Measurements at higher energies indicate that there is an increase in the relative abundances of nuclei with charge greater than 6 at energies above 50 TeV/nucleus (K. Asakimori et al., 1993) (1 TeV = 10^{12} eV).

Cosmic ray composition at low energies is often quoted at a fixed energy per nucleon. When presented in this way, protons constitute roughly 90% of the flux, helium nuclei about 10% and the remainder sum to a total of about 1%.

Certain radioactive isotopic ratios show lifetime effects. The ratio of Be^{10}/B^9 abundances is used to measure an "age" of cosmic rays since Be^{10} is unstable with a half life of about 1.6×10^6 years. A ratio of 0.6 is expected in the absence of Be^{10} decay and a ratio of about 0.2 is found experimentally (E. Juliusson, 1975; P. Meyer, 1981).

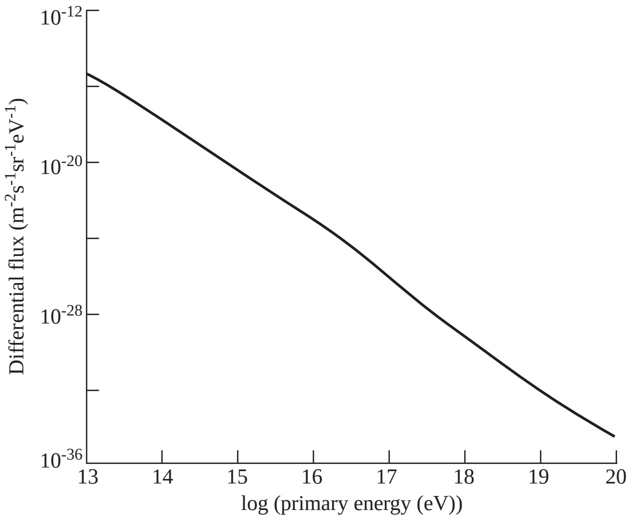

FIGURE 1. The energy spectrum of cosmic ray particles. This spectrum is of a differential form and can be converted to an integral spectrum by integration over all energies above a required threshold (E). Insofar as the spectrum approximates a power law of index –3, a simple conversion to the integral at an energy *E*/1.8 is obtained by multiplying the differential flux by the energy and dividing by 0.62.

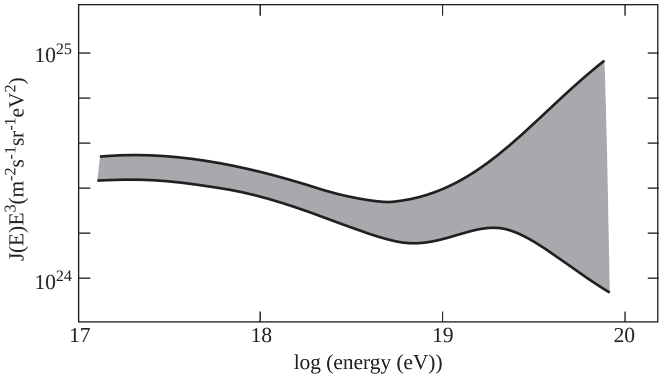

FIGURE 2. Energy spectrum at the highest energies. This spectrum (after Yoshida et al., 1995) has the differential spectrum multiplied by energy cubed. It is from a compilation of a number of measurements and indicates the good general agreement at the lower energies and a spread due to inadequate statistics at the highest energies.

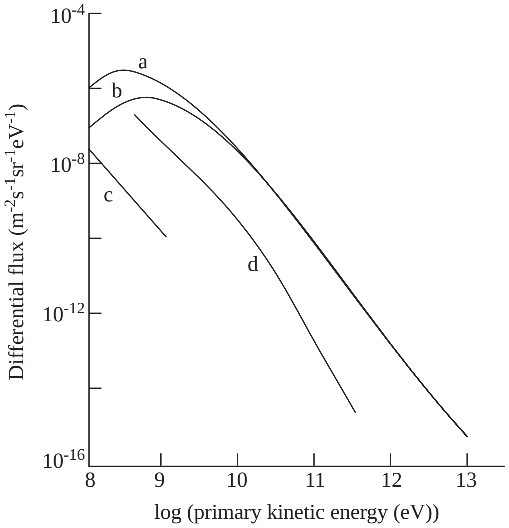

FIGURE 3. Energy spectrum of particles at lower energies. (a) Solar minimum proton energy spectrum. (b) Solar maximum proton energy spectrum. (c) Gamma-ray energy spectrum. (d) Local interstellar electron spectrum.

At higher energies, composition determinations are indirect and are rather contradictory and controversial. Experiments aim to differentiate between broad composition models. The measurement technique is based on studies of cosmic ray shower development. A rather direct technique for such studies is to use fluorescence observations of the shower development to determine the atmospheric depth of maximum development of the shower. Such observations suggest a heavy composition (large atomic number) at energies ~10^{17} eV which changes with increasing energy to a light composition (perhaps protonic) above ~10^{19} eV (T. K. Gaisser et al., 1993).

Primary Electrons

Primary electrons constitute about 1% of the cosmic ray beam. The positron to negative electron ratio is about 10% (J. M. Clem et al., 1995).

Antimatter in the Primary eam

The ratio of antiprotons to protons in the primary cosmic ray beam (at about 400 MeV) is about 10^{-5}. At about 10 GeV the ratio is about 10^{-3}. At the highest measured energies (10 TeV), the upper limit to the ratio is about 20% (S. Orito et al., 1995; M. Amenomori et al., 1995).

Primary Gamma-Rays

The flux of primary gamma-rays is low at high energies. At 1 GeV the ratio of gamma-rays to protons is about 10^{-6}. The arrival directions of these gamma-rays are strongly concentrated in the plane of the Milky Way although there is a diffuse, near isotropic background flux and some point sources have been detected.

Since the absorption cross section for gamma-rays above 100 MeV is approximately 20 mbarn/electron, less than 10% of gamma-rays reach mountain altitudes (A. W. Wolfendale, 1979; P. F. Michelson, 1994).

Sea Level Cosmic Radiation

The sea level cosmic ray dose is 300 millirad·yr^{-1} and the sea level ionization is 2.2×10^6 ion pairs m^{-3}s^{-1}. The sea level flux has a soft component, which can be absorbed in about 100 mm of lead (about 100 g·cm^{-2} of absorber) and a more penetrating (largely muon) hard component. The sea level radiation is largely produced in the atmosphere and is a secondary component from interactions of the primary particles. The steep primary energy spectrum means that most secondaries at sea level are from rather low energy primaries. Thus the secondary flux is dependent on the solar cycle and the geomagnetic latitude of the observer.

Absolute Flux of the Hard Component

Vertical Integral Intensity I(0) ~100 m^{-2}s^{-1}sr^{-1}
Angular dependence I(θ) ~ I(0) $\cos^2(\theta)$
Integrated Intensity ~200 m^{-2}s^{-1}
(O.C. Allkofer, 1975b).

Flux of the Soft Component

In free air, the soft component comprises about one third of the total cosmic ray flux.

Latitude Effect

The geomagnetic field influences the trajectories of lower energy cosmic rays approaching the Earth. As a result, the background flux is reduced by about 7% at the geomagnetic equator. The effect decreases towards the poles and is negligible at latitudes above about 40°.

Flux of Protons

The proton component is strongly attenuated by the atmosphere with an attenuation length (reduction by a factor of e) of about 120 g·cm^{-2}. It constitutes about 1% of the total vertical sea level flux.

Absorption

The soft component is absorbed in about 100 g·cm^{-2} of matter. The hard component is absorbed much more slowly:

Absorption in lead, 6% per 100 g·cm^{-2}
Absorption in rock, 8.5% per 100 g·cm^{-2}
Absorption in water, 10% per 100 g·cm^{-2}
(Absorption for depths less than 100 g·pd cm^{-2} is given by K. Greisen, 1943.)

Altitude Dependence

The cosmic ray background in the atmosphere has a maximum intensity of about 15 times that at sea level at a depth of about 150 g·cm^{-2} (15 km altitude). At maximum intensity, the soft and hard components contribute roughly equally but the hard component is then attenuated more slowly (S. Hayakawa, 1969).

Cosmic Ray Showers

High energy cosmic rays produce particle cascades in the atmosphere which can be detected at sea level provided that their energy exceeds about 100 GeV (such low energy cascades may be detected by using the most sensitive atmospheric Cerenkov detectors). The primary particle progressively loses energy which is transferred through the production of successive generations of secondary particles to a cascade of hadrons, an electromagnetic shower component (both positively and negatively charged electrons and gamma-rays) and muons. The secondary particles are relativistic and all travel effectively at the speed of light. As a result, they reach sea level at approximately the same time but, due to Coulomb scattering (for the electrons) and

production angles (for the pions producing the muons), are spread laterally into a disk-like shower front with a characteristic lateral width of several tens of meters and thickness (near the central shower core) of 2 to 3 m. The number of particles at sea level is roughly proportional to the primary particle energy:

Number of particles at sea level $\sim 10^{-10} \times$ energy (eV).

At altitudes below a few kilometers, the number of particles in a shower attenuates with an *attenuation length* of about 200 g·cm^{-2}.

i.e., particle number = original number × exp(–(depth increase)/200)

The above applies to an individual shower. The rate of observation of showers of a given size (particle number at the detector) at different depths of absorber attenuates with an *absorption length* of about 100 g·cm^{-2} (J.G. Wilson, 1976).

Atmospheric Background Light from Cosmic Rays

Cosmic ray particles produce Cerenkov light in the atmosphere and produce fluorescent light through the excitation of atmospheric molecules.

Cerenkov Light

High energy charged particles will cause the emission of Cerenkov light in air if their energies are above about 30 MeV (electrons). This threshold is pressure (and hence altitude) dependent. A typical Cerenkov light pulse (at sea level, 100 m from the central shower core) has a time spread of a few nanoseconds. Over this time, the photon flux between 430 and 530 nm would be $\sim 10^{14}$ m^{-2}s^{-1} for a primary particle energy of 10^{16} eV. For comparison, the night sky background flux is $\sim 6 \times 10^{11}$ photons m^{-2}s^{-1}sr^{-1} in the same wavelength band (J.V. Jelley, 1967).

Fluorescence Light

Cosmic ray particles in the atmosphere excite atmospheric molecules which then emit fluorescence light. This is weak compared to the highly collimated Cerenkov component when viewed in the direction of the incident cosmic ray particle but is emitted isotropically. Typical pulse widths are longer than 50 ns and may be up to several microseconds for the total pulse from distant large showers (R.M. Baltrusaitis et al., 1985).

Effects of Cosmic Rays

Cerenkov Effects in Transparent Media

Background cosmic ray particles will produce Cerenkov light in transparent material with a photon yield between wavelengths λ_1 and λ_2

$$\sim (2\pi/137)\sin^2(\theta_c)\int_{\lambda_1}^{\lambda_2} d\lambda/\lambda^2 \text{ photons (unit length)}^{-1}$$

where θ_c (the Cerenkov angle) = $\cos^{-1}$ (1/refractive index).

This background light is known to affect light detectors, e.g., photomultipliers, and can be a major source of background noise (R.W. Clay and A.G. Gregory, 1977).

Effects on Electronic Components

If background cosmic ray particles pass through electronic components, they may deposit sufficient energy to affect the state of, e.g., a transistor flip-flop. This effect may be significant where reliability is of great importance or the background flux is high. For instance, it has been estimated that, in communication satellite operation, an error rate of about 2×10^{-3} per transistor per year may be found. Permanent damage may also result. A significant error rate may be found even at sea level in large electronic memories. This error rate is dependent on the sensitivity of the component devices to the deposition of electrons in their sensitive volumes (J.F. Ziegler, 1981).

Biophysical Significance

When cosmic rays interact with living tissue, they produce radiation damage. The amount of the damage depends on the total dose of radiation. At sea level, this dose is small compared with doses from other sources but both the quantity and quality of the radiation change rapidly with altitude. Approximate dose rates under various conditions are:

Dose rates (mrem·yr^{-1})
Sea level cosmic rays, 30
Cosmic rays at 10 km (subsonic jets), 2000
Cosmic rays at 18 km (supersonic transports), 10,000
(c.f., mean total sea level dose, 300)

Astronauts would be subject to radiation from galactic (0.05 rads per day) and solar (a few hundred rads per solar flare) cosmic rays as well as large fluxes of low energy radiation when passing through the Van Allen belts (about 0.3 rads per traverse).

Both astronauts and SST travellers would be subject to a small flux of low energy heavy nuclei stopping in the body. Such particles are capable of destroying cell nuclei and could be particularly harmful in the early stages of the development of an embryo. The rates of heavy nuclei stopping in tissue in supersonic transports and spacecraft are approximately as follows:

Stopping nuclei ((cm^3 tissue)$^{-1}$ hr^{-1})
Supersonic transport (16 km), 0.0005
Supersonic transport (20 km), 0.005
Spacecraft, 0.15
(O. C. Allkofer, 1975a; O. C. Allkofer et al., 1974).

Carbon Dating

Radiocarbon is produced in the atmosphere due to the action of cosmic ray slow neutrons. Solar cycle modulation of the very low energy cosmic rays causes an anticorrelation of the atmospheric ^{14}C activity with sunspot number with a mean amplitude of about 0.5%. In the long term, modulation of cosmic rays by a varying magnetic field may be important (A.A. Burchuladze et al., 1979).

Practical Uses of Cosmic Rays

There are few direct practical uses of cosmic rays. Their attenuation in water and snow have, however, enabled automatic monitors of water and snow depth to be constructed. A search for hidden cavities in pyramids has been carried out using a muon “telescope”.

Other Effects

Stellar X-rays have been observed to affect the transmission times of radio signals between distant stations by altering the depth of the ionospheric reflecting layer. It has also been suggested that variations in ionization of the atmosphere due to solar modulation may have observable effects on climatic conditions.

REFERENCES

O.C. Allkofer, (1975a) *Introduction to Cosmic Radiation*, Verlag Karl Thiemig, Munchen, Germany.
O.O. Allkofer, (1975b) *J. Phys. G: Nucl. Phys.,* 1, L51.
O.C. Allkofer and W. Heinrich, (1974) *Health Phys.,* 27, 543.
M. Amenomori et al., (1995) Proc. 24th Int. Cosmic Ray Conf. Rome, 3, 85. Universita La Sapienza, Roma.
K. Asakimori et al., (1993) Proc. 23rd Int. Cosmic Ray Conf. Calgary, 2, 25, University of Calgary, Canada.
R.M. Baltrusaitis et al., (1985) *Nucl. Inst. Meth.,* A420, 410.
D.J. Bird et al., (1993) *Phys. Rev. Lett.,* 71, 3401.
A.A. Burchuladze, S.V. Pagava, P. Povinec, G. I. Togonidze, S. Usacev, (1979) Proc. 16th Int. Cosmic Ray Conf. Kyoto, 3, 201, Univ. of Tokyo, Japan.
R.W. Clay, (1987) *Aust. J. Phys.,* 40, 423.
R.W. Clay and A.G. Gregory, (1977) *J. Phys. A: Math. Gen.,* 10, 135.
J.M. Clem et al., (1995) Proc. 24th Int. Cosmic Ray Conf. Rome, 3, 5, Universita La Sapienza, Roma.
T.K. Gaisser et al., (1993) *Phys. Rev. D,* 47, 1919.
K. Greisen, (1943) *Phys. Rev.,* 63, 323.
S. Hayakawa, (1969) *Cosmic Ray Physics,* Wiley-Interscience, New York.
J.V. Jelley, (1967) *Prog. in Elementary Particle and Cosmic Ray Physics,* 9, 41.
E. Juliusson, (1975) Proc. 14th Int. Cosmic Ray Conf. Munich, 8, 2689, Max Planck Institute fur Extraterrestriche Physik, Munchen, Germany.
J. Linsley, (1981) *Origin of Cosmic Rays,* I.A.U. Symposium 94, 53, D. Reidel Publishing Co Dordrecht, Holland.
P. Meyer, (1981) *Origin of Cosmic Rays,* I.A.U. Symposium 94, 7, D. Reidel Publishing Co. Dordrecht, Holland.
P.F. Michelson (1994) in *Towards a Major Atmospheric Cerenkov Detector III*, 257, Ed. T. Kifune, Universal Academy Press Inc., Tokyo, Japan.
P. Sokolsky, (1989) *Introduction to Ultrahigh Energy Cosmic Ray Physics,* Addison Wesley Publishing Company.
T. Stanev et al., (1995) *Phys. Rev. Lett.,* 75, 3056.
S. Orito et al., (1995) Proc. 24th Int. Cosmic Ray Conf. Rome, 3, 76. Universita La Sapienza, Roma.
J.G. Wilson, (1976) *Cosmic Rays,* Wykeham Pub. (London) Lt., U.K.
A.W. Wolfendale, (1979) *Pramana,* 12, 631.
S.Yoshida et al., (1995) *Astroparticle Phys.,* 3, 105.
J.F. Ziegler, (1981) IEEE Trans. Electron Devices, ED-28, 560.

TECHNIQUES FOR MATERIALS CHARACTERIZATION

EXPERIMENTAL TECHNIQUES USED TO DETERMINE THE COMPOSITION, STRUCTURE, AND ENERGY STATES OF SOLIDS AND LIQUIDS

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The many experimental methods, originally designed to study the chemical and physical behavior of solids and liquids, have grown into a new field known as Materials Characterization (or Materials Analysis). During the past 30 years a host of techniques aimed at the study of surfaces and thin films has been added to the many tools for the analysis of bulk samples. The field has benefitted particularly from the development of computers and microprocessors, which have vastly increased the speed and accuracy of the measuring devices and the recording of their output. Materials characterization was and is a very important tool in the search for new physical and chemical phenomena. It plays an essential role in new applications of solids and liquids in industry, communications, and medicine. Many of its techniques are used in quality control, in safety regulations, and in the fight against pollution.

In most Materials Characterization experiments the sample is subjected to some kind of radiation: electromagnetic, acoustic, thermal, or particles (electrons, ions, neutrons, etc.). The surface analysis techniques usually require a high vacuum. As a result of interactions between the solid (or liquid) and the incoming radiation a beam of a similar (or a different) nature will emerge from the sample. Measurement of the physical and/or chemical attributes of this emerging radiation will yield qualitative, and often quantitative, information about the composition and the properties of the material being probed.

The modern tendency of describing practically everything in this world by a combination of a few letters (acronyms) has also penetrated the field of Materials Characterization. The table below gives the meaning of the acronym for every technique listed, the form and size of the required sample (bulk, surface, film, liquid, powder, etc.), the nature of the incoming and of the emerging radiation, the depth and the lateral spatial resolution that can be probed, and the information obtained from the experiment. The last column lists one or two major references to the technique described.

Technique	Sample	In	Out	Depth	Lateral resolution	Information obtained	Ref.
			OPTICAL AND MASS SPECTROSCOPIES FOR CHEMICAL ANALYSIS				
1. AAS Atomic Absorption Spectroscopy	Atomize (flame, electro, thermal, etc.)	Light e.g., glow discharge	Absorption spectrum	—	—	Concentration of atomic species (quantitative, using standards)	1,2
2. ICP-AES Induct. Coupled Plasma — Atomic Emission Spectroscopy	Atomize (flame, electro, thermal, ICP, etc.)	—	Emission spectrum	—	—	Concentration of atomic species (quantitative, using standards)	3
3. Dynamic SIMS Dynamic Secondary Ion Mass Spectroscopy	Surface	Ion beam (1–20 keV)	Secondary ions; analysis with mass spectrometer	2 nm–1 µm (or deeper: ion milling)	0.50 nm	Elemental and isotopic analysis; depth profile (all elements); detection limits: ppb-ppm	4
4. Static SIMS Static Secondary Ion Mass Spectroscopy	Surface	Ion beam (0.5–20 keV)	Secondary ions, analysis with mass spectrometer	0.1–0.5 nm	10 µm	Elemental analysis of surface layers; molecular analysis; detection limits: ppb-ppm	4
5. SNMS Sputtered Neutral Mass Spectroscopy	Surface, bulk	Plasma discharge; noble gases: 0.5–20 keV	Sputtered atoms ionized by atoms or electrons; then mass analyzed	0.1–0.5 nm (or deeper: ion milling)	1 cm	Elemental analysis $Z \geq 3$; depth profile; detection limit: ppm	4,6
6. SALI Surface Analysis by Laser Ionization	Surface	e-beam, ion-beam, or laser for sputtering	Sputtered atoms ionized by laser; then mass analyzed	0.1–0.5 nm up to 3 µm in milling mode	60 nm	Surface analysis; depth profiling	7
7. LIMS Laser Ionization Mass Spectroscopy	Surface, bulk	u.v. laser (ns pulses)	Ionized species; analyzed with mass spectrometer	50–150 nm	5 µm–1 mm	Elemental (micro)analysis; detection limits: 1–100 ppm	8
8. SSMS Spark Source Mass Spectroscopy	Sample in the form of two electrodes	High voltage R.F. spark produces ions	Ions — analyzed in mass spectrometer	1–5 µm	—	Survey of trace elements; detection limit: 0.01–0.05 ppm	9
9. GDMS Glow Discharge Mass Spectroscopy	Sample forms the cathode for a D.C. glow discharge	Sputtered atoms ionized in plasma	Ions — analyzed in mass spectrometer	0.1–100 µm	3–4 mm	(Bulk) trace element analysis; detection limit: sub-ppb	9,10
10. ICPMS Induct. Coupled Plasma Mass Spectroscopy	Liquid-dissolved sample carried by gas stream into R.F. induction coil	Ions produced in argon plasma	Ions — analyzed in quadrupole mass spectrometer	—	—	High sensitivity analysis of trace elements	11

TECHNIQUES FOR MATERIALS CHARACTERIZATION (continued)

	Technique	Sample	In	Out	Depth	Lateral resolution	Information obtained	Ref.
	PHOTONS — ABSORPTION, REFLECTION AND ELECTRON EMISSION							
11.	IRS Infrared Spectroscopy	Thin crystal, glass, liquid	I.R. light (W-filament, globar, Hg-arc)	I.R. spectrum	—	—	Electronic transitions (mainly in semiconductors and superconductors); vibrational modes (in crystals and molecules)	12,13, 14
12.	FTIR Fourier Transform I.R. Spectroscopy	Solid, liquid; transmission or reflection	White light (all frequencies)	Fourier Transform of spectrum (interferometer)	—	—	Spectra obtained at higher speed and resolution	15
13.	ATR Attenuated Total Reflection	Surface or thin crystal	—	—	μm's	—	Atomic or molecular spectra of surfaces and films	16
14.	(μ)-RS (Micro-) Raman Spectroscopy	Solid, liquid (1 μm–1 cm)	Laser beam, e.g., Ar-line, YAG-line	Raman spectra	0.5 μm	0.5 μm	Molecular and crystal vibrations	12,14, 17
15.	CARS Coherent Anti-Stokes Raman Spectroscopy	Solid, liquid (50 μm–3 cm)	Pump beam (ω_0)+ probe beam (ω_s)	Anti-Stokes spectrum	—	—	High resolution Raman spectra	14
16.	Ellipsometry	Transparent films, crystals, adsorbed layers	Polarized light	Change in polarization	0.05 nm–5 μm	25 μm (or sample thickness)	Refractive index *and* absorption	18,19
17.	UPS Ultraviolet Photo-electron Spectroscopy	Surfaces, adsorbed layers	u.v. light, 10–100 eV; 200 eV (synchrotron)	Electrons	0.2–10 nm	0.1–10 nm	Energies of electronic states of surfaces and free molecules	20,21
18.	PSD Photon Stimulated Desorption	Surfaces with adsorbed species	Far u.v. light $E > 10$ eV	Ions — analyzed with mass spectrometer	0.1–2 nm	—	Structure and desorption kinetics of adsorbed atoms and molecules	22
	X-RAYS							
19.	XRD X-Ray Diffraction	Single crystals, powders films	X-rays: $\lambda = 0.05$–0.2 nm (6–17 keV)	Diffracted X-ray beam	1–1000 μm	0.1–10 mm	Identification of crystallographic structures; all elements (low Z difficult)	23,24
20.	XRF/EDS X-Ray Fluorescence/Energy Dispersive Spectroscopy	Thin films, single layer	Prim. X-ray beam $\lambda = 0.02$–0.1 nm 12–80 keV	Fluorescent X-rays	1–100 μm	10 mm	Elemental analysis; all elements except H, He, Li — (EDS also used in XRD, SEM, TEM and EPMA)	25,26
21.	EXAFS Extended X-Ray Absorption Fine Structure	Films, foils	High intensity X-rays (synchrotron)	Spectrum near absorption edge	nm–μm	—	Local atomic structure: order/disorder in vicinity of absorbing atom	27
22.	XPS/ESCA X-Ray Photo-electron Spectroscopy/Electron Spect. for Chemical Analysis	Surfaces, thin films (≈20 atomic layers)	Soft X-rays (1–20 keV)	Core electrons; valence electrons	0.5–10 nm	5 nm–50 μm	(Quantitative) identification of all elements in surface layer or film	28,29
	ELECTRONS							
23.	CL Cathode Luminescence	Insulators, semiconductors	Electrons 5–50 keV	Photons 0.1–5 eV	1 nm–2 μn	1 or 2 μm	Energy levels of impurities and point defects	30
24.	APS Appearance Potential Spectroscopy	Surface (≈20 atomic layers)	Electrons (energy scan) 50–2000 eV	X-rays to pinpoint electron energy threshold	—	—	Identification of surface species	21, see also C

TECHNIQUES FOR MATERIALS CHARACTERIZATION (continued)

Technique	Sample	In	Out	Depth	Lateral resolution	Information obtained	Ref.
25. AES Auger Electron Spectroscopy	Thin films, surfaces	Electrons 3–10 keV	Auger electrons 20–2000 eV	0.3–3 nm	≈30 nm	Elemental composition of surface (except H, He); detection limit 0.1–1%	28,29
26. EELS Electron Energy Loss Spectroscopy	Very thin samples (<200 nm)	Electrons (100–400 keV)	(Retarded) electrons; minus 1–1000 eV	<200 nm	1–100 nm	Local elemental concentration; electronic structure, chem. bonding; interatomic distances	31
27. EXELFS Extended Electron Energy Loss Fine Structure	Thin films	Electrons (100–400 keV)	Electrons energies 0–30 eV above edge	<200 nm	1–100 nm	Density of states of valence electrons (above Fermi level)	27,32
28. ESD Electron Stimulated Desorption	Adsorbed species	Electrons $E > 10$ eV	Ions — analyzed with mass spectrometer	—	—	Structure and desorption properties of adsorbed atoms and molecules	22
29. ESDIAD ESD-Ion Angular Distribution	(See ESD)	(See ESD)	Directional dependence of emitted ions	—	—	Geometries of adsorbed species (atoms or molecules)	22
30. EPMA Electron Probe (X-Ray) Micro Analysis	Solid conductors and insulators <1 cm thick	Electrons 5–30 keV	Characteristic X-ray 0.1–15 keV	100 nm–5 µm	1 µm	Elemental analysis, $Z \leq 4$, major, minor and trace amounts	33,34
31. LEED Low Energy Electron Diffraction	Surface	Mono-energetic electron beam 10–1000 eV	Diffracted electrons	0.4–2 nm	<5 µm	Crystallographic structure of surface; resolution: 0.01 nm	35
32. RHEED Reflection High Energy Electron Diffraction	Surface	Electron beam at grazing angle 5–50 keV	Reflected electrons	0.2–10 nm	<5 µm	Surface symmetry	36,37
33. SEM Scanning Electron Microscopy	Bulk, films (conducting)	High energy electrons usually ~30 keV	Secondary and backscattered electrons	1 nm–5 µm	1–20 nm	Surface image, defect structure; resolution 5–15 nm; magnification 300,000×	33,34
34. (S)TEM (Scanning) Transmission Electron Microscopy	Thin specimen — <200 nm	High energy electrons typically 300 keV	Transmitted and diffracted electrons	(Sample thickness)	2–20 nm	(Defect) structure of cryst. solids; microchemistry; high resol.: 0.2 nm	33
35. FEM Field Emission Microscopy	Metals, alloys (sharp point)	—	Electron emission (with appl. electric field — 50 kV)	≈0.5 nm	10–100 nm	Surface image, crystallographic structure	34
36. STM Scanning Tunneling Microscopy	Polished or cleaved surface (conducting)	Tunneling current controls distance between sample and very sharp tip		1–5 nm	2–10 nm	Atomic-scale relief map of surface; resolution: vert. 0.002 nm, hor. 0.2 nm	39
37. SPM Scanned Probe Microscopy	Very flat surface	Any field: e.g. mechan. vibration recorded with laser probe; same with magnetic, electric or thermal field		1–100 nm	1–100 nm	Surface-magnetic field, surface-thermal conductivity, etc.	39a
38. AFM Atomic Force Microscopy	Very flat surface	Similar to STM; force measured with cantilever spring		0.5–5 nm	0.2–130 nm	Surface topography with atomic resolution; interatomic force	40
IONS AND NEUTRONS							
39. ISS (or LEIS) Ion Scattering Spectroscopy (Low Energy Ion Scattering)	Surface	Ion beam He^+ or Ne^+ <3 keV	Sputtered ions (energy analysis)	0.1–0.5 nm	1–100 µm	Elemental analysis (better for low Z) detection limits: 0.01–1%	41
40. FIM Field Ion Microscopy	Surface: metals, alloys; very sharp tip	(He gas above sample)	He ions + high electric field produce image	≈0.1 nm	0.1–2 nm	Atomic structure of surface	34,42
41. RBS Rutherford Back Scattering	Solids, thin films	Mono-energetic ions (H^+ or He^{++}) 0.5–3 MeV	Backscattered ions	10 nm–1 µm	1 mm	Element identification (Li to U) detection limit: 0.01–1%	46

TECHNIQUES FOR MATERIALS CHARACTERIZATION (continued)

Technique	Sample	In	Out	Depth	Lateral resolution	Information obtained	Ref.
42. NRA Nuclear Reaction Analysis	Solids, thin films	Mono-energetic ions (Li, Be, B, etc.) 200 keV–6 MeV	Protons, deuterons ^{3}He, α-particles, γ-rays	0.1–5 μm	10 μm–10 mm	Element identification (all) detection limit: 10^{-12}–10^{-2}	47
43. PIXE Particle Induced X-ray Emission	Thin films, surface layers	High energy ions (H^+ or He^{++})	Characteristic X-rays	<10 μm	1 μm–2 mm	Trace impurities: $Z > 3$ detection limit: 0.1–100 ppm (depending on sample thickness)	48
44. INS Ion Neutralization Spectroscopy	Surface	He-ions (≈5 eV)	Electrons	—	—	Energies of valence electrons	49
45. NAA Neutron Activation Analysis	Bulk, >0.5 g	Thermal neutrons	Characteristic γ-rays, (≈1 MeV)	Bulk	—	Trace concentrations (of isotopes) of elements: trans. metals, Pt-group; detection limit: 10^8–10^{14} atoms/cm^3	43
46. N(P)D Neutron (Powder) Diffraction	Crystalline solids	Thermal neutrons E ≈0.0025 eV	Diffracted neutrons	Bulk	—	Crystallographic structure; porosity, particle size	44
47. SANS Small Angle Neutron Scattering	Inhomogeneous solids; powders; porous samples	Thermal neutrons $2\theta = 10^{-2}$–10^{-4}	Scattered neutrons	1–25 mm	—	Average size of inhomogeneities; range: 1 nm–1 mm	45
			ACOUSTIC				
48. SLAM Scanning Laser Acoustic Microscopy	Bulk, film	Acoustic wave produced by laser 1 MHz–1 GHz	Reflected acoustic wave	μm–cm	0.1–20 mm	Defect structure; thickness measurement	50
			THERMAL				
49. DTA Differential Thermal Analysis	Specimen and reference sample	Uniform heating	Temperature difference	Bulk	—	Phase transitions, crystallization	51
50. DSC Differential Scanning Calorimetry	Specimen and ref. sample	Controlled heating	Measure heat required for equal temperature	Bulk	—	Phase transitions, crystallization; activation energies	51
51. TGA Thermo Gravimetric Analysis	Bulk, 1–100 g	Controlled heating	Weight as function of temperature (and time)	Bulk	—	Decomposition, non-stoichiometry, kinetics of reaction	52
			RESONANCE				
52. EPR (ESR) Electron Paramagnetic (Spin) Resonance	Paramagnetic solids or liquids	Microwave radiation in magnetic field 3–300 GHz; 1–100 kG	Microwave absorption (at resonance)	Bulk	—	Local environment of paramagnetic ion; concentration of paramagnetic, species; detection limit: 10^{11} spins/cm^3	53,54
53. ECR Electron Cyclotron Resonance	Semiconductors, metals; free electrons (low temperature)	Microwave radiation in magnetic field 10–30 GHz; 5–10 kG	Microwave absorption (at resonance)	Bulk	—	Electronic energy bands, effective masses	55
54. Mössbauer Effect	Source and absorber	Mono-energetic γ-rays: 5–100 keV	Mössbauer spectrum (Doppler shifted (lines)	50 m	1 cm	Interaction between nucleus and its environment (local electric, magnetic fields; bonds; valency; diffusion, etc.)	56
55. NMR (MRI) Nuclear Magnetic Resonance (Magnetic Resonance Imaging)	Solids, liquids	R.F. radiation + magnetic field; e.g. for protons: 60 MHz, 14 kG	R.F. absorption	<1 cm	1 cm	Quant. analysis; local magnetic environment; diffusion; imaging	58
56. ENDOR Electron Nuclear Double Resonance	Solids, liquids	R.F. + microwave radiation in magn. field.	Microwave absorption	—	—	Hyperfine interaction → local atomic structure	54

TECHNIQUES FOR MATERIALS CHARACTERIZATION (continued)

Technique	Sample	In	Out	Depth	Lateral resolution	Information obtained	Ref.
57. NQR Nuclear Quadrupole Resonance	Solids	R.F. radiation 0.5–1000 MHz	R.F. absorption	—	—	Asymmetry of the charge distribution at the nucleus	55,59
			OTHER				
58. BET Brunauer-Emmett-Teller	(Large) surface area 1–20 m^2/g	Adsorbed gas (e.g., N_2 at low temp.) as function of pressure (monolayer coverage)		—	—	Surface area measurement	60

REFERENCES

General References

A. Wachtman, J. B., *Characterization of Materials*, Butterworth-Heinemann, Boston, 1993.
B. Brundle, C. R., Evans, C. A., and Wilson, S., Eds., *Encyclopedia of Materials*, Butterworth-Heinemann, Boston, 1992.
C. Woodruff, D. P. and Delchar, T. A., *Modern Techniques of Surface Science*, Cambridge University Press, Cambridge, 1986.
D. *Metals Handbook,* 9th Edition, Vol. 10, Materials Characterization, Whan, R. E., Coordinator, American Society for Metals, Metals Park, OH, 1986.

Specific References

1. Slavin, M., *Atomic Absorption Spectroscopy*, 2nd Edition, John Wiley & Sons, New York, 1978.
2. Schrenk, W. G., *Analytical Atomic Spectroscopy*, Plenum Press, New York, 1975.
3. Dean, J. A. and Rains, T. E., *Flame Emission and Atomic Absorption Spectroscopy*, Vols. 1—3, Marcel Dekker, New York, 1969.
4. Benninghoven, A., Rudenauer, F. G., and Werner, H. W., *Secondary Ion Mass Spectroscopy*, John Wiley & Sons, New York, 1987.
5. Bird, J. R. and Williams, J. S., Eds., in *Ion Beams for Materials Analysis*, Academic Press, New York, 1989, pp. 515—537.
6. Smith, G. C., *Quantitative Surface Analysis for Materials Science*, The Institute of Metals, London, 1991.
7. Becker, E. H., in *Ion Spectroscopies for Surface Analysis*, Czanderna, A. W. and Hercules, D. M., Eds., Plenum Press, New York, 1991, p. 273.
8. Simons, D. S., *Int. J. Mass Spectrometry and Ion Processes*, 55, 15, 1983.
9. White, F. A. and Wood, G. M., *Mass Spectrometry: Applications in Science and Engineering*, John Wiley & Sons, New York, 1986.
10. Harrison, W. W. and Bentz, B. L., *Prog. Anal. Spectrometry*, 11, 53, 1988.
11. Bowmans, P. W. J. M., *Inductively Coupled Plasma Emission Spectroscopy*, Parts I and II, John Wiley & Sons, New York, 1987.
12. Brame, Jr., E. G. and Grasselli, J., *Infrared and Raman Spectroscopy*, Practical Spectroscopy Series, Vol. I, Marcel Dekker, New York, 1976.
13. Hollas, J. M., *Modern Spectroscopy*, John Wiley & Sons, New York, 1987.
14. Turrell, G., *Infrared and Raman Spectroscopy of Crystals*, Academic Press, New York and London, 1972.
15. Griffith, P. R. and Haseth, J. A., *Fourier Transform Infrared Spectroscopy*, John Wiley & Sons, New York, 1986.
16. Barnowski, M. K., *Fundamentals of Optical Fiber Communications*, Academic Press, New York, 1976.
17. Long, D. A., *Raman Spectroscopy*, McGraw-Hill, New York, 1977.
18. Azzam, R. M. A., *Ellipsometry and Polarized Light*, Elsevier-North Holland, Amsterdam, 1977.
19. Hecht, E., *Optics*, 2nd Edition, Addison-Wesley, Reading MA, 1987.
20. Brundle, C. R., in *Molecular Spectroscopy*, West, A. R., Ed., Heyden, London, 1976.
21. Park, R. L., in *Experimental Methods in Catalytic Research*, Vol. III, Anderson, R. B. and Dawson, P. T., Academic Press, New York, 1976, pp. 1—39.
22. Madey, T. E. and Stockbauer, R., in *Solid State Physics: Surfaces*, Vol. 22 of Methods of Experimental Physics, Park, R.L. and Lagally, M. G., Eds., Academic Press, New York, 1985.
23. Cullity, B. D., *Elements of X-Ray Diffraction*, 2nd Edition, Addison-Wesley, Reading, MA, 1978.
24. Schwartz, L. H. and Cohen, J. B., *Diffraction from Materials*, Springer Verlag, Berlin, 1987.

TECHNIQUES FOR MATERIALS CHARACTERIZATION (continued)

25. deBoer, D. K. G., in *Advances in X-Ray Analysis*, Vol. 34, Barrett, C. S. et. al., Eds., Plenum Press, New York, 1991.
26. Birks, L. S., *X-Ray Spectrochemical Analysis*, 2nd Edition, John Wiley & Sons, New York, 1969.
27. Bonnelle, C. and Mande, C., *Advances in X-Ray Spectroscopy*, Pergamon Press, Oxford, 1982.
28. *Practical Surface Analysis by Auger and X-Ray Photo-Electric Spectroscopy*, Briggs, D. and Seah, M. P., Eds., John Wiley & Sons, New York, 1983.
29. Powell, C. J. and Seah, M. P., *J. Vac. Sci. Technol. A*, Vol. 8, 735, 1990.
30. Yacobi, G. G. and Holt, D. B., *Cathodeluminescence Microscopy of Inorganic Solids*, Plenum Press, New York, 1990.
31. Egerton, R. F., *Electron Energy Loss Spectroscopy in the Electron Microscope*, Plenum Press, New York, 1986.
32. Disko, M. M., Krivanek, O. L., and Rez, P., *Phys. Rev.*, B25, 4252, 1982.
33. Goldstein, J. I., et. al., *Scanning Electron Microscopy and X-Ray Microanalysis*, 2nd Edition, Plenum Press, New York, 1986.
34. Murr, L. E., *Electron and Ion Microscopy and Microanalysis*, Marcel Dekker, New York, 1982.
35. Armstrong, R. A., in *Experimental Methods in Catalytic Research*, Vol. III, Anderson, R. B., and Dawson, P. T.,Eds., Academic Press, New York, 1976.
36. Dobson, P. J. et. al., *Vacuum*, 33, 593, 1983.
37. Rymer, T. B., *Electron Diffraction*, Methuen, London, 1970.
38. Reimer, L., *Transmission Election Microscopy*, Springer-Verlag, Berlin, 1984.
39. *Scanning Tunneling Microscopy and Related Methods*, Behm, R. J., Garcia, N., and Rohrer, H., Kluwer, Eds., Academic Publishers, Norwell, MA, 1990.

39a. Wikramasinghe, H.K., *Scientific American*, Vol. 261, No. 4, pp. 98—105, Oct. 1989.

40. Rugar, D. and Hansma, P., *Physics Today*, 43(10), pp. 23—30, 1990.
41. Feldman, C. C. and Mayer, J. W., *Fundamentals of Surface and Thin Film Analysis*, North-Holland, Amsterdam, 1986.
42. Muller, E. W. and Tsong, T. T., *Field Ion Microscopy*, Elsevier, Amsterdam, 1969.
43. Amiel, S., *Nondestructive Activation Analysis*, Elsevier, Amsterdam, 1981.
44. Bacon, G. E., *Neutron Diffraction*, 3rd Edition, Clarendon Press, Oxford, 1975.
45. Neutron Scattering, Part A., in *Methods of Experimental Physics*, Vol. 23, Skold, K. and Price, D. L., Eds., Academic Press, New York, 1986.
46. Chu, W. K., Mayer, J. W., and Nicolet, M. A., *Backscattering Spectroscopy*, Academic Press, New York, 1987.
47. Rickey, F. A., in *High Energy and Heavy Ion Beams in Materials Analysis*, Tesmer, J. R., et. al., Eds., MRS, 1990, pp. 3—26.
48. Johansson, S. A. E. and Campbell, J. L., *PIXE: A Novel Technique for Elemental Analysis*, John Wiley & Sons, New York, 1988.
49. Hagstrum, H. D., in *Inelastic Ion-Surface Collisions*, Tolk, N. H. et. al., Eds., Academic Press, New York, 1977, pp. 1—46.
50. Nikoonahad, M., in *Research Techniques in Nondestructive Testing*, Vol. VI, Sharpe, R.S., Ed., Academic Press, New York, 1984, pp. 217—257.
51. Gallagher, P. K., *Characterization of Materials by Thermoanalytical Techniques*, MRS - Bulletin, Vol. 13, No. 7, pp. 23—27, 1988.
52. Earnest, C. M., *Compositional Analysis by Thermogravimetry*, ASTM Special Technical Publication 997, 1988.
53. Poole, C. P., *Electron Spin Resonance — A Comprehensive Treatise on Experimental Techniques*, 2nd Edition, John Wiley & Sons, New York, 1983.
54. Atherton, N. M., *Principles of Electron Spin Resonance*, Ellis Horwood Ltd., Chichester, U.K., 1993.
55. Kittel, C., *Introduction to Solid State Physics*, 6th Edition, John Wiley & Sons, New York, 1986, p. 196.
56. Gibb, T. C., *Principles of Mössbauer Spectroscopy*, Chapman & Hall, London, 1976.
57. Slichter, C. P., *Principles of Magnetic Resonance*, 3rd Edition, Springer-Verlag, Berlin, 1990.
58. *NMR Spectroscopy Techniques*, Dybrowski, C. and Lichter, R. L., Eds., Marcel Dekker, New York, 1987.
59. Das, T. P. and Hahn, E. L., *Nuclear Quadrupole Resonance Spectroscopy*, Academic Press, New York, 1958.
60. Somorjai, G. A., *Principles of Surface Chemistry*, Prentice-Hall, Englewood Cliffs, NJ, 1972, p. 216.

SYMMETRY OF CRYSTALS

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The ability of a body to coincide with itself in its different positions regarding a coordinate system is called its symmetry. This property reveals itself in iteration of the parts of the body in space. The iteration may be done by reflection in mirror planes, rotation about certain axes, inversions and translations. These actions are called the symmetry operations. The planes, axes, points, etc., are known as symmetry elements. Essentially, mirror reflection is the only truly primitive symmetry operation. All other operations may be done by a sequence of reflections in certain mirror planes. Hence, the mirror plane is the only true basic symmetry element. But for clarity, it is convenient to use the other symmetry operations, and accordingly, the other aforementioned symmetry elements. The symmetry elements and operations are presented in Table 1.

The entire set of symmetry elements of a body is called its symmetry class. There are thirty-two symmetry classes that describe all crystals which have ever been noted in mineralogy or been synthesized (more than 150,000). The denominations and symbols of the symmetry classes are presented in Table 2.

There are several known approaches to classification of individual crystals in accordance with their symmetry and crystallochemistry. The particles which form a crystal are distributed in certain points in space. These points are separated by certain distances (translations) equal to each other in any chosen direction in the crystal. Crystal lattice is a diagram that describes the location of particles (individual or groups) in a crystal. The lattice parameters are three non-coplanar translations that form the crystal lattice. Three basic translations form the unit cell of a crystal. August Bravais (1848) has shown that all possible crystal lattice structures belong to one or another of fourteen lattice types (Bravais lattices). The Bravais lattices, both primitive and non-primitive, are the contents of Table 3.

Among the three-dimensional figures, there is a group of polyhedrons that are called regular, which have all faces of the same shape and all edges of the same size (regular polygons). It has been shown that there are only five regular polyhedrons. Because of their importance in crystallography and solid state physics, a brief description of these polyhedrons is included in Table 4.

The systematic description of crystal structures is presented primarily in the well known *Structurbericht*. The classification of crystals by the Structurbericht does not reflect their crystal class, the Bravais lattice, but is based on the crystallochemical type. This makes it inconvenient to use the Structurbericht categories for comparison of some individual crystals. Thus, there have been several attempts to provide a more convenient classification of crystals. Table 5 presents a compilation of different classifications which allows the reader to correlate the Structurbericht type with the international and Schoenflies point and space groups and with Pearson's symbols, based on the Bravais lattice and chemical composition of the class prototype. The information included in Table 5 has been chosen as an introduction to a more detailed crystallophysical and crystallochemical description of solids.

TABLE 1
Symmetry Operations and Elements

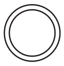
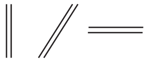
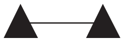
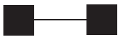
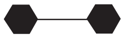
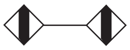
	Symmetry element			Presentation on the stereographic projection	
		Symbol			
Symmetry operation	**Name**	**International (Hermann-Mauguin)**	**Schoenflies**	**Parallel**	**Perpendicular**
Reflection in a plane	Plane	m	C_s		
Rotation by angle $\alpha = 360°/n$ about an axis	Axis	n = 1, 2, 3, 4 or 6	C_n		
		n = 2	C_2		
		n = 3	C_3		
		n = 4	C_4		
		n = 6	C_6		
Rotation about an axis and inversion in a symmetry center lying on the axis	Inversion (improper) axis	$\bar{n} = \bar{3}, \bar{4}, \bar{6}$	C_{ni}		
		$\bar{n} = \bar{3}$	C_{3i}		
		$\bar{n} = \bar{4}$	C_{4i}		

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TABLE 1
Symmetry Operations and Elements (continued)

Symmetry operation	Symmetry element: Name	Symbol: International (Hermann-Mauguin)	Symbol: Schoenflies	Presentation on the stereographic projection: Parallel	Perpendicular
		$\bar{n} = \bar{6}$	C_{6i}		
Inversion in a point	Center	$\bar{1}$	C_i	● ○	×
Parallel translation	Translation vector $\vec{a}, \vec{b}, \vec{c}$				
Reflection in a plane and translation parallel to the plane	Glide–plane	a, b, c, n, d			
Rotation about an axis and translation parallel to the axis	Screw axis	n_m (m = 1, 2, .., n – 1)			
Rotation about an axis and reflection in a plane perpendicular to the axis	Rotatory-reflection axis	$\tilde{n}$ $\tilde{n} = \tilde{1}, \tilde{2}, \tilde{3}, \tilde{4}, \tilde{6}$	S_n		

TABLE 2
The Thirty-Two Symmetry Classes

Crystal symbol	Primitive Int	Primitive Sch	Central Int	Central Sch	Planal Int	Planal Sch	Axial Int	Axial Sch	Plane-axial Int	Plane-axial Sch	Inversion primitive Int	Inversion primitive Sch	Inversion-planal Int	Inversion-planal Sch
Triclinic	1	C_1	$\bar{1}$	C_i										
Monoclinic					m	C_s	2	C_2	2/m	C_{2h}				
Orthorhombic					mm2	C_{2v}	222	D_2	mmm	D_{2h}				
Trigonal	3	C_3	$\bar{3}$	C_{3i}	3m	C_{3v}	32	D_3	$\bar{3}$m	C_{3d}				
Tetragonal	4	C_4	4/m	C_{4h}	4mm	C_{4v}	422	D_4	4/mmm	D_{4h}	$\bar{4}$	S_4	$\bar{4}2m$	D_{2d}
Hexagonal	6	C_6	6/m	C_{6h}	6mm	C_{6v}	622	D_6	6/mmm	D_{6h}	$\bar{6}$	C_{3h}	$\bar{6}m2$	D_{3h}
Cubic	23	T	m3	T_h	$\bar{4}3m$	T_d	432	O	m3m	O_h				

Class name[a] and its symbol — International (Int) and Schoenflies (Sch)

[a] Per Fedorov Institute of Crystallography, USSR Academy of Sciences, nomenclature.

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TABLE 3
The Fourteen Possible Space Lattices (Bravais Lattices)

Crystal system	Metric category of the system	No. of different lattices in the system	Lattice type[a] (marked by +)					No. of identi-points per unit cell	Characteristic parameters (marked by +)						Description of characteristic parameters $a \subset X, b \subset Y, c \subset Z$ $\alpha \equiv (b,c), \beta \equiv (a,c), \gamma \equiv (a,b)$	Symmetry of the lattice	
			P	C	I	F	R		a	b	c	α	β	γ		Int	Sch
Triclinic	Trimetric	1	+					1	+	+	+	+	+	+	$a \neq b \neq c, \alpha \neq \beta \neq \gamma$	1	C
Monoclinic	Trimetric	2	+	+				1 or 2	+	+	+		+		$a \neq b \neq c, \alpha = \gamma = 90° \neq \beta$	2/m	C_{2h}
Orthorhombic	Trimetric	4	+	+	+	+		1, 2 or 4	+	+	+				$a \neq b \neq c, \alpha = \beta = \gamma = 90°$	mmm	D_{2h}
Trigonal (rhombohedral)	Dimetric	1					+	1	+			+			$a = b = c, 120° > \alpha = \beta = \gamma \neq 90°$	3m	D_{3d}
Tetragonal	Dimetric	2	+		+			1 or 2	+		+				$a = b \neq c, \alpha = \beta = \gamma = 90°$	4/mmm	D_{4h}
Hexagonal	Dimetric	1	+					1	+		+				$a = b \neq c, \alpha = \beta = 90°, \gamma = 120°$	6/mmm	D_{6h}
Isometric (cubic)	Monometric	3	+		+	+		1, 2 or 4	+						$a = b = c, \alpha = \beta = \gamma = 90°$	m3m	O_h

[a] Designations of the space-lattice types: P — primitive, C — side-centered (base-centered), I — body-centered, F — face-centered, R — rhombohedral.

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TABLE 4
The Five Possible Regular Polyhedrons

Polyhedron	Symmetry (Schoenflies) Class	Symmetry (Schoenflies) Elements	Form of faces	Number of[a] Faces (F)	Number of[a] Edges (E)	Number of[a] Vertices (V)
Tetrahedron	T	$4C_3 3C_2$	Equilateral triangle	4	6	4
Cube (hexahedron)	O	$3C_4 4C_3 6C_2$	Square	6	12	8
Octahedron	O	$3C_4 4C_3 6C_2$	Equilateral triangle	8	12	6
Pentagonal dodecahedron	J	$6C_5 10C_3 15C_2$	Regular pentagon	12	30	20
Icosahedron	J	$6C_5 10C_3 15C_2$	Equilateral triangle	20	30	12

[a] Per formula by Leonhard Euler: F + V – E = 2

TABLE 5
Classification of Crystals

Strukturbericht symbol	Structure name	Symmetry group International	Symmetry group Schoenflies	Pearson symbol[a]	Standard ASTM E157-82a symbol[b]
1	2	3	4	5	6
A1	Cu	Fm3m	O^4_h	cF4	F
A2	W	Im3m	O^9_h	cI2	B
A3	Mg	$P6_3/mmc$	D^4_{6h}	hP2	H
A4	C	Fd3m	O^7_h	cF8	F
A5	Sn	If_1/amd	D^{19}_{4h}	tI4	U
A6	In	I4/mmm	D^{17}_{4h}	tI2	U
A7	As	$R\bar{3}m$	D^5_{3d}	hR2	R
A8	Se	$P3_121$ or $P3_221$	D^4_3 (D^6_3)	hP3	H
A10	Hg	$R\bar{3}m$	D^5_{3d}	hR1	R
A11	Ga	Cmca	D^{18}_{2h}	oC8	Q
A12	α-Mn	$I\bar{4}3m$	T^3_d	cI58	B
A13	β-Mn	$P4_132$	O^7	cP20	C
A15	OW_3	Pm3n	O^3_h	cP8	C
A20	α-U	Cmcm	D^{17}_{2h}	oC4	Q
B1	ClNa	Fm3m	O^5_h	cF8	F
B2	ClCs	Pm3m	O^1_h	cP2	C
B3	SZn	$F\bar{4}3m$	T^2_d	cF8	F
B4	SZn	$P6_3mc$	C^4_{6v}	hP4	H
$B8_1$	AsNi	$P6_3/mmc$	D^4_{6h}	hP4	H
$B8_2$	$InNi_2$	$P6_3/mmc$	D^4_{6h}	hP6	H
B9	HgS	$P3_121$ or $P3_221$	D^4_3 or D^6_3	hP6	H
B10	OPb	P4/nmm	D^7_{4h}	tP4	T
B11	γ-CuTi	P4/nmm	D^7_{4h}	tP4	T
B13	NiS	$R\bar{3}m$	D^5_{3d}	hR6	R
B16	GeS	Pnma	D^{16}_{2h}	oP8	O
B17	PtS	$P4_2/mmc$	D^9_{4h}	tP4	T
B18	CuS	$P6_3/mmc$	D^4_{6h}	hP12	H
B19	AuCd	Pmma	D^5_{2h}	oP4	O
B20	FeSi	$P2_13$	T^4	cP8	C
B27	BFe	Pnma	D^{16}_{2h}	oP8	O
B31	MnP	Pnma	D^{16}_{2h}	oP8	O
B32	NaTl	Fd3m	O^7_h	cF16	F
B34	Pds	$P4_2/m$	C^2_{4h}	tP16	T

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TABLE 5
Classification of Crystals (continued)

Strukturbericht symbol	Structure name	Symmetry group: International	Symmetry group: Schoenflies	Pearson symbol[a]	Standard ASTM E157-82a symbol[b]
1	2	3	4	5	6
B35	CoSn	P6/mmm	D^{1}_{6h}	hP6	H
B37	SeTl	I4/mcm	D^{18}_{4h}	tI16	U
B_e	CdSb	Pbca	D^{15}_{2h}	oP16	O
B_f (B33)	ξ-BCr	Cmcm	D^{17}_{2h}	oC8	Q
B_g	BMo	$I4_1/amd$	D^{19}_{4h}	tI4	U
B_h	CW	P6m2	D^{1}_{3h}	hP2	H
B_i	γ-CMo (AsTi)	$P6_3/mmc$	D^{4}_{6h}	hP8	H
C1	CaF_2	Fm3m	O^{5}_{h}	cF12	F
$C1_b$	AgAsMg	$F\bar{4}3m$	T^{2}_{d}	cF12	F
C2	FeS_2	Pa3	T^{6}_{h}	cP12	C
C3	Cu_2O	Pn3m	O^{4}_{h}	cP6	C
C4	O_2Ti	$P4_2/mnm$	D^{14}_{4h}	tP6	T
C6	CdI_2	$P\bar{3}m1$	D^{3}_{3d}	hP3	H
C7	MoS_2	$P6_3/mmc$	D^{4}_{6h}	hP6	H
$C11_a$	C_2Ca	I4/mmm	D^{17}_{4h}	tI6	U
$C11_b$	$MoSi_2$	I4/mmm	D^{17}_{4h}	tI6	U
C12	$CaSi_2$	$R\bar{3}m$	D^{5}_{3d}	hR6	R
C14	$MgZn_2$	$P6_3/mmc$	D^{4}_{6h}	hP12	H
C15	Cu_2Mg	Fd3m	O^{7}_{h}	cF24	F
$C15_b$	$AuBe_5$	$F\bar{4}3m$ or F23	T^{2}_{d} or T^{2}	cF24	F
C16	Al_2Cu	I4/mcm	D^{18}_{4h}	tI12	U
C18	FeS_2	Pnnm	D^{12}_{2h}	oP6	O
C19	$CdCl_2$	$R\bar{3}m$	D^{5}_{3d}	hR3	R
C22	Fe_2P	$P2\bar{6}m$	D^{1}_{3h}	hP9	H
C23	Cl_2Pb	Pnma	D^{16}_{2h}	oP12	O
C32	AlB_2	P6/mmm	D^{1}_{6h}	hP3	H
C33	Bi_2STe_2	$R\bar{3}m$	D^{5}_{3d}	hR5	R
C34	$AuTe_2$	C2/m (P2/m)	C^{3}_{2h} (C^{1}_{2h})	mC6	N
C36	$MgNi_2$	$P6_3/mmc$	D^{4}_{6h}	hP24	H
C38	Cu_2Sb	P4/nmm	D^{7}_{4h}	tP6	T
C40	$CrSi_2$	$P6_222$	D^{4}_{6}	hP9	H
C42	SiS_2	Ibam	D^{26}_{2h}	oI12	P
C44	GeS_2	Fdd2	C^{19}_{2v}	oF72	S
C46	$AuTe_2$	Pma2	C^{4}_{2v}	oP24	O
C49	Si_2Zr	Cmcm	D^{17}_{2h}	oC12	Q
C54	Si_2Ti	Fddd	D^{24}_{2h}	oF24	S
C_c	Si_2Th	$I4_1/amd$	D^{19}_{4h}	tI12	U
C_e	$CoGe_2$	Aba2	C^{17}_{2v}	oC23	Q
DO_2	As_3Co	Im3	T^{5}_{h}	cI32	B
DO_3	BiF_3	Fm3m	O^{5}_{h}	cF16	F
DO_9	O_3Re	Pm3m	O^{1}_{h}	cP4	C
DO_{11}	CFe_3	Pnma	D^{16}_{2h}	oP16	O
DO_{18}	$AsNa_3$	$P6_3/mmc$	D^{4}_{6h}	hP8	H
DO_{19}	Ni_3Sn	$P6_3/mmc$	D^{4}_{6h}	hP8	H
DO_{20}	Al_3Ni	Pnma	D^{16}_{2h}	oP16	O
DO_{21}	Cu_3P	$P\bar{3}c1$	D^{4}_{3d}	hP24	H
DO_{22}	Cu_3P	I4/mmm	D^{17}_{4h}	tI8	U
DO_{23}	Al_3Zr	I4/mmm	D^{17}_{4h}	tI16	U
DO_{24}	Ni_3Ti	$P6_3/mmc$	D^{4}_{6h}	hP16	H
DO_c	SiU_3	I4/mcm	D^{18}_{4h}	tI16	U
DO_e	Ni_3P	$I\bar{4}$	S^{2}_{4}	tI32	U
$D1_3$	Al_4Ba	I4/mmm	D^{17}_{4h}	tI10	U
$D1_a$	$MoNi_4$	I4/m	C^{5}_{4h}	tI10	U

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SYMMETRY OF CRYSTALS (continued)

TABLE 5
Classification of Crystals (continued)

Strukturbericht symbol	Structure name	Symmetry group: International	Symmetry group: Schoenflies	Pearson symbol[a]	Standard ASTM E157-82a symbol[b]
1	2	3	4	5	6
$D1_b$	Al_4U	Imma	D^{28}_{2h}	oI20	P
$D1_c$	$PtSn_4$	Aba2	C^{17}_{2v}	oC20	Q
$D1_e$	B_4Th	P4/mbm	D^{5}_{4h}	tP20	T
$D1_f$	BMn_4	Fddd	D^{24}_{2h}	oF40	S
$D2_1$	B_6Ca	Pm3m	O^{1}_{h}	cP7	C
$D2_3$	$NaZn_{13}$	Fm3m	O^{5}_{h}	cF112	F
$D2_b$	$Mn_{12}Th$	I4/mmm	D^{17}_{4h}	tI26	U
$D2_c$	MnU_6	I4/mcm	D^{18}_{4h}	tI28	U
$D2_d$	$CaCu_5$	P6/mmm	D^{1}_{6h}	hP6	H
$D2_f$	$B_{12}U$	Fm3m	O^{5}_{h}	cF52	F
$D2_h$	Al_6Mn	Cmcm	D^{17}_{2h}	oC28	Q
$D5_1$	α-Al_2O_3	$R\bar{3}c$	D^{6}_{3d}	hR10	R
$D5_2$	La_2O_3	$P\bar{3}m1$	D^{3}_{3d}	hP5	H
$D5_3$	Mn_2O_3	Ia3	T^{7}_{h}	cI80	B
$D5_8$	S_3Sb_2	Pnma	D^{16}_{2h}	oP20	O
$D5_9$	P_2Zn_3	$P4_2$/mmc	D^{9}_{4h}	tP40	T
$D5_{10}$	C_2C_3	Pnma	D^{16}_{2h}	oP20	O
$D5_{13}$	Al_3Ni_2	$P\bar{3}m1$	D^{3}_{3d}	hP5	H
$D5_a$	Si_2U_3	P4/mbm	D^{5}_{4h}	tP10	T
$D5_c$	C_3Pu_2	$I\bar{4}3d$	T^{6}_{d}	cI40	B
$D7_1$	Al_4C_3	$R\bar{3}m$	D^{5}_{3d}	hR7	R
$D7_3$	P_4Th_3	$I\bar{4}3d$	T^{6}_{d}	cI28	B
$D7_b$	B_4Ta_3	Immm	D^{25}_{2h}	oI14	P
$D8_1$	Fe_3Zn_{10}	Im3m	O^{9}_{h}	cI52	B
$D8_2$	Cu_5Zn_8	$I\bar{4}3m$	T^{3}_{d}	cI52	B
$D8_3$	Al_4Cu_9	$P\bar{4}3m$	T^{1}_{d}	cP52	C
$D8_4$	C_6Cr23	Fm3m	O^{5}_{h}	cF116	F
$D8_5$	Fe_7W_6	$R\bar{3}m$	D^{5}_{3d}	hR13	R
$D8_6$	$Cu_{15}Si_4$	$I\bar{4}3m$	T^{3}_{d}	cI76	B
$D8_8$	Mn_5Si_3	$P6_3$/mcm	D^{3}_{6h}	hP16	H
$D8_9$	Co_9S_8	Fm3m	O^{5}_{h}	cF68	F
$D8_{10}$	Al_8Cr_5	R3m	C^{5}_{3v}	hR26	R
$D8_{11}$	Al_5Co_2	$P6_3$/mcm	D^{3}_{6h}	hP28	H
$D8_a$	$Mn_{23}Th_6$	Fm3m	O^{5}_{h}	cF116	F
$D8_b$	σ-phase of Cr-Fe	$p\bar{4}_2$/mnm	D^{14}_{4h}	tP30	T
$D8_e$	$(Al,Zn)_{49}Mg_{32}$	Im3	T^{5}_{h}	cI162	B
$D8_f$	Ge_7Ir_3	Im3m	O^{9}_{h}	cI40	B
$D8_h$	B_5W_2	$P6_3$/mmc	D^{4}_{6h}	hP14	H
$D8_i$	B_5Mo_2	$R\bar{3}m$	D^{5}_{3d}	hR7	R
$D8_l$	B_3Cr_5	I4/mcm	D^{18}_{4h}	tI32	U
$D8_m$	Si_3W_5	I4/mcm	D^{18}_{4h}	tI32	U
$D10_1$	C_3Cr_7	P31c	C^{4}_{3v}	hP80	H
$D10_2$	Fe_3Th_7	$P6_3$mc	C^{4}_{6v}	hP20	H
$E0_1$	ClFPb	P4/nmm	D^{7}_{4h}	tP6	T
$E1_1$	$CuFeS_2$	$I\bar{4}2d$	D^{12}_{2d}	tI16	U
$E2_1$	CaO_3Ti	Pm3m	O^{1}_{h}	cP5	C
$E2_4$	S_3Sn_2	Pnma	D^{16}_{2h}	oP20	O
E3	Al_2CdS_4	$I\bar{4}$	S^{2}_{4}	tI14	U
$E9_3$	$SiFe_3W_3$	Fd3m	O^{7}_{h}	cF112	F
$E9_a$	Al_7Cu_2Fe	P4/mnc	D^{6}_{4h}	tP40	T
$E9_b$	$AlLi_3N_2$	Ia3	T^{7}_{h}	cI96	B
$F0_1$	NiSSb	$P2_13$	T^4	cP12	C
$F5_1$	$CrNaS_2$	$R\bar{3}m$ or R32	D^{5}_{3d} or D^{7}_{3}	hR4	R
$F5_6$	CuS_2Sb	Pnma	D^{16}_{2h}	oP16	O

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TABLE 5
Classification of Crystals (continued)

Strukturbericht symbol	Structure name	Symmetry group		Pearson symbol[a]	Standard ASTM E157-82a symbol[b]
		International	Schoenflies		
1	2	3	4	5	6
$H1_1$	Al_2MgO_4	Fd3m	O^7_h	cF56	F
$H2_4$	Cu_3S_4V	$P\bar{4}3m$	T^1_d	cP8	C
$H2_5$	$AsCu_3S_4$	$Pmn2_1$	C^7_{2v}	oP16	O
$L1_0$	AuCu	P4/mmm	D^1_{4h}	tP4	T
$L1_2$	$AlCu_3$	Pm3m	O^1_h	cP4	C
$L2_1$	$AlCu_2Mn$	Fm3m	O^5_h	cF16	F
$L2_2$	Sb_2Tl_7	Im3m	O^9_h	cI54	B
$L'2_b$	H_2Th	I4/mmm	D^{17}_{4h}	tI6	U
L′3	Fe_2N	$P6_3/mmc$	D^4_{6h}	hP3	H
$L6_0$	$CuTi_3$	P4/mmm	D^1_{4h}	tP4	T

[a] The first letter denotes the crystal system: triclinic (a), monoclinic (m), orthorhombic (o), tetragonal (t), hexagonal (h) and cubic (c). Trigonal (rhombohedral) system is presented by combination hR. The second letter of Pearson's symbol denotes lattice type: primitive (P), edge- (base-) centered (C), body-centered (I) or face-centered (F). The following number denotes amount of atoms in the crystal unit cell.

[b] Standard ASTM E157-82a has the Bravais lattices designations as following: C — primitive cubic; B — body-centered cubic; F — face-centered cubic; T — primitive tetragonal; U — body-centered tetragonal; R — rhombohedral; H — hexagonal; O — primitive orthorhombic; P — body-centered orthorhombic; Q — base-centered orthorhombic; S — face-centered orthorhombic; M — primitive monoclinic; N — centered monoclinic; A — triclinic.

REFERENCES

1. A. Schoenflies, *Kristallsysteme und Kristallstructur*, Leipzig, 1891.
2. E. S. Fedorow, Zusammenstellung der kristallographischen Resultate, *Zs. Krist.*, 20, 1892.
3. P. Groth, *Elemente der physikalischen und chemischen Krystallographie*, R. Oldenbourg, München/Berlin, 1921.
4. N. V. Belov, *Class Method of Deriving Space Groups of Symmetry*, Trudy Instituta Kristallodraffi imeni Fedorova (Transactions of the Fedorov Inst. of Crystallography), 5, 25, 1951, in Russian.
5. W. B. Pearson, *Handbook of Lattice Spacings and Structures of Metals and Alloys*, Vol. 1, Pergamon Press, 1958; Vol. 2, 1967.
6. Ch. Kittel, *Introduction to Solid State Physics*, John Wiley & Sons, 1956.
7. G. S. Zhdanov, *Fizika Tverdogo Tela (Solid State Physics)*, Moscow University Press, 1962, in Russian.
8. M. J. Buerger, *Elementary Crystallography*, John Wiley & Sons, 1963.
9. F. D. Bloss, *Crystallography & Crystal Chemistry*, Holt, Rinehart & Winston, 1971.
10. T. Janssen, *Crystallographic Groups*, North-Holland/American Elsevier, 1973.
11. M. P. Shaskolskaya, *Kristallografiya (Crystallography)*, Vysshaya Shkola, Moscow, 1976, in Russian.
12. T. Hahn, Ed., Internat. *Tables for Crystallography*, Vol. A, D. Reidel Publishing, Boston, 1983.
13. Crystal Data. Determinative Tables, Volumes 1—6, 1966—1983, JCPDS-Intern Centre for Diffraction Data and U.S. Dept. of Commerce.
14. R. W. G. Wyckoff, *Crystal Structures*, 2nd ed., Volumes 1–6, Interscience, New York, 1963.
15. C.J. Bradley and A.P. Cracknell, *The Mathematical Theory of Symmetry in Solids*, Clarendon Press, Oxford, 1972.
16. International Tables for Crystallography. Volume A, *Space–Group Symmetry*, T. Hahn, Ed., 1989; Volume B, *Reciprocal Space*, U. Schmueli, Ed.; Volume C, *Mathematical, Physical and Chemical Tables*, A. J. C. Wilson, Ed., Kluwer Academic Publishers, Dordrecht, 1989.
17. G. R. Desiraju, *Crystal Engineering: The Design of Organic Solids*, Elsevier, Amsterdam, 1989.
18. M. Senechal, *Crystalline Symmetries: An Informal Mathematical Introduction*, Adam Hilger Publ., Bristol, 1990.
19. C. Hammond, *Introduction to Crystallography*, Oxford University Press, 1990.
20. N.W. Alcock, *Bonding and Structure: Structural Principles in Inorganic and Organic Chemistry*, Ellis Norwood Publ., 1990.
21. T. C. W. Mak and G. D. Zhou. *Crystallography in Modern Chemistry: A Resource Book of Crystal Structures*, Wiley–Interscience, New York, 1992.
22. S. C. Abrahams, K. Mirsky, and R. M. Nielson, *Acta Cryst*, B52, 806 (1996); B52, 1057 (1996).
23. C. Marcos, A. Panalague, D. B. Morciras, S. Garcia–Granda and M. R. Dias. *Acta Cryst*, B52, 899 (1996).

Crystallographic Computing

24. A. C. Larson, *Crystallographic Computing*, Manksgaard, Copenhagen, 1970.
25. G. M. Sheldrick, SHELXS86. Crystallographic Computing 3, Clarendon Press, Oxford, 1986; SHELXL93. Program for the Refinement of Crystal Structures, University of Göttingen Press, 1993.
26. Inorganic Crystal Structure Database, CD–ROM. Sci. Inf. Service. E-mail: SISI@Delphi.com.

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IONIC RADII IN CRYSTALS

Ionic radii are a useful tool for predicting and visualizing crystal structures. This table lists a set of ionic radii R_i in Å units for the most common coordination numbers *CN* of positive and negative ions. The values are based on experimental crystal structure determinations, supplemented by empirical relationships, and theoretical calculations. The notation sq after the coordination number indicates a square configuration, while py indicates pyramidal.

The advice of Howard T. Evans and Marvin J. Weber in preparing this table is appreciated.

REFERENCES

1. Shannon, R. D., *Acta Crystallogr.* A32, 751, 1976.
2. Jia, Y.Q., *J. Solid State Chem.* 95, 184, 1991.

Ion	*CN*	R_i/Å
Anions		
F^{-1}	6	1.33
Cl^{-1}	6	1.81
Br^{-1}	6	1.96
I^{-1}	6	2.20
OH^{-1}	4	1.35
	6	1.37
O^{-2}	2	1.21
	6	1.40
	8	1.42
S^{-2}	6	1.84
Se^{-2}	6	1.98
Te^{-2}	6	2.21
Cations		
Ac^{+3}	6	1.12
Ag^{+1}	4	1.00
	6	1.15
	8	1.28
Ag^{+2}	4sq	0.79
	6	0.94
Al^{+3}	4	0.39
	5	0.48
	6	0.54
Am^{+3}	6	0.98
	8	1.09
Am^{+4}	6	0.85
	8	0.95
As^{+3}	6	0.58
As^{+5}	4	0.34
	6	0.46
Au^{+1}	6	1.37
Au^{+3}	4sq	0.64
	6	0.85
Ba^{+2}	6	1.35
	8	1.42
	12	1.61
Be^{+2}	4	0.27
	6	0.45
Bi^{+3}	5	0.96
	6	1.03
	8	1.17
Bi^{+5}	6	0.76
Bk^{+3}	6	0.96
Bk^{+4}	6	0.83
	8	0.93
Br^{+5}	3py	0.31
Br^{+7}	4	0.25
	6	0.39
C^{+4}	4	0.15
	6	0.16
Ca^{+2}	6	1.00
	8	1.12
	10	1.23
	12	1.34
Cd^{+2}	4	0.78
	6	0.95
	8	1.10
	12	1.31
Ce^{+3}	6	1.01
	8	1.14
	10	1.25
	12	1.34
Ce^{+4}	6	0.87
	8	0.97
	10	1.07
	12	1.14
Cf^{+3}	6	0.95
Cf^{+4}	6	0.82
	8	0.92
Cl^{+5}	3py	0.12
Cl^{+7}	4	0.08
Cm^{+3}	6	0.97
Cm^{+4}	6	0.85
	8	0.95
Co^{+2}	4	0.56
	6	0.65
	8	0.90
Co^{+3}	6	0.55
Cr^{+2}	6	0.73
Cr^{+3}	6	0.62
Cr^{+4}	4	0.41
	6	0.55
Cr^{+6}	4	0.26
	6	0.44
Cs^{+1}	6	1.67
	8	1.74
	10	1.81
	12	1.88
Cu^{+1}	2	0.46
	4	0.60
	6	0.77
Cu^{+2}	4sq	0.57
	6	0.73
Dy^{+2}	6	1.07
	8	1.19
Dy^{+3}	6	0.91
	8	1.03
Er^{+3}	6	0.89
	8	1.00
Eu^{+2}	6	1.17
	8	1.25
	10	1.35
Eu^{+3}	6	0.95
	8	1.07
F^{+7}	6	0.08
Fe^{+2}	4	0.63
	6	0.61
	8	0.92
Fe^{+3}	4	0.49
	6	0.55
	8	0.78
Fr^{+1}	6	1.80
Ga^{+3}	4	0.47
	6	0.62
Gd^{+3}	6	0.94
	8	1.05
Ge^{+2}	6	0.73
Ge^{+4}	4	0.39
	6	0.53
Hf^{+4}	4	0.58
	6	0.71
	8	0.83
Hg^{+1}	6	1.19
Hg^{+2}	2	0.69
	4	0.96
	6	1.02
	8	1.14
I^{+5}	3py	0.44
	6	0.95
I^{+7}	4	0.42
	6	0.53
In^{+3}	4	0.62
	6	0.80
Ir^{+3}	6	0.68
Ir^{+4}	6	0.63
Ir^{+5}	6	0.57
K^{+1}	4	1.37
	6	1.38
	8	1.51
	12	1.64
La^{+3}	6	1.03
	8	1.16
	10	1.27
	12	1.36
Li^{+1}	4	0.59
	6	0.76

IONIC RADII IN CRYSTALS (continued)

Ion	*CN*	R_i/Å
	8	0.92
Lu^{+3}	6	0.86
	8	0.97
Mg^{+2}	4	0.57
	6	0.72
	8	0.89
Mn^{+2}	4	0.66
	6	0.83
	8	0.96
Mn^{+3}	6	0.58
Mn^{+4}	4	0.39
	6	0.53
Mn^{+5}	4	0.33
Mn^{+6}	4	0.26
Mn^{+7}	4	0.25
Mo^{+3}	6	0.69
Mo^{+4}	6	0.65
Mo^{+5}	4	0.46
	6	0.61
Mo^{+6}	4	0.41
	6	0.59
	7	0.73
N^{+3}	6	0.16
N^{+5}	6	0.13
Na^{+1}	4	0.99
	6	1.02
	8	1.18
	9	1.24
	12	1.39
Nb^{+3}	6	0.72
	8	0.79
Nb^{+4}	6	0.68
Nb^{+5}	4	0.48
	6	0.64
	8	0.74
Nd^{+3}	6	0.98
	8	1.12
	9	1.16
	12	1.27
Ni^{+2}	4sq	0.49
	6	0.69
Ni^{+3}	6	0.56
Np^{+3}	6	1.01
Np^{+4}	6	0.87
Np^{+5}	6	0.75
Np^{+6}	6	0.72
Os^{+4}	6	0.63
Os^{+5}	6	0.58
Os^{+6}	6	0.55
Os^{+8}	4	0.39
P^{+5}	4	0.17
	6	0.38
Pa^{+3}	6	1.04
Pa^{+4}	6	0.90
Pa^{+5}	6	0.78
Pb^{+2}	6	1.19
	8	1.29
	10	1.40
	12	1.49
Pb^{+4}	4	0.65

Ion	*CN*	R_i/Å
	6	0.78
	8	0.94
Pd^{+2}	4sq	0.64
	6	0.86
Pd^{+3}	6	0.76
Pd^{+4}	6	0.62
Pm^{+3}	6	0.97
	8	1.09
Po^{+4}	6	0.97
Pr^{+3}	6	0.99
	8	1.13
Pr^{+4}	6	0.85
	8	0.96
Pt^{+2}	4sq	0.60
	6	0.80
Pt^{+4}	6	0.63
Pu^{+3}	6	1.00
Pu^{+4}	6	0.86
Pu^{+5}	6	0.74
Pu^{+6}	6	0.71
Ra^{+2}	8	1.48
	12	1.70
Rb^{+1}	6	1.52
	8	1.61
	10	1.66
	12	1.72
Re^{+4}	6	0.63
Re^{+5}	6	0.58
Re^{+6}	6	0.55
Re^{+7}	4	0.38
	6	0.53
Rh^{+3}	6	0.67
Rh^{+4}	6	0.60
Rh^{+5}	6	0.55
Ru^{+3}	6	0.68
Ru^{+4}	6	0.62
Ru^{+5}	6	0.57
Ru^{+7}	4	0.38
Ru^{+8}	4	0.36
S^{+4}	6	0.37
S^{+6}	4	0.12
	6	0.29
Sb^{+3}	4py	0.76
	6	0.76
Sb^{+5}	6	0.60
Sc^{+3}	6	0.75
	8	0.87
Se^{+4}	6	0.50
Se^{+6}	4	0.28
	6	0.42
Si^{+4}	4	0.26
	6	0.40
Sm^{+2}	6	1.19
	8	1.27
Sm^{+3}	6	0.96
	8	1.08
	12	1.24
Sn^{+4}	4	0.55
	6	0.69
	8	0.81

Ion	*CN*	R_i/Å
Sr^{+2}	6	1.18
	8	1.26
	10	1.36
	12	1.44
Ta^{+3}	6	0.72
Ta^{+4}	6	0.68
Ta^{+5}	6	0.64
Tb^{+3}	6	0.92
	8	1.04
Tb^{+4}	6	0.76
	8	0.88
Tc^{+4}	6	0.65
Te^{+4}	4	0.66
	6	0.97
Te^{+6}	4	0.43
	6	0.56
Th^{+4}	6	0.94
	8	1.05
	10	1.13
	12	1.21
Ti^{+2}	6	0.86
Ti^{+3}	6	0.67
Ti^{+4}	4	0.42
	6	0.61
	8	0.74
Tl^{+1}	6	1.50
	8	1.59
	12	1.70
Tl^{+3}	4	0.75
	6	0.89
	8	0.98
Tm^{+2}	6	1.01
	7	1.09
Tm^{+3}	6	0.88
	8	0.99
U^{+3}	6	1.03
U^{+4}	6	0.89
	8	1.00
	12	1.17
U^{+5}	6	0.76
U^{+6}	2	0.45
	4	0.52
	6	0.73
	8	0.86
V^{+2}	6	0.79
V^{+3}	6	0.64
V^{+4}	5	0.53
	6	0.58
	8	0.72
V^{+5}	4	0.36
	5	0.46
	6	0.54
W^{+4}	6	0.66
W^{+5}	6	0.62
W^{+6}	4	0.42
	5	0.51
	6	0.60
Y^{+3}	6	0.90
	8	1.02
	9	1.08

IONIC RADII IN CRYSTALS (continued)

Ion	***CN***	***R*$_i$/Å**	**Ion**	***CN***	***R*$_i$/Å**	**Ion**	***CN***	***R*$_i$/Å**
Yb^{+2}	6	1.02	Zn^{+2}	4	0.60		6	0.72
	8	1.14		6	0.74		8	0.84
Yb^{+3}	8	0.99		8	0.90		9	0.89
	9	1.04	Zr^{+4}	4	0.59			

POLARIZABILITIES OF ATOMS AND IONS IN SOLIDS

H. P. R. Frederikse

The polarization of a solid dielectric medium, $\boldsymbol{P}$, is defined as the dipole moment per unit volume averaged over the volume of a crystal cell. A component of $\boldsymbol{P}$ can be expanded as a function of the electric field $\boldsymbol{E}$:

$$P_i = \sum_j a_j E_j + \sum_{jk} b_{jk} E_j E_k$$

For relatively small electric fields in isotropic substances $\boldsymbol{P} = \chi_e \boldsymbol{E}$, where χ_e is the electric susceptibility. If the medium is made up of N atoms (or ions) per unit volume, the polarization is $\boldsymbol{P} = N\boldsymbol{p}_m$ where $\boldsymbol{p}_m$ is the average dipole moment per atom. The polarizability α can be defined as $\boldsymbol{p}_m = \alpha \boldsymbol{E}_0$, where $\boldsymbol{E}_0$ is the local field at the position of the atom. Using the Lorentz method to calculate the local field one finds:

$$\boldsymbol{P} = N\alpha(\boldsymbol{E} + 4\pi\boldsymbol{P}) = \chi_e \boldsymbol{E}$$

Together with the definition of the dielectric constant (relative permittivity) , $\varepsilon = 1 + 4\pi\chi_e$, this leads to:

$$\alpha = \frac{3}{4\pi N}\left(\frac{\varepsilon - 1}{\varepsilon + 2}\right)$$

This expression is known as the Clausius-Mossotti equation.

The total polarization associated with atoms, ions, or molecules is due to three different sources:

1. Electronic polarization arises because the center of the local electronic charge cloud around the nucleus is displaced under the action of the field: $P_e = N\alpha_e E_0$ where α_e is the *electronic polarizability*.
2. Ionic polarization occurs in ionic materials because the electric field displaces cations and anions in opposite directions: $P_i = N\alpha_i E_0$, where α_i is the *ionic polarizability*.
3. Orientational polarization can occur in substances composed of molecules that have permanent electric dipoles. The alignment of these dipoles depends on temperature and leads to an *orientational polarizability* per molecule: $\alpha_{or} = p^2/3kT$, where p is the permanent dipole moment per molecule, k is the Boltzmann constant, and T is the temperature.

Because of the different nature of these three polarization processes the response of a dielectric solid to an applied electric field will strongly depend on the frequency of the field. The resonance of the electronic excitation in insulators (dielectrics) takes place in the ultraviolet part of the spectrum; the characteristic frequency of the lattice vibrations is located in the infrared, while the orientation of dipoles requires fields of much lower frequencies (below 10^{10} Hz). This response to electric fields of different frequencies is shown in Figure 1. Values of the electronic polarizabilities for selected atoms and ions are given in Table 1.

REFERENCES

1. Kittel, C., *Introduction to Solid State Physics*, Fourth Edition, John Wiley & Sons, New York, 1971.
2. Lerner, R.G., and Trigg, G.L., Editors, *Encyclopedia of Physics*, *Second Edition*, VCH Publishers, New York, 1990.
3. Ralls, K.M., Courtney, T.H., and Wulff, J., *An Introduction to Materials Science and Engineering*, John Wiley & Sons, New York, 1976.

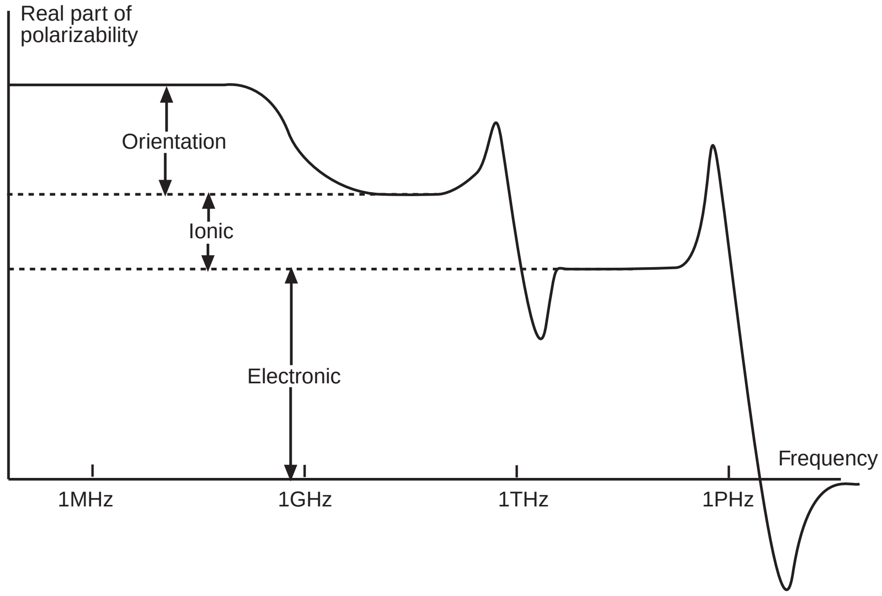


Figure 1. Schematic graph of the frequency dependence of the different contributions to polarizability.

TABLE 1
Electronic Polarizabilities in Units of 10^{-24} cm^3

						He 0.201
Li^+ 0.029	**Be^{2+}** 0.008	**B^{3+}** 0.003	**C^{4+}** 0.0013	**O^{2-}** 3.88	**F^-** 1.04	**Ne** 0.39
Na^+ 0.179	**Mg^{2+}** 0.094	**Al^{3+}** 0.052	**Si^{4+}** 0.0165	**S^{2-}** 10.2	**Cl^-** 3.66	**Ar** 1.62
K^+ 0.83	**Ca^{2+}** 0.47	**Sc^{3+}** 0.286	**Ti^{4+}** 0.185	**Se^{2-}** 10.5	**Br^-** 4.77	**Kr** 2.46
Rb^+ 1.40	**Sr^{2+}** 0.86	**Y^{3+}** 0.55	**Zr^{4+}** 0.37	**Te^{2-}** 14.0	**I^-** 7.1	**Xe** 3.99
Cs^+ 2.42	**Ba^{2+}** 1.55	**La^{3+}** 1.04	**Ce^{4+}** 0.73			

Data from Pauling, L., *Proc. R. Soc. London*, A114, 181, 1927. See also Jaswal, S.S. and Sharma, T.P., *J. Phys. Chem. Solids*, 34, 509, 1973.

Values are appropriate for cgs units. To convert to SI, use the relation

$$\alpha(\mathrm{SI})/\mathrm{C\ m^2V^{-1}} = 1.11265 \cdot 10^{-16}\ \alpha(\mathrm{cgs})/\mathrm{cm^3}$$

LATTICE ENERGIES

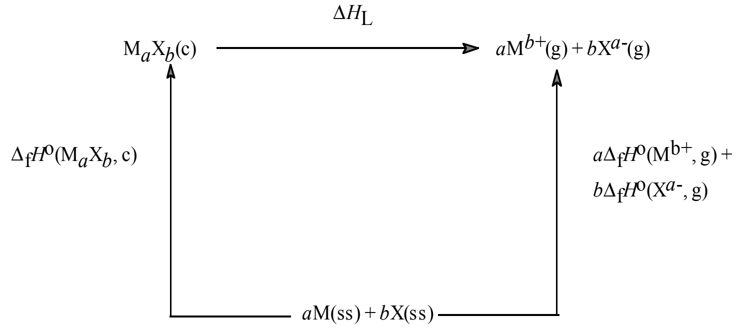
H. D. B. Jenkins and H. K. Roobottom

THERMOCHEMICAL CYCLE AND CALCULATED VALUES

Table 1 contains calculated values of the lattice energies (total lattice potential energies), U_{POT}, of crystalline salts, M_aX_b,. U_{POT} is expressed in units of kilojoules per mole, kJ mol^{-1}. M and X can be either simple or complex ions. Substances are arranged by chemical class.

Also listed in the table is the lattice energy, U_{POT}^{BFHC}, obtained from the application of the Born - Fajans - Haber cycle (BHFC) described below, using the "Standard Thermochemical Properties of Chemical Substances" table in Section 5 of this *Handbook*, References 1 through 4, and certain other data which are given in Table 3 below.

The lattice enthalpy, ΔH_L, is given by the cycle:



where (ss) is the standard state of the element concerned.

The lattice enthalpy, ΔH_L, is obtained using the equation:

$$\Delta H_L = a\Delta_f H^o(M^{b+}, g) + b\Delta_f H^o(X^{a-}, g) - \Delta_f H^o(M_aX_b, c)$$

and is futher related to the total lattice potential energy, U_{POT}, by the relationship:

$$\Delta H_L = U_{POT} + \left[a\left(\frac{n_M}{2} - 2\right) + b\left(\frac{n_X}{2} - 2\right)\right]RT$$

where n_M and n_X equal 3 for monatomic ions, 5 for linear polyatomic ions and 6 for polyatomic non-linear ions.

METHOD OF ESTIMATION OF VALUES NOT TABULATED

In cases where the lattice energy is not tabulated and we want to furnish an estimate, then the Kapustinskii equation[5] can be used to obtain a value (in kJ mol^{-1}):

$$U_{POT} = \frac{121.4 z_a z_b v}{(r_a + r_b)}\left(1 - \frac{0.0345}{(r_a + r_b)}\right)$$

where z_a and z_b are the moduli of the charges on the v ions in hte lattice and r_a and r_b (in nm) are the thermochemical radii given in Table 2. The r_a for metal ions is taken to be the Goldschmidt[6] radius.

To cite an example, if we wish to estimate the lattice energy of the salt $[NH_4^+][HF_2^-]$ using the above procedure, we see that Table 2 gives the thermochemical radius (r_a) for NH_4^+ to be 0.136 nm and that for HF_2^- (r_b) to be 0.172 nm. The lattice potential energy is then estimated to be 700 kJ mol^{-1} compared with the calculated value of 705 kJ mol^{-1}and the Born - Fajans - Haber cycle value of 658 kJ mol^{-1}.

REFERENCES

1. Wagman, D. D., Evans, W. H., Parker, V. B., Schumm, R. H., Halow, I., Bailey, S. M., Churney, K. L., and Nuttall, R. L., *The NBS Tables of Chemical Thermodynamic Properties, J. Phys. Chem. Ref. Data*, Vol. 11, Suppl. 2, 1982.
2. Chase, M. W., Davies, C. A., Downey, J. R., Frurip, D. J., McDonald, R. A., and Syverud, A. N., *JANAF Thermochemical Tables, Third Edition, J. Phys. Chem. Ref. Data*, Vol. 14, Suppl. 1, 1985.
3. Lias, S. G., Bartmess, J. E., Liebman, J. F., Holmes, J. L., Levin, R. D., and Mallard, W. G., *Gas-Phase Ion and Neutral Thermochemistry, J. Phys. Chem. Ref. Data*, Vol. 17, Suppl. 1, 1988.
4. Jenkins, H. D. B., and Pratt, K. F., *Adv. Inorg. Chem. Radiochem.*, *22*, 1, 1978.
5. Kapustinskii, A. F., *Quart. Rev.*, *10*, 283-294., 1956.
6. Goldschmidt, V. M., *Skrifter Norske Videnskaps-Akad.* Oslo, I, Mat.-Naturn. Kl, 1926. See also Dasent, W. E., *Inorganic Energetics*, 2nd ed., Cambridge University Press, 1982.
7. Jenkins, H. D. B., Roobottom, H. K., Passmore, J., and Glasser, L., *J. Chem. Education,* in press.

Table 1
LATTICE ENERGIES (kJ mol^{-1})

Substance	Calc. U_{POT}	U_{POT}^{BHFC}
Acetates		
$Li(CH_3COO)$	-	843
$Na(CH_3COO)$	828	807
$K(CH_3COO)$	749	726
$Rb(CH_3COO)$	715	-
$Cs(CH_3COO)$	682	-
Acetylides		
CaC_2	2911	2902
SrC_2	2788	2782
BaC_2	2647	2652
Azides		
LiN_3	861	875
NaN_3	770	784
KN_3	697	-
RbN_3	674	691
CsN_3	665	674
AgN_3	854	910
TlN_3	689	742
$Ca(N_3)_2$	2186	2316
$Sr(N_3)_2$	2056	2187
$Ba(N_3)_2$	2021	-
$Mn(N_3)_2$	2408	2348
$Cu(N_3)_2$	2730	2738
$Zn(N_3)_2$	2840	2970
$Cd(N_3)_2$	2446	2576
$Pb(N_3)_2$	-	2300
Bihalide Salts		
$LiHF_2$	821	847
$NaHF_2$	755	748
KHF_2	657	660
$RbHF_2$	627	631
$CsHF_2$	607	-
NH_4HF_2	705	658
$CsHCl_2$	601	-
Me_4NHCl_2	427	-
Et_4NHCl_2	346	-
Bu_4NHCl_2	290	-
Bicarbonates		
$NaHCO_3$	820	656
$KHCO_3$	741	573
$RbHCO_3$	707	522
$CsHCO_3$	678	520
NH_4HCO_3	-	577
Borides		
CaB_6	5146	-
SrB_6	5104	-
BaB_6	5021	-
YB_6	7447	-
LaB_6	7406	-
CeB_6	10083	-
PrB_6	7447	—
NdB_6	7447	-
PmB_6	7406	-
SmB_6	7447	-
EuB_6	5104	-
GdB_6	7489	-
TbB_6	7489	-
DyB_6	7489	-
HoB_6	7489	-
ErB_6	7489	-
TmB_6	7489	-
YbB_6	5146	-
LuB_6	7489	-
ThB_6	10167	-
Borohydrides		
$LiBH_4$	778	-
$NaBH_4$	703	694
KBH_4	655	638
$RbBH_4$	648	-
$CsBH_4$	628	-
Borohalides		
$LiBF_4$	699	749
$NaBF_4$	657	674
KBF_4	611	616
$RbBF_4$	577	590
$CsBF_4$	556	565
NH_4BF_4	582	-
$KBCl_4$	506	497
$RbBCl_4$	489	486
$CsBCl_4$	473	-
Carbonates		
Li_2CO_3	2523	2254
Na_2CO_3	2301	2016
K_2CO_3	2084	1846
Rb_2CO_3	2000	1783
Cs_2CO_3	1920	1722
$MgCO_3$	3138	3122
$CaCO_3$	2804	2811
$SrCO_3$	2720	2688
$BaCO_3$	2615	2554
$MnCO_3$	3046	3092
$FeCO_3$	3121	3169
$CoCO_3$	3443	3235
$CuCO_3$	3494	-
$ZnCO_3$	3121	3273
$CdCO_3$	2929	3052
$SnCO_3$	2904	-
$PbCO_3$	2728	2750
Cyanates		
LiNCO	849	-
NaNCO	807	816
KNCO	726	734
RbNCO	692	-
CsNCO	661	-
NH_4NCO	724	-
Cyanides		
LiCN	874	
NaCN	766	759
KCN	692	686
RbCN	638	-
CsCN	601	-
$Ca(CN)_2$	2268	2240

Table 1
LATTICE ENERGIES (kJ mol⁻¹) (continued)

Substance	Calc. U_{POT}	U_{POT}^{BHFC}
$Sr(CN)_2$	2138	-
$Ba(CN)_2$	2001	2009
NH_4CN	617	691
AgCN	(741)	935
$Zn(CN)_2$	2809	2817
$Cd(CN)_2$	2583	2591
Formates		
$Li(HCO_2)$	865	-
$Na(HCO_2)$	791	804
$K(HCO_2)$	713	722
$Rb(HCO_2)$	685	-
$Cs(HCO_2)$	651	-
$NH_4(HCO_2)$	715	-
Germanates		
Mg_2GeO_4	7991	-
Ca_2GeO_4	7301	7306
Sr_2GeO_4	6987	-
Ba_2GeO_4	6653	6643
Halates		
$LiBrO_3$	883	880
$NaBrO_3$	803	791
$KBrO_3$	740	722
$RbBrO_3$	720	705
$CsBrO_3$	694	681
$NaClO_3$	770	785
$KClO_3$	711	721
$RbClO_3$	690	703
$CsClO_3$	-	679
$LiIO_3$	975	974
$NaIO_3$	883	876
KIO_3	820	780
$RbIO_3$	791	-
$CsIO_3$	761	-
Halides		
LiF	1030	1049
LiCl	834	864
LiBr	788	820
LiI	730	764
NaF	910	930
NaCl	769	790
NaBr	732	754
NaI	682	705
KF	808	829
KCl	701	720
KBr	671	691
KI	632	650
RbF	774	795
RbCl	680	695
RbBr	651	668
RbI	617	632
CsF	744	759
CsCl	657	670
CsBr	632	647
CsI	600	613
FrF	715	-
FrCl	632	-
FrBr	611	-
FrI	582	-
CuCl	992	996
CuBr	969	978
CuI	948	966
AgF	953	974
AgCl	910	918
AgBr	897	905
AgI	881	892
AuCl	1013	1066
AuBr	1029	1059
AuI	1027	1070
InCl	-	764
InBr	-	767
InI	-	733
TlF	-	850
TlCl	738	751
TlBr	720	734
TlI	692	710
Me_4NCl	566	-
Me_4NBr	553	-
Me_4NI	544	-
PH_4Br	616	-
PH_4I	590	-
BeF_2	3464	3526
$BeCl_2$	3004	3033
$BeBr_2$	2950	2914
BeI_2	2780	2813
MgF_2	2926	2978
$MgCl_2$	2477	2540
$MgBr_2$	2406	2451
MgI_2	2293	2340
CaF_2	2640	2651
$CaCl_2$	2268	2271
$CaBr_2$	2132	-
CaI_2	1971	2087
SrF_2	2476	2513
$SrCl_2$	2142	2170
SrI_2	1984	1976
BaF_2	2347	2373
$BaCl_2$	2046	2069
$BaBr_2$	1971	1995
BaI_2	1862	1890
RaF_2	2284	-
$RaCl_2$	2004	-
$RaBr_2$	1929	-
RaI_2	1803	-
$ScCl_2$	2380	-
$ScBr_2$	2291	-
ScI_2	2201	-
TiF_2	2724	-
$TiCl_2$	2439	2514
$TiBr_2$	2360	2430
TiI_2	2259	2342
VCl_2	2607	2593
VBr_2	-	2534

Table 1
LATTICE ENERGIES (kJ mol^{-1}) (continued)

Substance	Calc. U_{POT}	U_{POT}^{BHFC}	Substance	Calc. U_{POT}	U_{POT}^{BHFC}
VI_2	-	2470	YF_3	4983	-
CrF_2	2778	2939	YCl_3	4506	4524
$CrCl_2$	2540	2601	YI_3	4240	4258
$CrBr_2$	2377	2536	TiF_3	5644	-
CrI_2	2269	2440	$TiCl_3$	5134	5153
$MoCl_2$	2737	2746	$TiBr_3$	5012	5023
$MoBr_2$	2742	2753	TiI_3	4845	-
MoI_2	2630	-	$ZrCl_3$	-	4791
MnF_2	2644	-	$ZrBr_3$	-	4758
$MnCl_2$	2510	2551	ZrI_3	-	4591
$MnBr_2$	2448	2482	VF_3	5895	-
MnI_2	2212	-	VCl_3	5322	5329
FeF_2	2849	2967	VBr_3	5214	5224
$FeCl_2$	2569	2641	VI_3	5121	5136
$FeBr_2$	2515	2577	$NbCl_3$	5062	-
FeI_2	2439	2491	$NbBr_3$	4980	-
CoF_2	3004	3042	NbI_3	4860	-
$CoCl_2$	2707	2706	CrF_3	6033	6065
$CoBr_2$	2640	2643	$CrCl_3$	5518	5529
CoI_2	2569	2561	$CrBr_3$	5355	-
NiF_2	3098	3089	CrI_3	5275	5294
$NiCl_2$	2753	2786	MoF_3	6459	-
$NiBr_2$	2729	2721	$MoCl_3$	5246	5253
NiI_2	2607	2637	$MoBr_3$	5156	-
$PdCl_2$	2778	2818	MoI_3	5073	-
$PdBr_2$	2741	2751	MnF_3	6017	-
PdI_2	2748	2760	$MnCl_3$	5544	-
CuF_2	3046	3102	$MnBr_3$	5448	-
$CuCl_2$	2774	2824	MnI_3	5330	-
$CuBr_2$	2715	2774	$TcCl_3$	5270	-
CuI_2	2640	-	$TcBr_3$	5215	-
AgF_2	2942	2967	TcI_3	5188	-
ZnF_2	3021	3053	FeF_3	5870	-
$ZnCl_2$	2703	2748	$FeCl_3$	5364	5436
$ZnBr_2$	2648	2689	$FeBr_3$	5333	5347
ZnI_2	2581	2619	FeI_3	5117	-
CdF_2	2809	2830	$RuCl_3$	5245	5257
$CdCl_2$	2552	2565	$RuBr_3$	5223	5232
$CdBr_2$	2507	2517	RuI_3	5222	5235
CdI_2	2441	2455	CoF_3	5991	-
HgF_2	2757	-	$RhCl_3$	5641	5665
$HgCl_2$	2657	2664	IrF_3	(6112)	-
$HgBr_2$	2628	2639	$IrBr_3$	(4794)	-
HgI_2	2628	2624	NiF_3	(6111)	-
SnF_2	2551	-	AuF_3	(5777)	-
$SnCl_2$	2297	2310	$AuCl_3$	(4605)	-
$SnBr_2$	2251	2256	$ZnCl_3$	5832	-
SnI_2	2193	2206	$ZnBr_3$	5732	-
PbF_2	2535	2543	ZnI_3	5636	-
$PbCl_2$	2270	2282	AlF_3	5924	6252
$PbBr_2$	2219	2230	$AlCl_3$	5376	5513
PbI_2	2163	2177	$AlBr_3$	5247	5360
ScF_3	5492	5540	AlI_3	5070	5227
$ScCl_3$	4874	4901	GaF_3	5829	6238
$ScBr_3$	4729	4761	$GaCl_3$	5217	5665
ScI_3	4640	-	$GaBr_3$	4966	5569

Table 1
LATTICE ENERGIES (kJ mol^{-1}) (continued)

Substance	Calc. U_{POT}	U_{POT}^{BHFC}
GaI_3	4611	5496
$InCl_3$	4736	5183
$InBr_3$	4535	5117
InI_3	4234	5001
TlF_3	5493	-
$TlCl_3$	5258	5278
$TlBr_3$	5171	-
TlI_3	5088	-
$AsBr_3$	5497	5365
AsI_3	4824	5295
SbF_3	5295	5324
$SbCl_3$	5032	4857
$SbBr_3$	4954	4776
SbI_3	4867	4692
$BiCl_3$	4689	4707
BiI_3	3774	-
LaF_3	4682	-
$LaCl_3$	4263	4242
$LaBr_3$	4209	-
LaI_3	3916	3986
$CeCl_3$	4394	4348
CeI_3	-	4061
$PrCl_3$	4322	4387
PrI_3	-	4101
$NdCl_3$	4343	4415
$SmCl_3$	4376	4450
$EuCl_3$	4393	4490
$GdCl_3$	4406	4495
$DyCl_3$	4481	4529
$HoCl_3$	4501	4572
$ErCl_3$	4527	4591
$TmCl_3$	4548	4608
TmI_3	-	4340
$YbCl_3$	-	4651
$AcCl_3$	4096	-
UCl_3	4243	-
$NpCl_3$	4268	-
$PuCl_3$	4289	-
$PuBr_3$	(3959)	-
$AmCl_3$	4293	-
TiF_4	10012	9908
$TiCl_4$	9431	-
$TiBr_4$	9288	9059
TiI_4	9108	8918
ZrF_4	8853	8971
$ZrCl_4$	8021	8144
$ZrBr_4$	7661	7984
ZrI_4	7155	7801
MoF_4	8795	-
$MoCl_4$	8556	9603
$MoBr_4$	8510	9500
MoI_4	8427	-
$SnCl_4$	8355	8930
$SnBr_4$	7970	8852
PbF_4	9519	-
CrF_2Cl	5795	-
CrF_2Br	5753	-
CrF_2I	5669	-
$CrCl_2Br$	5448	-
$CrCl_2I$	5381	5429
$CrBr_2I$	5330	5370
CuFCl	2891	-
CuFBr	2853	-
CuFI	2803	-
CuClBr	2753	-
CuClI	2694	-
CuBrI	2669	-
FeF_2Cl	5711	-
FeF_2Br	5653	-
FeF_2I	5569	-
$FeCl_2Br$	5339	-
$FeCl_2I$	5272	-
$FeBr_2I$	5209	-
$LiIO_2F_2$	845	-
$NaIO_2F_2$	766	756
KIO_2F_2	699	689
$RbIO_2F_2$	674	-
$CsIO_2F_2$	636	-
$NH_4IO_2F_2$	678	-
$AgIO_2F_2$	736	685
Hydrides		
LiH	916	918
NaH	807	807
KH	711	713
RbH	686	684
CsH	648	653
VH	1184	(1344)
NbH	1163	(1633)
PdH	979	1368
CuH	828	1254
TiH	996	1407
ZrH	916	1590
HfH	904	-
LaH	828	-
TaH	1021	-
CrH	1050	-
NiH	929	-
PtH	937	-
AgH	941	-
AuH	1033	1108
TlH	745	-
GeH	950	-
PbH	778	-
BeH_2	3205	3306
MgH_2	2791	2718
CaH_2	2410	2406
SrH_2	2250	2265
BaH_2	2121	2133
ScH_2	2711	2744
YH_2	(2598)	2733
LaH_2	2380	2522
CeH_2	2414	2509

Table 1
LATTICE ENERGIES (kJ mol^{-1}) (continued)

Substance	Calc. U_{POT}	U_{POT}^{BHFC}
PrH_2	2448	2405
NdH_2	2464	2394
PmH_2	2519	-
SmH_2	2510	2389
GdH_2	2494	2651
AcH_2	2372	-
ThH_2	2711	2738
PuH_2	2519	-
AmH_2	2544	-
TiH_2	2866	2864
ZrH_2	2711	2999
CuH_2	2941	-
ZnH_2	2870	-
HgH_2	2707	-
AlH_3	5924	5969
FeH_3	5724	-
ScH_3	5439	-
YH_3	5063	4910
LaH_3	4895	4493
FeH_3	5724	-
GaH_3	5690	-
InH_3	5092	-
TlH_3	5092	-
Hydroselenides		
NaHSe	703	732
KHSe	644	712
RbHSe	623	689
CsHse	598	669
Hydrosulphides		
LiHS	768	862
NaHS	723	771
RbHS	655	682
CsHS	628	657
NH_4HS	661	718
$Ca(HS)_2$	2184	(2171)
$Sr(HS)_2$	2063	-
$Ba(HS)_2$	1979	(1956)
Hydroxides		
LiOH	1021	1028
NaOH	887	892
KOH	789	796
RbOH	766	765
CsOH	721	732
$Be(OH)_2$	3477	3620
$Mg(OH)_2$	2870	2998
$Ca(OH)_2$	2506	2637
$Sr(OH)_2$	2330	2474
$Ba(OH)_2$	2142	2330
$Ti(OH)_2$	-	2953
$Mn(OH)_2$	2909	3008
$Fe(OH)_2$	2653	3044
$Co(OH)_2$	2786	3109
$Ni(OH)_2$	2832	3186
$Pd(OH)_2$	-	3189
$Cu(OH)_2$	2870	3229
CuOH	1006	-
AgOH	918	845
AuOH	1033	-
TlOH	705	874
$Zn(OH)_2$	2795	3151
$Cd(OH)_2$	2607	2909
$Hg(OH)_2$	2669	-
$Sn(OH)_2$	2489	2721
$Pb(OH)_2$	2376	-
$Sc(OH)_3$	5063	5602
$Y(OH)_3$	4707	-
$La(OH)_3$	4443	-
$Cr(OH)_3$	5556	6299
$Mn(OH)_3$	6213	-
$Al(OH)_3$	5627	-
$Ga(OH)_3$	5732	6368
$In(OH)_3$	5280	-
$Tl(OH)_3$	5314	-
$Ti(OH)_4$	9456	-
$Zr(OH)_4$	8619	-
$Mn(OH)_4$	10933	-
$Sn(OH)_4$	9188	9879
Imides		
CaNH	3293	-
SrNH	3146	-
BaNH	2975	-
Metavanadates		
Li_3VO_4	3945	-
Na_3VO_4	3766	-
K_3VO_4	3376	-
Rb_3VO_4	3243	-
Cs_3VO_4	3137	-
Nitrates		
$LiNO_3$	848	854
$NaNO_3$	755	763
KNO_3	685	694
$RbNO_3$	662	671
$CsNO_3$	648	650
$AgNO_3$	820	832
$TlNO_3$	690	707
$Mg(NO_3)_2$	2481	2521
$Ca(NO_3)_2$	2268	2247
$Sr(NO_3)_2$	2176	2151
$Ba(NO_3)_2$	2062	2035
$Mn(NO_3)_2$	2318	2478
$Fe(NO_3)_2$	-	(2580)
$Co(NO_3)_2$	2560	2647
$Ni(NO_3)_2$	-	2729
$Cu(NO_3)_2$	-	2739
$Zn(NO_3)_2$	2376	2649
$Cd(NO_3)_2$	2238	2462
$Sn(NO_3)_2$	2155	2254
$Pb(NO_3)_2$	2067	2208
Nitrides		
ScN	7547	7506
LaN	6876	6793
TiN	8130	8033

Table 1
LATTICE ENERGIES (kJ mol[-1]) (continued)

Substance	Calc. U_{POT}	U_{POT}^{BHFC}
ZrN	7633	7723
VN	8283	8233
NbN	7939	8022
CrN	8269	8358
Nitrites		
$NaNO_2$	774	772
KNO_2	699	687
$RbNO_2$	724	765
$CsNO_2$	690	-
Oxides		
Li_2O	2799	2814
Na_2O	2481	2478
K_2O	2238	2232
Rb_2O	2163	2161
Cs_2O	2131	2063
Cu_2O	3273	3189
Ag_2O	3002	2910
Tl_2O	2659	2575
LiO_2	(878)	(872)
NaO_2	799	821
KO_2	741	751
RbO_2	706	721
CsO_2	679	696
Li_2O_2	2592	2557
Na_2O_2	2309	22717
K_2O_2	2114	2064
Rb_2O_2	2025	1994
Cs_2O_2	1948	1512
MgO_2	3356	3526
CaO_2	3144	3132
SrO_2	3037	2977
KO_3	697	707
BeO	4514	4443
MgO	3795	3791
CaO	3414	3401
SrO	3217	3223
BaO	3029	3054
TiO	3832	3811
VO	3932	3863
MnO	3724	3745
FeO	3795	3865
CoO	3837	3910
NiO	3908	4010
PdO	3736	-
CuO	4135	4050
ZnO	4142	3971
CdO	3806	-
HgO	3907	-
GeO	3919	-
SnO	3652	-
PbO	3520	-
Sc_2O_3	13557	13708
Y_2O_3	12705	-
La_2O_3	12452	-
Ce_2O_3	12661	-
Pr_2O_3	12703	-
Nd_2O_3	12736	-
Pm_2O_3	12811	-
Sm_2O_3	12878	-
Eu_2O_3	12945	-
Gd_2O_3	12996	-
Tb_2O_3	13071	-
Dy_2O_3	13138	-
Ho_2O_3	13180	-
Er_2O_3	13263	-
Tm_2O_3	13322	-
Yb_2O_3	13380	-
Lu_2O_3	13665	-
Ac_2O_3	12573	-
Ti_2O_3	-	14149
V_2O_3	15096	14520
Cr_2O_3	15276	14957
Mn_2O_3	15146	15035
Fe_2O_3	14309	14774
Al_2O_3	15916	-
Ga_2O_3	15590	15220
In_2O_3	13928	-
Pb_2O_3	(14841)	-
CeO_2	9627	-
ThO_2	10397	-
PaO_2	10573	-
VO_2(g)	10644	-
NpO_2	10707	-
PuO_2	10786	-
AmO_2	10799	-
CmO_2	10832	-
TiO_2	12150	-
ZrO_2	11188	-
MoO_2	11648	-
MnO_2	12970	-
SiO_2	13125	-
GeO_2	12828	-
SnO_2	11807	-
PbO_2	11217	-
Perchlorates		
$LiClO_4$	709	715
$NaClO_4$	643	641
$KClO_4$	599	595
$RbClO_4$	564	576
$CsClO_4$	636	550
NH_4ClO_4	583	580
$Ca(ClO_4)_2$	1958	1971
$Sr(ClO_4)_2$	1862	1862
$Ba(ClO_4)_2$	1795	1769
Permanganates		
$NaMnO_4$	661	-
$KMnO_4$	607	-
$RbMnO_4$	586	-
$CsMnO_4$	565	-
$Ca(MnO_4)_2$	1937	-
$Sr(MnO_4)_2$	1845	-
$Ba(MnO_4)_2$	1778	-

Table 1
LATTICE ENERGIES (kJ mol^{-1}) (continued)

Substance	Calc. U_{POT}	U_{POT}^{BHFC}
Phosphates		
$Mg_3(PO_4)_2$	11632	11407
$Ca_3(PO_4)_2$	10602	10479
$Sr_3(PO_4)_2$	10125	10075
$Ba_3(PO_4)_2$	9652	9654
$MnPO_4$	7397	-
$FePO_4$	7251	7300
BPO_4	8201	-
$AlPO_4$	7427	7507
$GaPO_4$	7381	-
Selenides		
Li_2Se	2364	-
Na_2Se	2130	-
K_2Se	1933	-
Rb_2Se	1837	-
Cs_2Se	1745	-
Ag_2Se	2686	-
Tl_2Se	2209	-
BeSe	3431	-
MgSe	3071	-
CaSe	2858	2862
SrSe	2736	-
BaSe	2611	-
MnSe	3176	-
Selenites		
Li_2SeO_3	2171	-
Na_2SeO_3	1950	1916
K_2SeO_3	1774	1749
Rb_2SeO_3	1715	1675
Cs_2SeO_3	1640	-
Tl_2SeO_3	1879	-
Ag_2SeO_3	2113	2148
$BeSeO_3$	3322	-
$MgSeO_3$	3012	2998
$CaSeO_3$	2732	-
$SrSeO_3$	2586	2588
$BaSeO_3$	2460	2451
Selenates		
Li_2SeO_4	2054	-
Na_2SeO_4	1879	-
K_2SeO_4	1732	-
Rb_2SeO_4	1686	-
Cs_2SeO_4	1615	-
Cu_2SeO_4	2201	-
Ag_2SeO_4	2033	-
Tl_2SeO_4	1766	-
Hg_2SeO_4	2163	-
$BeSeO_4$	3448	-
$MgSeO_4$	2895	-
$CaSeO_4$	2632	-
$SrSeO_4$	2489	-
Sulphides		
Li_2S	2464	2472
Na_2S	2192	2203
K_2S	1979	(2052)
Rb_2S	1929	1949
Cs_2S	1892	1850
$(NH_4)_2S$	2008	(2026)
Cu_2S	2786	2865
Ag_2S	2606	2677
Au_2S	2908	-
Tl_2S	2298	2258
Sulphates		
Li_2SO_4	2229	2142
Na_2SO_4	1827	1938
K_2SO_4	1700	1796
Rb_2SO_4	1636	1748
Cs_2SO_4	1596	1658
$(NH_4)_2SO_4$	1766	1777
Cu_2SO_4	2276	2166
Ag_2SO_4	2104	1989
Tl_2SO_4	1828	1722
Hg_2SO_4	-	2127
$CaSO_4$	2489	2480
$SrSO_4$	2577	2484
$BaSO_4$	2469	2374
$MnSO_4$	2920	2825
Ternary Salts		
Cs_2CuCl_4	1393	-
Rb_2ZnCl_4	1529	-
Cs_2ZnCl_4	1492	-
Rb_2ZnBr_4	1498	-
Cs_2ZnBr_4	1454	-
Cs_2ZnI_4	1386	-
$CsGaCl_4$	494	-
$NaAlCl_4$	556	-
$CsAlCl_4$	486	-
$NaFeCl_4$	492	-
Rb_2CoCl_4	1447	-
Cs_2CoCl_4	1391	-
K_2PtCl_4	1574	1550
Cs_2GeF_6	1573	-
$(NH_4)_2GeF_6$	1657	-
Cs_2GeCl_6	1404	1419
K_2HfCl_6	1345	1461
K_2IrCl_6	1442	1440
Na_2MoCl_6	1526	1504
K_2MoCl_6	1418	1412
Rb_2MoCl_6	1399	1399
Cs_2MoCl_6	1347	1347
K_2NbCl_6	1375	1398
Rb_2NbCl_6	1371	1385
Cs_2NbCl_6	1381	1344
K_2OsCl_6	1447	1447
Cs_2OsCl_6	1409	-
K_2OsBr_6	1396	-
K_2PdCl_6	1481	1493
Rb_2PdCl_6	1449	-
Cs_2PdCl_6	1426	-
Rb_2PbCl_6	1343	1343

Table 1
LATTICE ENERGIES (kJ mol^{-1}) (continued)

Substance	Calc. U_{POT}	U_{POT}^{BHFC}
Cs_2PbCl_6	1344	-
$(NH_4)_2PbCl_6$	1355	-
K_2PtCl_6	1468	1471
Rb_2PtCl_6	1464	-
Cs_2PtCl_6	1444	-
$(NH_4)_2PtCl_6$	1468	-
Tl_2PtCl_6	1546	-
Ag_2PtCl_6	1773	1881
$BaPtCl_6$	2047	2070
K_2PtBr_6	1423	1392
Ag_2PtBr_6	1791	2276
K_2PtI_6	1421	-
K_2ReCl_6	1416	1442
Rb_2ReCl_6	1414	-
Cs_2ReCl_6	1398	-
K_2ReBr_6	1375	1375
K_2SiF_6	1670	1765
Rb_2SiF_6	1639	1673
Cs_2SiF_6	1604	1498
Tl_2SiF_6	1675	-
K_2SnCl_6	1363	1390
Rb_2SnCl_6	1361	1363
Cs_2SnCl_6	1358	-
Tl_2SnCl_6	1437	-
$(NH_4)_2SnCl_6$	1370	1344
Rb_2SnBr_6	1309	-
Cs_2SnBr_6	1306	-
Rb_2SnI_6	1226	-
Cs_2SnBr_6	1243	-
K_2TeCl_6	1318	1320
Rb_2TeCl_6	1321	-
Cs_2TeCl_6	1323	-
Tl_2TeCl_6	1392	-
$(NH_4)_2TeCl_6$	1318	-
K_2RuCl_6	1451	-
Rb_2CoF_6	1688	-
Cs_2CoF_6	1632	-
K_2NiF_6	1721	-
Rb_2NiF_6	1688	-
Rb_2SbCl_6	1357	-
Rb_2SeCl_6	1409	-
Cs_2SeCl_6	1397	-
$(NH_4)_2SeCl_6$	1420	-
$(NH_4)_2PoCl_6$	1338	-
Cs_2PoBr_6	1286	-
Cs_2CrF_6	1603	-
Rb_2MnF_6	1688	-
Cs_2MnF_6	1620	-
K_2MnCl_6	1462	-
Rb_2MnCl_6	1451	-
$(NH_4)_2MnCl_6$	1464	-
Cs_2TeBr_6	1306	-
Cs_2TeI_6	1246	-
K_2TiCl_6	1412	1447
Rb_2TiCl_6	1415	1416
Cs_2TiCl_6	1402	1384
Tl_2TiCl_6	1560	1553
K_2TiBr_6	1379	1379
Rb_2TiBr_6	1341	1331
Cs_2TiBr_6	1339	1306
Na_2UBr_6	1504	-
K_2UBr_6	1484	-
Rb_2UBr_6	1473	-
Cs_2UBr_6	1459	-
K_2WCl_6	1398	1423
Rb_2WCl_6	1397	1434
Cs_2WCl_6	1392	1366
K_2WBr_6	1408	1408
Rb_2WBr_6	1361	1391
Cs_2WBr_6	1362	1332
K_2ZrCl_6	1339	1371
Rb_2ZrCl_6	1341	-
Cs_2ZrCl_6	1339	1307
Tellurides		
Li_2Te	2212	-
Na_2Te	1997	2095
K_2Te	1830	-
Rb_2Te	1837	-
Cs_2Te	1745	-
Cu_2Te	2706	2683
Ag_2Te	2607	2600
Tl_2Te	2084	2172
BeTe	3319	-
MgTe	2878	3081
CaTe	2721	-
Thiocyanates		
LiCNS	764	(765)
NaCNS	682	682
KCNS	623	616
RbCNS	623	619
CsCNS	623	568
NH_4CNS	605	611
$Ca(CNS)_2$	2184	2118
$Sr(CNS)_2$	2063	1957
$Ba(CNS)_2$	1979	1852
$Mn(CNS)_2$	2280	2351
$Zn(CNS)_2$	2335	2560
$Cd(CNS)_2$	2201	2374
$Hg(CNS)_2$	2146	2492
$Sn(CNS)_2$	2117	2142
$Pb(CNS)_2$	2058	-
Vanadates		
$LiVO_3$	810	-
$NaVO_3$	761	-
KVO_3	686	-
$RbVO_3$	657	-
$CsVO_3$	628	-

Table 2
THERMOCHEMICAL RADII (nm)

Ion	Radius	
Singly Charged Anions		
AgF_4^-	0.231	± 0.019
$AlBr_4^-$	0.321	± 0.023
$AlCl_4^-$	0.317	± 0.019
AlF_4^-	0.214	± 0.023
AlH_4^-	0.226	± 0.019
AlI_4^-	0.374	± 0.019
AsF_6^-	0.243	± 0.019
AsO_2^-	0.211	± 0.019
$Au(CN)_2^-$	0.266	± 0.019
$AuCl_4^-$	0.288	± 0.019
AuF_4^-	0.240	± 0.019
AuF_6^-	0.235	± 0.038
$B(OH)_4^-$	0.229	± 0.019
BF_4^-	0.205	± 0.019
BH_4^-	0.205	± 0.019
Br^-	0.190	± 0.019
BrF_4^-	0.231	± 0.019
BrO_3^-	0.214	± 0.019
$CF_3SO_3^-$	0.230	± 0.049
$CH_3CO_2^-$	0.194	± 0.019
Cl^-	0.168	± 0.019
ClO_2^-	0.195	± 0.019
ClO_3^-	0.208	± 0.019
ClO_4^-	0.225	± 0.019
$ClS_2O_6^-$	0.260	± 0.049
CN^-	0.187	± 0.023
$Cr_3O_8^-$	0.276	± 0.019
$CuBr_4^-$	0.315	± 0.019
F^-	0.126	± 0.019
$FeCl_4^-$	0.317	± 0.019
$GaCl_4^-$	0.328	± 0.019
H^-	0.148	± 0.019
$H_2AsO_4^-$	0.227	± 0.019
$H_2PO_4^-$	0.213	± 0.019
HCO_2^-	0.200	± 0.019
HCO_3^-	0.207	± 0.019
HF_2^-	0.172	± 0.019
HSO_4^-	0.221	± 0.019
I^-	0.211	± 0.019
I_2Br^-	0.261	± 0.019
I_3^-	0.272	± 0.019
I_4^-	0.300	± 0.019
IBr_2^-	0.251	± 0.019
ICl_2^-	0.235	± 0.019
ICl_4^-	0.307	± 0.019
$IO_2F_2^-$	0.233	± 0.019
IO_3^-	0.218	± 0.019
IO_4^-	0.231	± 0.019
IrF_6^-	0.242	± 0.019
MnO_4^-	0.220	± 0.019
MoF_6^-	0.241	± 0.019
$MoOF_5^-$	0.241	± 0.019
N_3^-	0.180	± 0.019
NCO^-	0.193	± 0.019
$NbCl_6^-$	0.338	± 0.049
NbF_6^-	0.254	± 0.019
$Nb_2F_{11}^-$	0.311	± 0.038
NbO_3^-	0.194	± 0.019
NH_2^-	0.168	± 0.019
$NH_2CH_2COO^-$	0.252	± 0.019
NO_2^-	0.187	± 0.019
NO_3^-	0.200	± 0.019
O_2^-	0.165	± 0.019
O_3^-	0.199	± 0.034
OH^-	0.152	± 0.019
OsF_6^-	0.252	± 0.020
PaF_6^-	0.249	± 0.019
PdF_6^-	0.252	± 0.019
PF_6^-	0.242	± 0.019
PO_3^-	0.204	± 0.019
PtF_6^-	0.247	± 0.019
PuF_5^-	0.239	± 0.019
ReF_6^-	0.240	± 0.019
ReO_4^-	0.227	± 0.019
RuF_6^-	0.242	± 0.019
S_6^-	0.305	± 0.019
SCN^-	0.209	± 0.019
$SbCl_6^-$	0.320	± 0.019
SbF_6^-	0.252	± 0.019
$Sb_2F_{11}^-$	0.312	± 0.038
$Sb_3F_{14}^-$	0.374	± 0.038
$SeCl_5^-$	0.258	± 0.038
$SeCN^-$	0.230	± 0.019
SeH^-	0.195	± 0.019
SH^-	0.191	± 0.019
SO_3F^-	0.214	± 0.019
$S_3N_3^-$	0.231	± 0.038
$S_3N_3O_4^-$	0.252	± 0.038
$TaCl_6^-$	0.352	± 0.019
TaF_6^-	0.250	± 0.019
TaO_3^-	0.192	± 0.019
UF_6^-	0.301	± 0.019
VF_6^-	0.235	± 0.019
VO_3^-	0.201	± 0.019
WCl_6^-	0.337	± 0.019
WF_6^-	0.246	± 0.019
WOF_5^-	0.241	± 0.019
Doubly Charged Anions		
AmF_6^{2-}	0.255	± 0.019
$Bi_2Br_8^{2-}$	0.392	± 0.055
$Bi_6Cl_{20}^{2-}$	0.501	± 0.073
$CdCl_4^{2-}$	0.307	± 0.019
$CeCl_6^{2-}$	0.352	± 0.019
CeF_6^{2-}	0.249	± 0.019
CO_3^{2-}	0.189	± 0.019
$CoCl_4^{2-}$	0.306	± 0.019
CoF_4^{2-}	0.209	± 0.019
CoF_6^{2-}	0.256	± 0.019
$Cr_2O_7^{2-}$	0.292	± 0.019
CrF_6^{2-}	0.253	± 0.019
CrO_4^{2-}	0.229	± 0.019

Table 2
THERMOCHEMICAL RADII (nm) (continued)

Ion	Radius
$CuCl_4^{2-}$	0.304 ± 0.019
CuF_4^{2-}	0.213 ± 0.019
$GeCl_6^{2-}$	0.335 ± 0.019
GeF_6^{2-}	0.244 ± 0.019
HfF_6^{2-}	0.248 ± 0.019
HgI_4^{2-}	0.377 ± 0.019
$IrCl_6^{2-}$	0.332 ± 0.019
$MnCl_6^{2-}$	0.314 ± 0.031
MnF_4^{2-}	0.219 ± 0.019
MnF_6^{2-}	0.241 ± 0.019
$MoBr_6^{2-}$	0.364 ± 0.019
$MoCl_6^{2-}$	0.338 ± 0.019
MoF_6^{2-}	0.274 ± 0.019
MoO_4^{2-}	0.231 ± 0.019
$NbCl_6^{2-}$	0.343 ± 0.019
NH^{2-}	0.128 ± 0.019
$Ni(CN)_4^{2-}$	0.322 ± 0.019
NiF_4^{2-}	0.211 ± 0.019
NiF_6^{2-}	0.249 ± 0.019
O^{2-}	0.141 ± 0.019
O_2^{2-}	0.167 ± 0.019
$OsBr_6^{2-}$	0.365 ± 0.019
$OsCl_6^{2-}$	0.336 ± 0.019
OsF_6^{2-}	0.276 ± 0.019
$PbCl_4^{2-}$	0.279 ± 0.019
$PbCl_6^{2-}$	0.347 ± 0.019
PbF_6^{2-}	0.268 ± 0.019
$PdBr_6^{2-}$	0.354 ± 0.019
$PdCl_4^{2-}$	0.313 ± 0.019
$PdCl_6^{2-}$	0.333 ± 0.019
PdF_6^{2-}	0.252 ± 0.019
$PoBr_6^{2-}$	0.380 ± 0.019
PoI_6^{2-}	0.428 ± 0.019
$Pt(NO_2)_3Cl_3^{2-}$	0.364 ± 0.019
$Pt(NO_2)_4Cl_2^{2-}$	0.383 ± 0.019
$Pt(OH)_2^{2-}$	0.333 ± 0.019
$Pt(SCN)_6^{2-}$	0.451 ± 0.019
$PtBr_4^{2-}$	0.324 ± 0.019
$PtBr_6^{2-}$	0.363 ± 0.019
$PtCl_4^{2-}$	0.307 ± 0.019
$PtCl_6^{2-}$	0.333 ± 0.019
PtF_6^{2-}	0.245 ± 0.019
$PuCl_6^{2-}$	0.349 ± 0.019
$ReBr_6^{2-}$	0.371 ± 0.019
$ReCl_6^{2-}$	0.337 ± 0.019
ReF_6^{2-}	0.256 ± 0.019
ReF_8^{2-}	0.276 ± 0.019
ReH_9^{2-}	0.257 ± 0.019
ReI_6^{2-}	0.421 ± 0.026
RhF_6^{2-}	0.240 ± 0.019
$RuCl_6^{2-}$	0.336 ± 0.019
RuF_6^{2-}	0.248 ± 0.019
S^{2-}	0.189 ± 0.019
$S_2O_3^{2-}$	0.251 ± 0.019
$S_2O_4^{2-}$	0.262 ± 0.019
$S_2O_5^{2-}$	0.270 ± 0.019
$S_2O_6^{2-}$	0.283 ± 0.019
$S_2O_7^{2-}$	0.275 ± 0.019
$S_2O_8^{2-}$	0.291 ± 0.019
$S_3O_6^{2-}$	0.302 ± 0.019
$S_4O_6^{2-}$	0.325 ± 0.019
$S_6O_6^{2-}$	0.382 ± 0.019
ScF_6^{2-}	0.276 ± 0.019
Se^{2-}	0.181 ± 0.019
$SeBr_6^{2-}$	0.363 ± 0.019
$SeCl_6^{2-}$	0.336 ± 0.019
SeO_4^{2-}	0.229 ± 0.019
SiF_6^{2-}	0.248 ± 0.019
SiO_3^{2-}	0.195 ± 0.019
SmF_4^{2-}	0.218 ± 0.019
$Sn(OH)_6^{2-}$	0.279 ± 0.020
$SnBr_6^{2-}$	0.374 ± 0.019
$SnCl_6^{2-}$	0.345 ± 0.019
SnF_6^{2-}	0.265 ± 0.019
SnI_6^{2-}	0.427 ± 0.019
SO_3^{2-}	0.204 ± 0.019
SO_4^{2-}	0.218 ± 0.019
$TcBr_6^{2-}$	0.363 ± 0.019
$TcCl_6^{2-}$	0.337 ± 0.019
TcF_6^{2-}	0.244 ± 0.019
TcH_9^{2-}	0.260 ± 0.019
TcI_6^{2-}	0.419 ± 0.019
Te^{2-}	0.220 ± 0.019
$TeBr_6^{2-}$	0.383 ± 0.019
$TeCl_6^{2-}$	0.353 ± 0.019
TeI_6^{2-}	0.430 ± 0.019
TeO_4^{2-}	0.238 ± 0.019
$Th(NO_3)_6^{2-}$	0.424 ± 0.019
$ThCl_6^{2-}$	0.360 ± 0.019
ThF_6^{2-}	0.263 ± 0.019
$TiBr_6^{2-}$	0.356 ± 0.019
$TiCl_6^{2-}$	0.335 ± 0.019
TiF_6^{2-}	0.252 ± 0.019
UCl_6^{2-}	0.354 ± 0.019
UF_6^{2-}	0.256 ± 0.019
VO_3^{2-}	0.204 ± 0.019
WBr_6^{2-}	0.363 ± 0.019
WCl_6^{2-}	0.339 ± 0.019
WO_4^{2-}	0.237 ± 0.019
$WOCl_5^{2-}$	0.334 ± 0.019
$ZnBr_4^{2-}$	0.335 ± 0.019
$ZnCl_4^{2-}$	0.306 ± 0.019
ZnF_4^{2-}	0.219 ± 0.019
ZnI_4^{2-}	0.384 ± 0.019
$ZrBr_4^{2-}$	0.334 ± 0.019
$ZrCl_4^{2-}$	0.306 ± 0.019
$ZrCl_6^{2-}$	0.348 ± 0.019
ZrF_6^{2-}	0.258 ± 0.019
Multi-Charged Anions	
AlH_6^{3-}	0.256 ± 0.042
AsO_4^{3-}	0.237 ± 0.042
$CdBr_6^{4-}$	0.374 ± 0.038

Table 2
THERMOCHEMICAL RADII (nm) (continued)

Ion	Radius	
$CdCl_6^{4-}$	0.352	± 0.038
CeF_6^{3-}	0.278	± 0.038
CeF_7^{3-}	0.282	± 0.038
$Co(CN)_6^{3-}$	0.349	± 0.038
$Co(NO_2)_6^{3-}$	0.343	± 0.038
$CoCl_5^{3-}$	0.320	± 0.038
CoF_6^{3-}	0.258	± 0.042
$Cr(CN)_6^{3-}$	0.351	± 0.038
CrF_6^{3-}	0.254	± 0.042
$Cu(CN)_4^{3-}$	0.312	± 0.038
$Fe(CN)_6^{3-}$	0.347	± 0.038
FeF_6^{3-}	0.298	± 0.042
HfF_7^{3-}	0.277	± 0.042
InF_6^{3-}	0.268	± 0.038
$Ir(CN)_6^{3-}$	0.347	± 0.038
$Ir(NO_2)_6^{3-}$	0.338	± 0.038
$Mn(CN)_6^{3-}$	0.350	± 0.038
$Mn(CN)_6^{5-}$	0.401	± 0.042
$MnCl_6^{4-}$	0.349	± 0.038
N^{3-}	0.180	± 0.042
$Ni(NO_2)_6^{3-}$	0.342	± 0.038
$Ni(NO_2)_6^{4-}$	0.383	± 0.038
NiF_6^{3-}	0.250	± 0.042
O^{3-}	0.288	± 0.038
P^{3-}	0.224	± 0.042
PaF_8^{3-}	0.299	± 0.042
PO_4^{3-}	0.230	± 0.042
PrF_6^{3-}	0.281	± 0.038
$Rh(NO_2)_6^{3-}$	0.345	± 0.038
$Rh(SCN)_6^{3-}$	0.428	± 0.042
TaF_8^{3-}	0.284	± 0.042
TbF_7^{3-}	0.290	± 0.038
$Tc(CN)_6^{5-}$	0.410	± 0.042
ThF_7^{3-}	0.282	± 0.042
$TiBr_6^{3-}$	0.315	± 0.038
TlF_6^{3-}	0.271	± 0.038
UF_7^{3-}	0.285	± 0.042
YF_6^{3-}	0.275	± 0.038
ZrF_7^{3-}	0.273	± 0.038
Singly Charged Cations		
$N(CH_3)_4^+$	0.234	± 0.019
$N_2H_5^+$	0.158	± 0.019
$N_2H_6^{2+}$	0.158	± 0.029
$NH(C_2H_5)_3^+$	0.274	± 0.019
$NH_3C_2H_5^+$	0.193	± 0.019
$NH_3C_3H_7^+$	0.225	± 0.019
$NH_3CH_3^+$	0.177	± 0.019
NH_3OH^+	0.147	± 0.019
NH_4^+	0.136	± 0.019
$NH_3C_2H_4OH^+$	0.203	± 0.019
$As_3S_4^+$	0.244	± 0.027
$As_3Se_4^+$	0.253	± 0.027
$AsCl_4^+$	0.221	± 0.027
Br_2^+	0.155	± 0.027
Br_3^+	0.204	± 0.027
Br_3^-	0.238	± 0.027

Ion	Radius	
Br_5^+	0.229	± 0.027
$BrClCNH_2^+$	0.175	± 0.027
BrF_2^+	0.183	± 0.027
BrF_4^+	0.172	± 0.027
$C_{10}F_8^+$	0.265	± 0.027
$C_6F_6^+$	0.228	± 0.027
$Cl(SNSCN)_2^+$	0.347	± 0.027
$Cl_2C{=}NH_2^+$	0.173	± 0.027
Cl_2F^+	0.165	± 0.027
Cl_3^+	0.182	± 0.027
ClF_2^+	0.147	± 0.027
ClO_2^+	0.118	± 0.027
$GaBr_4^-$	0.317	± 0.038
I_2^+	0.185	± 0.027
I_3^+	0.225	± 0.027
I_5^+	0.263	± 0.027
IBr_2^+	0.196	± 0.027
ICl_2^+	0.175	± 0.036
IF_6^+	0.209	± 0.027
$N(S_3N_2)_2^+$	0.258	± 0.027
$N(SCl)_2^+$	0.186	± 0.027
$N(SeCl)_2^+$	0.246	± 0.027
$N(SF_2)_2^+$	0.214	± 0.027
N_2F^+	0.156	± 0.027
NO^+	0.145	± 0.027
NO_2^+	0.153	± 0.027
O_2^+	0.140	± 0.027
$O_2(SCCF_3Cl)_2^+$	0.275	± 0.027
$ONCH_3CF_3^+$	0.200	± 0.027
$OsOF_5^-$	0.246	± 0.038
$P(CH_3)_3Cl^+$	0.197	± 0.027
$P(CH_3)_3D^+$	0.196	± 0.027
PCl_4^+	0.235	± 0.027
$ReOF_5^-$	0.245	± 0.038
$S(CH_3)_2Cl^+$	0.207	± 0.027
$S(N(C_2H_5)_3)_3^+$	0.439	± 0.027
$S_2(CH_3)_2Cl^+$	0.265	± 0.027
$S_2(CH_3)_2CN^+$	0.223	± 0.027
$S_2(CH_3)_3^+$	0.233	± 0.027
$S_2Br_5^+$	0.267	± 0.027
S_2N^+	0.159	± 0.034
$S_2N_2C_2H_3^+$	0.211	± 0.027
$S_2NC_2(PhCH_3)_2^+$	0.310	± 0.027
$S_2NC_3H_4^+$	0.218	± 0.027
$S_2NC_4H_8^+$	0.225	± 0.027
$S_3(CH_3)_3^+$	0.239	± 0.027
$S_3Br_3^+$	0.245	± 0.027
$S_3C_3H_7^+$	0.199	± 0.027
$S_3C_4F_6^+$	0.261	± 0.027
$S_3CF_3CN^+$	0.263	± 0.027
$S_3Cl_3^+$	0.233	± 0.027
$S_3N_2^+$	0.201	± 0.027
$S_3N_2Cl^+$	0.232	± 0.027
$S_4N_3^+$	0.231	± 0.027
$S_4N_3(Ph)_2^+$	0.316	± 0.027
$S_4N_4H^+$	0.178	± 0.027

Table 2
THERMOCHEMICAL RADII (nm) (continued)

Ion	Radius	
$S_5N_5^+$	0.257	± 0.027
S_7I^+	0.262	± 0.027
$Sb(NPPh_3)_4^+$	0.518	± 0.027
SBr_3^+	0.220	± 0.027
$SCH_3O_2^+$	0.183	± 0.027
$SCH_3P(CH_3)_3^+$	0.248	± 0.027
$SCH_3PCH_3Cl_2^+$	0.205	± 0.027
$SCl(C_2H_5)_2^+$	0.207	± 0.027
$SCl_2CF_3^+$	0.207	± 0.027
$SCl_2CH_3^+$	0.204	± 0.027
SCl_3^+	0.185	± 0.027
$Se_3Br_3^+$	0.253	± 0.027
$Se_3Cl_3^+$	0.245	± 0.027
$Se_3N_2^+$	0.288	± 0.042
$Se_3NC_{l2}^+$	0.163	± 0.027
Se_6I^+	0.260	± 0.027
$SeBr_3^+$	0.182	± 0.027
$SeCl_3^+$	0.192	± 0.027
SeF_3^+	0.179	± 0.027
SeI_3^+	0.238	± 0.027
SeN_2Cl^+	0.196	± 0.027
$SeNCl_2^+$	0.157	± 0.027
$(SeNMe_3)_3^+$	0.406	± 0.027
$SeS_2N_2^+$	0.282	± 0.042
$SF(C_6F_5)_2^+$	0.294	± 0.027
$SF_2CF_3^+$	0.198	± 0.027
$SF_2N(CH_3)_2^+$	0.210	± 0.027
SF_3^+	0.172	± 0.027
$SFS(C(CF_3)_2)_2^+$	0.275	± 0.027
$SH_2C_3H_7^+$	0.210	± 0.027
SN^+	0.158	± 0.027
$SNCl_5(CH_3CN)^-$	0.290	± 0.038
$(SNPMe_3)_3^+$	0.308	± 0.027
$SNSC(CH_3)N^+$	0.225	± 0.027
$SNSC(CN)CH^+$	0.209	± 0.027
$SNSC(Ph)N^+$	0.251	± 0.027
$SNSC(Ph)NS_3N_2^+$	0.327	± 0.027
$SNSC(PhCH_3)N^+$	0.264	± 0.027
$(Te(N(SiMe_3)_2)_2^+$	0.371	± 0.027
$Te(N_3)_3^+$	0.226	± 0.027
$Te_4Nb_3OTe_2I_6^+$	0.407	± 0.027
$TeBr_3^+$	0.235	± 0.027
$TeCl_3^+$	0.216	± 0.027
$TeCl_3$(15-crown-5)$^+$	0.282	± 0.027
TeI_3^+	0.243	± 0.027
$Xe_2F_{11}^+$	0.266	± 0.027
$Xe_2F_3^+$	0.221	± 0.027
XeF^+	0.174	± 0.027
XeF_3^+	0.183	± 0.027
XeF_5^+	0.186	± 0.027
$XeOF_3^+$	0.186	± 0.027
Doubly Charged Cations		
$Co_2S_2(CO)_6^{2+}$	0.263	± 0.035
$FeW(Se)_2(CO)^{2+}$	0.260	± 0.035
I_4^{2+}	0.207	± 0.035
$Mo(Te_3)(CO)_4^{2+}$	0.234	± 0.035
S_{19}^{2+}	0.292	± 0.035
$S_2(S(CH_3)_2)_2^{2+}$	0.230	± 0.035
$S_2I_4^{2+}$	0.231	± 0.035
$S_3N_2^{2+}$	0.184	± 0.035
$S_3NCCNS_3^{2+}$	0.220	± 0.035
S_3Se^{2+}	0.326	± 0.035
$S_4N_4^{2+}$	0.186	± 0.035
$S_6N_4^{2+}$	0.232	± 0.035
S_8^{2+}	0.182	± 0.035
Se_{10}^{2+}	0.253	± 0.035
Se_{17}^{2+}	0.236	± 0.035
Se_{19}^{2+}	0.296	± 0.035
$Se_2I_4^{2+}$	0.218	± 0.035
$Se_3N_2^{2+}$	0.182	± 0.035
Se_4^{2+}	0.152	± 0.035
$Se_4S_2N_4^{2+}$	0.224	± 0.035
Se_8^{2+}	0.186	± 0.035
$SeN_2S_2^{2+}$	0.182	± 0.035
$(SNP(C_2H_5)_3)_2^{2+}$	0.312	± 0.035
$TaBr_6^-$	0.351	± 0.049
$Te(trtu)_4^{2+}$	0.328	± 0.035
$Te(tu)_4^{2+}$	0.296	± 0.035
$Te_2(esu)_4Br_2^{2+}$	0.356	± 0.035
$Te_2(esu)_4Cl_2^{2+}$	0.361	± 0.035
$Te_2(esu)_4I_2^{2+}$	0.342	± 0.035
$Te_2Se_2^{2+}$	0.192	± 0.035
$Te_2Se_4^{2+}$	0.222	± 0.035
$Te_2Se_8^{2+}$	0.252	± 0.035
$Te_3S_3^{2+}$	0.217	± 0.035
Te_3Se^{2+}	0.193	± 0.035
Te_4^{2+}	0.169	± 0.035
Te_8^{2+}	0.187	± 0.035
$W(CO)_4$(h3-Te)$^{2+}$	0.234	± 0.035
$W_2(CO)_{10}Se_4^{2+}$	0.290	± 0.035
Multi-Charged Cations		
I_{15}^{3+}	0.442	± 0.051
$Te_2(su)_6^{4+}$	0.453	± 0.034

Ligand abbreviations: su = selenourea; esu = ethyleneselenourea; tu = thiourea; ph = phenyl.

Table 3
ANCILLARY THERMOCHEMICAL DATA (kJ mol^{-1})

Species	State	$\Delta_f H^o$
AsO_4^{3-}	g	(289)
BrO_3^-	g	-145
ClO_4^-	g	-344
CN^-	g	66
CO_3^{2-}	g	-321
$Fe(NO_3)_2$	c	(-448)
HF_2^-	g	-774
$HfCl_6^{2-}$	g	-1640
$IO_2F_2^-$	g	-693
IO_3^-	g	-208
$IrCl_6^{2-}$	g	-785
$LiCH_3O_2$	c	(-745)
$NbCl_6^{2-}$	g	-1224
$NH_2CH_2CO_2^-$	g	-564
O_2^{2-}	g	553
$PdCl_6^{2-}$	g	-749
PO_4^-	g	291
$PtCl_6^{2-}$	g	-774
$ReBr_6^{2-}$	g	-689
$ReCl_6^{2-}$	g	-919
$Ti(OH)_2$	c	-778

THE MADELUNG CONSTANT AND CRYSTAL LATTICE ENERGY

If U is the crystal lattice energy and M is the Madelung constant, then[a]

$$U = \frac{N M z_i z_j \; e^2}{r}(1 - 1/n)$$

Substance	Ion type	Crystal form[b]	*M*
Sodium chloride, NaCl	M^+, X^-	FCC	1.74756
Cesium chloride, CsCl	M^+, X^-	BCC	1.76267
Calcium chloride, $CaCl_2$	M^{++}, $2X^-$	Cubic	2.365
Calcium fluoride (fluorite), CaF_2	M^{++}, $2X^-$	Cubic	2.51939
Cadmium chloride, $CdCl_2$	M^{++}, $2X^-$	Hexagonal	2.244[c]
Cadmium iodide (α), CdI_2	M^{++}, $2X^-$	Hexagonal	2.355[c]
Magnesium fluoride, MgF_2	M^{++}, $2X^-$	Tetragonal	2.381[c]
Cuprous oxide (cuprite), Cu_2O	$2M^+$, X^{--}	Cubic	2.22124
Zinc oxide, ZnO	M^{++}, X^{--}	Hexagonal	1.4985[c]
Sphalerite (zinc blende), ZnS	M^{++}, X^{--}	FCC	1.63806
Wurtzite, ZnS	M^{++}, X^{--}	Hexagonal	1.64132[c]
Titanium dioxide (anatase), TiO_2	M^{4+}, $2X^{--}$	Tetragonal	2.400[c]
Titanium dioxide (rutile), TiO_2	M^{4+}, $2X^{--}$	Tetragonal	2.408[c]
β-Quartz, SiO_2	M^{4+}, $2X^{--}$	Hexagonal	2.2197[c]
Corundum, Al_2O_3	$2M^{3+}$, $3X^{--}$	Rhombohedral	4.1719

[a] N is Avogadro's number, z_i and z_j are the integral charges on the ions(in units of e), and e is the charge on the electron in electrostatic units ($e = 4.803 \times 10^{-10}$ esu). r is the shortest distance between cation-anion pairs in centimeters. Then U is in ergs (1 erg = 10^{-7} J).

[b] FCC = face centered cubic; BCC = body centered cubic.

[c] For tetragonal and hexagonal crystals the value of M depends on the details of the lattice parameters.

The Born Exponent, n is:

Ion type	*n*
He, Li^+	5
Ne, Na^+, F^-	7
Ar, K^+, Cu^+, Cl^-	9
Kr, Rb^+, Ag^+, Br^-	10
Xe, Cs^+, Au^+, I^-	12

For a crystal with a mixed-ion type, an average of the values of n in this table is to be used (6 for LiF, for example).

ELASTIC CONSTANTS OF SINGLE CRYSTALS

H. P. R. Frederikse

This table gives selected values of elastic constants for single crystals. The values believed most reliable were selected from the original literature. The substances are arranged by crystal system and, within each system, alphabetically by name. A reference to the original literature is given for each value; a useful compilation of published values from many sources may be found in Reference 1 below.

Data are given for the single-crystal density and for the elastic constants c_{ij}, in units of 10^{11} N/m^2, which is equivalent to 10^{12} dyn/cm^2.

GENERAL REFERENCES

1. Simmons, G., and Wang, H., *Single Crystal Elastic Constants and Calculated Aggregate Properties: A Handbook, Second Edition*, The MIT Press, Cambridge, MA, 1971.
2. Gray, D.E., Ed., *American Institute of Physics Handbook, Third Edition*, McGraw-Hill, New York, 1972.

CUBIC CRYSTALS

Name	Formula	ρ/g cm^{-3}	*T*/K	Ref.	C_{11}	C_{12}	C_{44}
Aluminum	Al	2.6970	298	1	1.0675	0.6041	0.2834
Aluminum antimonide	AlSb	4.3600	300	2	0.8939	0.4427	0.4155
Ammonium bromide	NH_4Br	2.4314	300	3	0.3414	0.0782	0.0722
Ammonium chloride	NH_4Cl	1.5279	290	4	0.3814	0.0866	0.0903
Argon	Ar	1.7710	4.2	5	0.0529	0.0135	0.0159
Barium fluoride	BaF_2	4.8860	298	6	0.9199	0.4157	0.2568
Barium nitrate	$Ba(NO_3)_2$	3.2560	293	7	0.2925	0.2065	0.1277
Calcium fluoride	CaF_2	3.810	298	8	1.6420	0.4398	0.8406
Calcium telluride	CaTe	5.8544	298	9	0.5351	0.3681	0.1994
Cesium	Cs	1.9800	78	10	0.0247	0.0206	0.0148
Cesium bromide	CsBr	4.4560	298	11	0.3063	0.0807	0.0750
Cesium chloride	CsCl	3.9880	298	11	0.3644	0.0882	0.0804
Cesium iodide	CsI	4.5250	298	11	0.2446	0.0661	0.0629
Chromite	$FeCr_2O_4$	4.4500	RT	12	3.2250	1.4370	1.1670
Chromium	Cr	7.20	298	13	3.398	0.586	0.990
Cobalt oxide	CoO	6.44	298	14	2.6123	1.4699	0.8300
Cobalt zinc ferrite	$CoZnFeO_2$	5.43	303	12	2.660	1.530	0.780
Copper	Cu	8.932	298	15	1.683	1.221	0.757
Gallium antimonide	GaSb	5.6137	298	16	0.8839	0.4033	0.4316
Gallium arsenide	GaAs	5.3169	298	17	1.1877	0.5372	0.5944
Gallium phosphide	GaP	4.1297	300	18	1.4120	0.6253	0.7047
Garnet (yttrium-iron)	$Y_3Fe_2(FeO_4)_3$	5.17	298	19	2.680	1.106	0.766
Germanium	Ge	5.313	298	20	1.2835	0.4823	0.6666
Gold	Au	19.283	296.5	21	1.9244	1.6298	0.4200
Indium antimonide	InSb	5.7890	298	22	0.6720	0.3670	0.3020
Indium arsenide	InAs	5.6720	293	23	0.8329	0.4526	0.3959
Indium phosphide	InP	4.78	RT	24	1.0220	0.5760	0.4600
Iridium	Ir	22.52	300	25	5.80	2.42	2.56
Iron	Fe	7.8672	298	26	2.26	1.40	1.16
Lead	Pb	11.34	296	27	0.4966	0.4231	0.1498
Lead fluoride	PbF_2	7.79	300	28	0.8880	0.4720	0.2454
Lead nitrate	$Pb(NO_3)_2$	4.547	293	29	0.3729	0.2765	0.1347
Lead telluride	PbTe	8.2379	303.2	30	1.0795	0.0764	0.1343
Lithium	Li	0.5326	298	31	0.1350	0.1144	0.0878
Lithium bromide	LiBr	3.47	RT	32	0.3940	0.1880	0.1910
Lithium chloride	LiCl	2.068	295	33	0.4927	0.2310	0.2495
Lithium fluoride	LiF	2.638	RT	34	1.1397	0.4767	0.6364
Lithium iodide	LiI	4.061	RT	32	0.2850	0.1400	0.1350
Magnesium oxide	MgO	3.579	298	20	2.9708	0.9536	1.5613
Magnetite	Fe_3O_4	5.18	RT	32	2.730	1.060	0.971
Manganese oxide	MnO	5.39	298	35	2.23	1.20	0.79
Mercury telluride	HgTe	8.079	290	36	0.548	0.381	0.204
Molybdenum	Mo	10.2284	273	37	4.637	1.578	1.092

CUBIC CRYSTALS (continued)

Name	Formula	ρ/g cm^{-3}	*T*/K	Ref.	C_{11}	C_{12}	C_{44}
Nickel	Ni	8.91	298	15	2.481	1.549	1.242
Niobium	Nb	8.578	300	38	2.4650	1.3450	0.2873
Palladium	Pd	12.038	300	39	2.2710	1.7604	0.7173
Platinum	Pt	21.50	300	40	3.4670	2.5070	0.7650
Potassium	K	0.851	295	41	0.0370	0.0314	0.0188
Potassium bromide	KBr	2.740	298	11	0.3468	0.0580	0.0507
Potassium chloride	KCl	1.984	298	11	0.4069	0.0711	0.0631
Potassium cyanide	KCN	1.553	RT	32	0.1940	0.1180	0.0150
Potassium fluoride	KF	2.480	295	33	0.6490	0.1520	0.1232
Potassium iodide	KI	3.128	300	42	0.2710	0.0450	0.0364
Pyrite	FeS_2	5.016	RT	43	3.818	0.310	1.094
Rubidium	Rb	1.58	170	44	0.0296	0.0250	0.0171
Rubidium bromide	RbBr	3.350	300	45	0.3152	0.0500	0.0380
Rubidium chloride	RbCl	2.797	300	45	0.3624	0.0612	0.0468
Rubidium iodide	RbI	3.551	300	45	0.2556	0.0382	0.0278
Silicon	Si	2.331	298	46	1.6578	0.6394	0.7962
Silver	Ag	10.50	300	47	1.2399	0.9367	0.4612
Silver bromide	AgBr	5.585	300	48	0.5920	0.3640	0.0616
Sodium	Na	0.971	299	49	0.0739	0.0622	0.0419
Sodium bromate	$NaBrO_3$	3.339	RT	32	0.5450	0.1910	0.1500
Sodium bromide	NaBr	3.202	300	33	0.3970	0.1001	0.0998
Sodium chlorate	$NaClO_3$	2.485	RT	50	0.4920	0.1420	0.1160
Sodium chloride	NaCl	2.163	298	11	0.4947	0.1288	0.1287
Sodium fluoride	NaF	2.804	300	51	0.9700	0.2380	0.2822
Sodium iodide	NaI	3.6689	300	52	0.3007	0.0912	0.0733
Spinel	$MgAl_2O_4$	3.6193	298	53	2.9857	1.5372	1.5758
Strontium fluoride	SrF_2	4.277	300	54	1.2350	0.4305	0.3128
Strontium nitrate	$Sr(NO_3)_2$	2.989	293	29	0.4255	0.2921	0.1590
Strontium oxide	SrO	4.99	300	55	1.601	0.435	0.590
Strontium titanate	$SrTiO_3$	5.123	RT	56	3.4817	1.0064	4.5455
Tantalum	Ta	16.626	298	57	2.6023	1.5446	0.8255
Tantalum carbide	TaC	14.65	RT	58	5.05	0.73	0.79
Thallium bromide	TlBr	7.4529	298	59	0.3760	0.1458	0.0757
Thorium	Th	11.694	300	60	0.7530	0.4890	0.4780
Thorium oxide	ThO_2	9.991	298	61	3.670	1.060	0.797
Tin telluride	SnTe	6.445	300	62	1.1250	0.0750	0.1172
Titanium carbide	TiC	4.940	RT	107	5.00	1.13	1.75
Tungsten	W	19.257	297	64	5.2239	2.0437	1.6083
Uranium carbide	UC	13.63	300	65	3.200	0.850	0.647
Uranium dioxide	UO_2	10.97	298	66	3.960	1.210	0.641
Vanadium	V	6.022	300	67	2.287	1.190	0.432
Zinc selenide	ZnSe	5.262	298	68	0.8096	0.4881	0.4405
Zinc sulfide	ZnS	4.088	298	68	1.0462	0.6534	0.4613
Zinc telluride	ZnTe	5.636	298	68	0.7134	0.4078	0.3115
Zirconium carbide	ZrC	6.606	298	63	4.720	0.987	1.593

TETRAGONAL CRYSTALS

Name	Formula	ρ/g cm^{-3}	T/*K*	Ref.	C_{11}	C_{12}	C_{13}	C_{16}	C_{33}	C_{44}	C_{66}
Ammonium dihydrogen arsenate (ADA)	$NH_4H_2AsO_4$	2.3110	298	69	0.6747	-0.106	0.1652		0.3022	0.0685	0.0639
Ammonium dihydrogen phosphate (ADP)	$NH_4H_2PO_4$	1.8030	293	69	0.6200	-0.050	0.1400		0.3000	0.0910	0.0610
Barium titanate	$BaTiO_3$	5.9988	298	70	2.7512	1.7897	1.5156		1.6486	0.5435	1.1312
Calcium molybdate	$CaMoO_4$	4.255	298	79	1.447	0.664	0.466	0.134	1.265	0.369	0.451
Indium	In	7.300	RT	71	0.4450	0.3950	0.4050		0.4440	0.0655	0.1220
Magnesium fluoride	MgF_2	3.177	RT	72	1.237	0.732	0.536		1.770	0.552	0.978
Nickel sulfate hexahydrate	$NiSO_4 \cdot 6H_2O$	2.070	RT	73	0.3209	0.2315	0.0209		0.2931	0.1156	0.1779
Potassium dihydrogen arsenate (KDA)	KH_2AsO_4	2.867	RT	12	0.530	-0.060	-0.020		0.370	0.120	0.070
Potassium dihydrogen phosphate (KDP)	KH_2PO_4	2.388	RT	71	0.7140	-0.049	0.1290		0.5620	0.1270	0.0628
Rubidium dihydrogen phosphate (RDP)	RbH_2PO_4	2.800	298	74	0.5562	-0.064	0.0279		0.4398	0.1142	0.0350
Rutile	TiO_2	4.260	298	75	2.7143	1.7796	1.4957		4.8395	1.2443	1.9477
Tellurium oxide	TeO_2	5.99	RT	76	0.5320	0.4860	0.2120		1.0850	0.2440	0.5520
Tin (white)	Sn	7.29	288	77	0.7529	0.6156	0.4400		0.9552	0.2193	0.2336
Zircon	$ZrSiO_4$	4.70	RT	78	2.585	1.791	1.542		3.805	0.733	1.113

ORTHORHOMBIC CRYSTALS

Name	Formula	ρ/g cm^{-3}	*T*/K	Ref.	C_{11}	C_{12}	C_{13}	C_{22}	C_{23}	C_{33}	C_{44}	C_{55}	C_{66}
Acenaphthene	$C_{12}H_{10}$	1.220	293	80	0.1380	0.0210	0.0410	0.1262	0.0460	0.1117	0.0265	0.0290	0.0185
Ammonium sulfate	$(NH_4)_2SO_4$	1.774	293	81	0.3607	0.1651	0.1580	0.2981	0.1456	0.3534	0.1025	0.0717	0.0974
Aragonite	$CaCO_3$	2.93	RT	82	1.5958	0.3663	0.0197	0.8697	0.1597	0.8503	0.4132	0.2564	0.4274
Barite	$BaSO_4$	4.40	RT	82	0.8941	0.4614	0.2691	0.7842	0.2676	1.0548	0.1190	0.2874	0.2778
Benzene	C_6H_6	1.061	250	83	0.0614	0.0352	0.0401	0.0656	0.0390	0.0583	0.0197	0.0378	0.0153
Benzophenone	$(C_6H_5)_2CO$	1.219	RT	32	0.1070	0.0550	0.0169	0.1000	0.0321	0.0710	0.0203	0.0155	0.0353
Bronzite	$(MgFe)SiO_3$	3.38	RT	78	1.876	0.686	0.605	1.578	0.561	2.085	0.700	0.592	0.544
Calcium sulfate	$CaSO_4$	2.962	RT	84	0.9382	0.1650	0.1520	1.845	0.3173	1.1180	0.3247	0.2653	0.0926
Celestite	$SrSO_3$	3.96	RT	12	1.044	0.773	0.605	1.061	0.619	1.286	0.135	0.279	0.266
Cesium sulfate	Cs_2SO_4	4.243	293	81	0.4490	0.1958	0.1815	0.4283	0.1800	0.3785	0.1326	0.1319	0.1323
Fosterite	Mg_2SiO_4	3.224	298	85	3.2848	0.6390	0.6880	1.9980	0.7380	2.3530	0.6515	0.8120	0.8088
Iodic acid	HIO_3	4.630	RT	73	0.3030	0.1194	0.1169	0.5448	0.0548	0.4359	0.1835	0.2193	0.1736
Lithium ammonium tartrate	$LiNH_4C_4H_4O_6 \cdot 4H_2O$	1.71	RT	12	0.3864	0.1655	0.0875	0.5393	0.2007	0.3624	0.1190	0.0667	0.2326
Magnesium sulfate heptahydrate	$MgSO_4 \cdot 7H_2O$	1.68	RT	86	0.325	0.174	0.182	0.288	0.182	0.315	0.078	0.156	0.090
Natrolite	$(Na,Al)SiO_3$	2.25	RT	78	0.716	0.261	0.297	0.632	0.297	1.378	0.196	0.248	0.423
Nickel sulfate heptahydrate	$NiSO_4 \cdot 7H_2O$	1.948	RT	86	0.353	0.198	0.201	0.311	0.201	0.335	0.091	0.172	0.099
Olivine	$(MgFe)SiO_4$	3.324	RT	87	3.240	0.590	0.790	1.980	0.780	2.490	0.667	0.810	0.793
Potassium pentaborate	$KB_5O_8 \cdot 4H_2O$	1.74	RT	71	0.582	0.229	0.174	0.359	0.231	0.255	0.164	0.046	0.057
Potassium sulfate	K_2SO_4	2.665	293	81	0.5357	0.1999	0.2095	0.5653	0.1990	0.5523	0.195	0.1879	0.1424
Rochelle salt	$NaK(C_4H_4O_6) \cdot 4H_2O$	1.79	RT	71	0.255	0.141	0.116	0.381	0.146	0.371	0.134	0.032	0.098
Rubidium sulfate	Rb_2SO_4	3.621	293	81	0.5029	0.1965	0.1999	0.5098	0.1925	0.4761	0.1626	0.1589	0.1407
Sodium ammonium tartrate	$NaNH_4C_4H_4O_6 \cdot 4H_2O$	1.587	RT	12	0.3685	0.2725	0.3083	0.5092	0.3472	0.5541	0.1058	0.0303	0.0870
Sodium tartrate	$Na_2C_4H_4O_6 \cdot 2H_2O$	1.794	RT	12	0.461	0.286	0.320	0.547	0.352	0.665	0.124	0.031	0.098
Strontium formate dihydrate	$Sr(CHO_2)_2 \cdot 2H_2O$	2.25	RT	12	0.4391	0.1037	-0.149	0.3484	-0.014	0.3746	0.1538	0.1075	0.1724
Sulfur	S	2.07	RT	12	0.240	0.133	0.171	0.205	0.159	0.483	0.043	0.087	0.076
Thallium sulfate	$TlSO_4$	6.776	293	81	0.4106	0.2573	0.2288	0.3885	0.2174	0.4268	0.1125	0.1068	0.0751
Topaz	$Al_2SiO_3(OH,F)_2$	3.52	RT	82	2.8136	1.2582	0.8464	3.8495	0.8815	2.9452	1.0811	1.3298	1.3089
Uranium (alpha)	U	19.0453	293	88	2.1486	0.4622	0.2176	1.9983	1.0764	2.6763	1.2479	0.7379	0.7454
Zinc sulfate heptahydrate	$ZnSO_4 \cdot 7H_2O$	1.970	RT	86	0.3320	0.1720	0.2000	0.2930	0.1980	0.3200	0.0780	0.1530	0.0830

MONOCLINIC CRYSTALS

Name	Formula	ρ/g cm^{-3}	*T*/K	Ref.	C_{11}	C_{12}	C_{13}	C_{15}	C_{22}
Aegirine	$(NaFe)Si_2O_6$	3.50	RT	89	1.858	0.685	0.707	0.098	1.813
Anthracene	$C_{14}H_{10}$	1.258	RT	90	0.0852	0.0672	0.0590	-0.0192	0.1170
Cobalt sulfate heptahydrate	$CoSO_4{\cdot}7H_2O$	1.948	RT	86	0.335	0.205	0.158	0.016	0.378
Diopside	$(CaMg)Si_2O_6$	3.31	RT	91	2.040	0.884	0.0883	-0.193	1.750
Dipotassium tartrate	$KHC_4H_4O_6$	1.97	RT	12	0.4294	0.1399	0.3129	-0.0105	0.3460
Feldspar (microceine)	$KAlSi_3O_8$	2.56	RT	92	0.664	0.438	0.259	-0.033	1.710
Ferrous sulfate heptahydrate	$FeSO_4{\cdot}7H_2O$	1.898	RT	86	0.349	0.208	0.174	-0.020	0.376
Lithium sulfate monohydrate	$Li_2SO_4{\cdot}H_2O$	2.221	RT	32	0.5250	0.1715	0.1730	-0.0196	0.5060
Naphthalene	$C_{10}H_8$	1.127	RT	93	0.0780	0.0445	0.0340	-0.006	0.0990
Potassium tartrate	$K_2C_4H_4O_6$	1.987	RT	32	0.3110	0.1720	0.1690	0.0287	0.3900
Sodium thiosulfate	$Na_2S_2O_3$	1.7499	RT	12	0.3323	0.1814	0.1875	0.0225	0.2953
Stilbene	$(C_6H_5CH)_2$	1.60	RT	94	0.0930	0.0570	0.0670	-0.003	0.0920
Triglycine sulfate (TGS)	$(NH_2CH_2COOH)_3{\cdot}H_2SO_4$	1.68	RT	32	0.4550	0.1720	0.1980	-0.030	0.3210

Name	C_{23}	C_{25}	C_{33}	C_{35}	C_{44}	C_{46}	C_{55}	C_{66}
Aegirine	0.626	0.094	2.344	0.214	0.692	0.077	0.510	0.474
Anthracene	0.0375	-0.0170	0.1522	-0.0187	0.0272	0.0138	0.0242	0.0399
Cobalt sulfate heptahydrate	0.158	-0.018	0.371	-0.047	0.060	0.016	0.058	0.101
Diopside	0.482	-0.196	2.380	-0.336	0.675	-0.113	0.588	0.705
Dipotassium tartrate	0.1173	0.0176	0.6816	0.0294	0.0961	-0.0044	0.1270	0.0841
Feldspar (microceine)	0.192	-0.148	1.215	-0.131	0.143	-0.015	0.238	0.361
Ferrous sulfate heptahydrate	0.172	-0.019	0.360	-0.014	0.064	0.001	0.056	0.096
Lithium sulfate monohydrate	0.0368	0.0571	0.5400	-0.0254	0.1400	-0.0054	0.1565	0.2770
Naphthalene	0.0230	-0.0270	0.1190	0.0290	0.0330	-0.0050	0.0210	0.0415
Potassium tartrate	0.1330	0.0182	0.5540	0.0710	0.0870	0.0072	0.1040	0.0826
Sodium thiosulfate	0.1713	0.0983	0.4590	-0.0678	0.0569	-0.0268	0.1070	0.0598
Stilbene	0.0485	-0.005	0.0790	-0.005	0.0325	0.0050	0.0640	0.0245
Triglycine sulfate (TGS)	0.2080	-0.0036	0.2630	-0.0500	0.0950	-0.0026	0.1110	0.0620

ELASTIC CONSTANTS OF SINGLE CRYSTALS (continued)

HEXAGONAL CRYSTALS

Name	Formula	ρ/g cm^{-3}	*T*/K	Ref.	C_{11}	C_{12}	C_{13}	C_{33}	C_{55}
Apatite	$Ca_5(PO_4)_3(OH,F,Cl)$	3.218	RT	12	1.667	0.131	0.655	1.396	0.663
Beryl	$Be_3Al_2Si_6O_{18}$	2.68	RT	12	2.800	0.990	0.670	2.480	0.658
Beryllium	Be	1.8477	300	95	2.923	0.267	0.140	3.364	1.625
Beryllium oxide	BeO	3.01	RT	96	4.70	1.68	1.19	4.94	1.53
Cadmium	Cd	8.652	300	97	1.1450	0.3950	0.3990	0.5085	0.1985
Cadmium selenide	CdSe	5.655	298	68	0.7046	0.4516	0.3930	0.8355	0.1317
Cadmium sulfide	CdS	4.824	298	98	0.8431	0.5208	0.4567	0.9183	0.1458
Cobalt	Co	8.836	298	99	3.071	1.650	1.027	3.581	0.755
Dysprosium	Dy	8.560	298	100	0.7466	0.2616	0.2233	0.7871	0.2427
Erbium	Er	9.064	298	100	0.8634	0.3050	0.2270	0.8554	0.2809
Gadolinium	Gd	7.888	298	101	0.6667	0.2499	0.2132	0.7191	0.2089
Hafnium	Hf	12.727	298	102	1.881	0.772	0.661	1.969	0.557
Ice	H_2O(solid)	0.920	250	103	0.1410	0.0660	0.0624	0.1515	0.0288
Indium	In	7.2788	300	104	0.4535	0.4006	0.4151	0.4515	0.0651
Magnesium	Mg	1.7364	298	105	0.5950	0.2612	0.2180	0.6155	0.1635
Rhenium	Re	21.024	298	100	6.1820	2.7530	2.0780	6.8350	1.6060
Ruthenium	Ru	12.3615	298	100	5.6260	1.8780	1.6820	6.2420	1.8060
Thallium	Tl	11.560	300	106	0.4080	0.3540	0.2900	0.5280	0.0726
Titanium	Ti	4.5063	298	102	1.6240	0.9200	0.6900	1.8070	0.4670
Titanium diboride	TiB_2	4.95	RT	107	6.90	4.10	3.20	4.40	2.50
Yttrium	Y	4.472	300	108	0.7790	0.2850	0.2100	0.7690	0.2431
Zinc	Zn	7.134	295	109	1.6368	0.3640	0.5300	0.6347	0.3879
Zinc oxide	ZnO	5.6760	298	110	2.0970	1.2110	1.0510	2.1090	0.4247
Zinc sulfide	ZnS	4.089	298	96	1.2420	0.6015	0.4554	1.4000	0.2864
Zirconium	Zr	6.505	298	102	1.434	0.728	0.653	1.648	0.320

TRIGONAL CRYSTALS

Name	Formula	ρ/g cm^{-3}	*T*/K	Ref.	C_{11}	C_{12}	C_{13}	C_{14}	C_{33}	C_{44}
Aluminum oxide	Al_2O_3	3.986	300	111	4.9735	1.6397	1.1220	-0.2358	4.9911	1.4739
Aluminum phosphate	$AlPO_4$	2.556	RT	73	1.0503	0.2934	0.6927	-0.1271	1.3353	0.2314
Antimony	Sb	6.70	295	112	1.0130	0.3450	0.2920	0.2090	0.4500	0.3930
Bismuth	Bi	9.80	295	112	0.6370	0.2490	0.2470	0.0717	0.3820	0.1123
Calcite	$CaCO_3$	2.712	300	113	1.4806	0.5578	0.5464	-0.2058	0.8557	0.3269
Hematite	Fe_2O_3	5.240	RT	82	2.4243	0.5464	0.1542	-0.1247	2.2734	0.8569
Lithium niobate	$LiNbO_3$	4.70	RT	114	2.030	0.530	0.750	0.090	2.450	0.600
Lithium tantalate	$LiTaO_3$	7.45	RT	114	2.330	0.470	0.800	-0.110	2.750	0.940
Quartz	SiO_2	2.6485	298	115	0.8680	0.0704	0.1191	-0.1804	1.0575	0.5820
Selenium	Se	4.838	300	116	0.1870	0.0710	0.2620	0.0620	0.7410	0.1490
Sodium nitrate	$NaNO_3$	2.27	RT	12	0.8670	0.1630	0.1600	0.0820	0.3740	0.2130
Tourmaline		3.05	RT	82	2.7066	0.6927	0.0872	-0.0774	1.6070	0.6682

REFERENCES

1. Thomas, J. F., *Phys. Rev.*, 175, 955-962, 1968.
2. Bolef, D. I. and M. Menes, *J. Appl. Phys.*, 31, 1426-1427, 1960.
3. Garland, C. W. and C. F. Yarnell, *J. Chem. Phys.*, 44, 1112-1120, 1966.
4. Garland, C. W. and R. Renard, *J. Chem. Phys.*, 44, 1130-1139, 1966.

5. Gsänger, M., H. Egger and E. Lüscher, *Phys. Letters*, 27A, 695-696, 1968.
6. Wong, C. and D. E. Schuele, *J. Phys. Chem. Solids*, 29, 1309-1330, 1968.
7. Haussühl, S., *Phys. Stat. Sol.*, 3, 1072-1076, 1963.
8. Wong, C. and D. E. Schuele, *J. Phys. Chem. Solids*, 28, 1225-1231, 1967.
9. McSkimin, H. J. and D. G. Thomas, *J. Appl. Phys.*, 33, 56-59, 1962.
10. Kollarits, F. J. and J. Trivisonno, *J. Phys. Chem. Solids*, 29, 2133-2139, 1968.
11. Slagle, D. D. and H. A. McKinstry, *J. Appl. Phys.*, 38, 446-458, 1967.
12. Hearmon, R. F. S., *Adv. Phys.*, 5, 323-382, 1956.
13. Sumer, A. and J. F. Smith, *J. Appl. Phys.*, 34, 2691-2694, 1963.
14. Alexandrov, K. S. et. al., *Sov. Phys. Sol. State*, 10, 1316-1321, 1968.
15. Epstein, S. G. and O. N. Carlson, *Acta Metal.*, 13, 487-491, 1965.
16. McSkimin, H. J., et. al., *J. Appl. Phys.*, 39, 4127-4128, 1968.
17. McSkimin, H. J., et. al., *J. Appl. Phys.*, 38, 2362-2364, 1967.
18. Weil, R. and W. O. Groves, *J. Appl. Phys.*, 39, 4049-4051, 1968.
19. Bateman, T. B., *J. Appl. Phys.*, 37, 2194-2195, 1966.
20. Bogardus, E. H., *J. Appl. Phys.*, 36, 2504-2513, 1965.
21. Golding, B., S. C. Moss and B. L. Averbach, *Phys. Rev.*, 158, 637-645, 1967.
22. Bateman, T. B., H. J. McSkimin and J. M. Whelan, *J. Appl. Phys.*, 30, 544-545, 1959.
23. Gerlich, D., *J. Appl. Phys.*, 35, 3062, 1964.
24. Hickernell, F. S. and W. R. Gayton, *J. Appl. Phys.*, 37, 462, 1966.
25. MacFarlane, R. E., et. al., *Phys. Letters*, 20, 234-235, 1966.
26. Leese, J. and A. E. Lord Jr., *J. Appl. Phys.*, 39, 3986-3988, 1968.
27. Miller, R. A. and D. E. Schuele, *J. Phys. Chem. Solids*, 30, 589-600, 1969.
28. Wasilik, J. H. and M. L. Wheat, *J. Appl. Phys.*, 36, 791-793, 1965.
29. Haussühl, S., *Phys. Stat. Sol.*, 3, 1072-1076, 1963.
30. Houston, B., et. al., *J. Appl. Phys.*, 39, 3913-3916, 1968.
31. Trivisonno, J. and C. S. Smith, *Acta Metal.*, 9, 1064-1071, 1961.
32. Alexandrov, K. S. and T. V. Ryzhova, *Sov. Phys. Cryst.*, 6, 228-252, 1961.
33. Lewis, J. T., A. Lehoczky and C. V. Briscoe, *Phys. Rev.*, 161, 877-887, 1967.
34. Drabble, J. R. and R. E. B. Strathen, *Proc. Phys. Soc.*, 92, 1090-1995, 1967.
35. Oliver, D. W., *J. Appl. Phys.*, 40, 893, 1969.
36. Alper, T., and G. A. Saunders, *J. Phys. Chem. Solids*, 28, 1637-1642, 1967.
37. Dickinson, J. M. and P. E. Armstrong, *J. Appl. Phys.*, 38, 602-606, 1967.
38. Bolef, D. I., *J. Appl. Phys.*, 32, 100-105, 1961.
39. Rayne, J. A., *Phys. Rev.*, 112, 1125-1130, 1958.
40. MacFarlane, R. E., et. al., *Phys. Letters*, 18, 91-92, 1965.
41. Smith, P. A. and C. S. Smith, *J. Phys. Chem. Solids*, 26, 279-289, 1965.
42. Norwood, M. H. and C. V. Briscoe, *Phys. Rev.*, 112, 45-48, 1958.
43. Simmons, G. and F. Birch, *J. Appl. Phys.*, 34, 2736-2738, 1963.
44. Gutman, E. J. and J. Trivisonno, *J. Phys. Chem. Sol.*, 28, 805-809, 1967.
45. Ghafelehbashi, M., et. al., *J. Appl. Phys.*, 41, 652-666, 1970.
46. McSkimin, H. J. and P. Andreatch Jr., *J. Appl. Phys.*, 35, 2161-2165, 1964.
47. Neighbours, J. R. and G. A. Alers, *Phys. Rev.*, 111, 707-712, 1958.
48. Hidshaw, W., J. T. Lewis, and C. V. Briscoe, *Phys. Rev.*, 163, 876-881, 1967.
49. Daniels, W. B., *Phys. Rev.*, 119, 1246-1252, 1960.
50. Viswanathan, R., *J. Appl. Phys.*, 37, 884-886, 1966.
51. Miller, R. A. and C. S. Smith, *J. Phys. Chem. Sol.*, 25, 1279-1292, 1964.
52. Claytor, R. N. and B. J. Marshall, *Phys. Rev.*, 120, 332-334, 1960.
53. Schreiber, E., *J. Appl. Phys.*, 38, 2508-2511, 1967.
54. Gerlich, D., *Phys. Rev.*, 136, A1366-A1368, 1964.
55. Johnston, D. L., P. H. Thrasher and R. J. Kearney, *J. Appl. Phys.*, 41, 427-428, 1970.
56. Poindexter, E. and A. A. Giardini, *Phys. Rev.*, 110, 1069, 1958.
57. Soga, N., *J. Appl. Phys.*, 37, 3416-3420, 1966.
58. Bartlett, R. W. and C. W. Smith, *J. Appl. Phys.*, 38, 5428-5429, 1967.
59. Morse, G. E. and A. W. Lawson, *J. Phys. Chem. Sol.*, 28, 939-950, 1967.
60. Armstrong, P. E., O. N. Carlson and J. F. Smith, *J. Appl. Phys.*, 30, 36-41, 1959.
61. Macedo, P. M., W. Capps and J. B. Wachtman, *J. Am. Cer. Soc.*, 47, 651, 1964.
62. Beattie, A. G., *J. Appl. Phys.*, 40, 4818-4821, 1969.
63. Chang, R. and L. J. Graham, *J. Appl Phys.*, 37, 3778-3783, 1966.
64. Lowrie, R. and A. M. Gonas, *J. Appl. Phys.*, 38, 4505-4509. 1967.
65. Graham, L. J., H. Nadler and R. Chang, *J. Appl. Phys.*, 34, 1572-1573, 1963.

66. Wachtman, J. B. Jr., et. al., *J. Nucl. Mat.*, 16, 39-41, 1965.
67. Bolef, D. I., *J. Appl. Phys.*, 32, 100-105, 1961.
68. Berlincourt, D., H. Jaffe and L. R. Shiozawa, *Phys. Rev.*, 129, 1009-1017, 1963.
69. Adhav. R. S. J. *Acoust. Soc. Am.*, 43, 835-838, 1968.
70. Berlincourt, D. and H. Jaffe, *Phys. Rev.*, 111, 143-148, 1958.
71. Huntington, H. B., in *Solid State Pysics*, *Vol. 7*, Seitz, F., and Turnbull, D., Ed., pp. 213-285; Academic Press, New York 1958.
72. Cutler, H. R., J. J. Gibson and K. A. McCarthy, *Sol. State Comm.*, 6, 431-433, 1968.
73. Mason, W. P., *Piezoelectric Crystals and Their Application to Ultrasonics*, D. Van Nostrand Co., Inc., New York, 1950.
74. Adhav, R. S., *J. Appl. Phys.*, 40, 2725-2727, 1969.
75. Manghnani, M. H., *J. Geophys. Res.*, 74, 4317-4328, 1969.
76. Uchida, N. and Y. Ohmachi, *J. Appl Phys.*, 40, 4692-4695, 1969.
77. House, D. G. and E. Y. Vernon, *Br. J. Appl. Phys.*, 11, 254-259, 1960.
78. Ryzhova, T. V., et. al., *Bull. Acad. Sci. USSR, Earth Phys. Ser.*, English Transl., no. 2, 111-113, 1966.
79. Alton, W. J. and A. J. Barlow, *J. Appl. Phys.*, 38, 3817-3820, 1967.
80. Michard, F., et. al., *C. R. Acad. Sci., Paris*, 265, 565-567, 1967.
81. Haussühl, S., *Acta Cryst.*, 18, 839-842, 1965.
82. Hearmon, R. F. S., *Rev. Mod. Phys.*, 18, 409-440, 1946.
83. Heseltine, J. C. W., D. W. Elliott and O. B. Wilson, *J. Chem. Phys.*, 40, 2584-2587, 1964.
84. Schwerdtner, W. M., et. al., *Canad. J. Earth Sci.*, 2, 673-683, 1965.
85. Kumazawa, M. and O. L. Anderson, *J. Geophys. Res.*, 74, 5961-5972, 1969 .
86. Alexandrov, K. S., et. al., *Sov. Phys. Cryst.*, 7, 753-755, 1963.
87. Verma, R. K., *J. Geophys. Soc.*, 65, 757-766, 1960.
88. McSkimin, H. J. and E. S. Fisher, *J. Appl. Phys.*, 31, 1627-1639, 1960.
89. Alexandrov, K. S. and T.V. Ryzhova, *Bull. Acad. Sci. USSR, Geophys. Ser.*, English Transl., no.8, 871-875, 1961.
90. Afanaseva, G. K., et. al, *Phys. Stat. Sol.*, 24, K61-K63, 1967.
91. Alexandrov, K. S., et. al., *Sov. Phys. Cryst.*, 8, 589-591, 1964.
92. Alexandrov, K. S. and T. V Ryzhova, *Bull Acad. Sci. USSR, Geophys. Ser.*, English Transl., no.2, 129-131, 1962.
93. Alexandrov, K. S., et. al., *Sov. Phys. Cryst.*, 8, 164-166, 1963.
94. Teslenko, V. F., et. al., *Sov. Phys. Cryst.*, 10, 744-747, 1966.
95. Smith, J. F. and C. L. Arbogast, *J. Appl. Phys.*, 31, 99-102, 1960.
96. Cline, C. F., H. L. Dunegan and G. M. Henderson, *J. Appl. Phys.*, 38, 1944-1948, 1967.
97. Chang, Y. A. and L. Himmel, *J. Appl. Phys.*, 37, 3787-3790, 1966.
98. Gerlich, D., *J. Phys. Chem. Solids*, 28, 2575-2579, 1967.
99. McSkimin, H. J., *J. Appl. Phys.*, 26, 406-409, 1955.
100. Fisher, E. S. and D. Dever, *Trans. Met. Soc. AIME*, 239, 48-57, 1967.
101. Fisher, E. S. and D. Dever, *Proc. Conf. Rare Earth Res.*, 6th, Gatlinburg, Tenn., 522-533, 1967.
102. Fisher, E. S. and C. J. Renken, Phys. Rev., 135, A482-A494, 1964.
103. Proctor, T. M. Jr., *J. Acoust. Soc. Am.*, 39, 972-977, 1966.
104. Chandrasekhar, B. S. and J. A. Rayne, *Phys. Rev.*, 124, 1011-1041, 1961.
105. Wazzan, A. R. and L. B. Robinson, *Phys. Rev.*, 155, 586-594, 1967.
106. Ferris, R. W., et. al., *J. Appl. Phys.*, 34, 768-770, 1963.
107. Gilman, J. J. and B. W. Roberts, *J. Appl. Phys.*, 32, 1405, 1961.
108. Smith, J. F. and J. A. Gjevre, *J. Appl. Phys.*, 31, 645-647, 1960.
109. Alers, G. A. and J. R. Neighbours, *J. Phys. Chem. Solids*, 7, 58-64, 1908.
110. Bateman, T. B., *J. Appl. Phys.*, 33, 3309-3312, 1962.
111. Tefft, W. E., *J. Res. Natl. Bur. Stand.*, 70A, 277-280, 1966.
112. DeBretteville, Jr., A. et. al., *Phys. Rev.*, 148, 575-579, 1966.
113. Dandekar, D. P. and A. L. Ruoff, *J. Appl. Phys.*, 39, 6004-6009, 1968.
114. Warner, A. W., M. Onoe and G. A. Coquin, *J. Acoust. Soc. Am.*, 42, 1223-1231, 1967.
115. McSkimin, H. J., P. Andreatch and R. N. Thurston, *J. Appl. Phys.*, 36, 1624-1632, 1965.
116. Mort, J., *J. Appl. Phys.*, 38, 3414-3415, 1967.

ELECTRICAL RESISTIVITY OF PURE METALS

The first part of this table gives the electrical resistivity, in units of $10^{-8}\ \Omega$ m, for 28 common metallic elements as a function of temperature. The data refer to polycrystalline samples. The number of significant figures indicates the accuracy of the values. However, at low temperatures (especially below 50 K) the electrical resistivity is extremely sensitive to sample purity. Thus the low-temperature values refer to samples of specified purity and treatment. The references should be consulted for further information on this point, as well as for values at additional temperatures.

The second part of the table gives resistivity values in the neighborhood of room temperature for other metallic elements that have not been studied over an extended temperature range.

REFERENCES

1. C. Y. Ho, et al., *J. Phys. Chem. Ref. Data*, 12, 183—322, 1983; 13, 1069—1096, 1984; 13, 1097—1130, 1984, 13, 1131—1172, 1984.
2. R. A. Matula, *J. Phys Chem. Ref. Data*, 8, 1147—1298, 1979.
3. T. C. Chi, *J. Phys. Chem. Ref. Data*, 8, 339—438, 1979; 8, 439—498, 1979.
4. K. H. Hellwege, Ed., *Landolt-Börnstein Numerical Data and Functional Relationships in Science and Technology*, Group III, Vol. 15, Subvolume a, Springer-Verlag, Heidelberg, 1982.
5. L. A. Hall, *Survey of Electrical Resistivity Measurements on 16 Pure Metals in the Temperature Range 0 to 273 K*, NBS Technical Note 365, U.S. Superintendent of Documents, 1968.

ELECTRICAL RESISTIVITY IN $10^{-8}\ \Omega$ m

T/K	Aluminum	Barium	Beryllium	Calcium	Cesium	Chromium	Copper
1	0.000100	0.081	0.0332	0.045	0.0026		0.00200
10	0.000193	0.189	0.0332	0.047	0.243		0.00202
20	0.000755	0.94	0.0336	0.060	0.86		0.00280
40	0.0181	2.91	0.0367	0.175	1.99		0.0239
60	0.0959	4.86	0.067	0.40	3.07		0.0971
80	0.245	6.83	0.075	0.65	4.16		0.215
100	0.442	8.85	0.133	0.91	5.28	1.6	0.348
150	1.006	14.3	0.510	1.56	8.43	4.5	0.699
200	1.587	20.2	1.29	2.19	12.2	7.7	1.046
273	2.417	30.2	3.02	3.11	18.7	11.8	1.543
293	2.650	33.2	3.56	3.36	20.5	12.5	1.678
298	2.709	34.0	3.70	3.42	20.8	12.6	1.712
300	2.733	34.3	3.76	3.45	21.0	12.7	1.725
400	3.87	51.4	6.76	4.7		15.8	2.402
500	4.99	72.4	9.9	6.0		20.1	3.090
600	6.13	98.2	13.2	7.3		24.7	3.792
700	7.35	130	16.5	8.7		29.5	4.514
800	8.70	168	20.0	10.0		34.6	5.262
900	10.18	216	23.7	11.4		39.9	6.041

T/K	Gold	Hafnium	Iron	Lead	Lithium	Magnesium	Manganese
1	0.0220	1.00	0.0225		0.007	0.0062	7.02
10	0.0226	1.00	0.0238		0.008	0.0069	18.9
20	0.035	1.11	0.0287		0.012	0.0123	54
40	0.141	2.52	0.0758		0.074	0.074	116
60	0.308	4.53	0.271		0.345	0.261	131
80	0.481	6.75	0.693	4.9	1.00	0.557	132
100	0.650	9.12	1.28	6.4	1.73	0.91	132
150	1.061	15.0	3.15	9.9	3.72	1.84	136
200	1.462	21.0	5.20	13.6	5.71	2.75	139
273	2.051	30.4	8.57	19.2	8.53	4.05	143
293	2.214	33.1	9.61	20.8	9.28	4.39	144
298	2.255	33.7	9.87	21.1	9.47	4.48	144
300	2.271	34.0	9.98	21.3	9.55	4.51	144
400	3.107	48.1	16.1	29.6	13.4	6.19	147
500	3.97	63.1	23.7	38.3		7.86	149

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ELECTRICAL RESISTIVITY OF PURE METALS (continued)

T/K	Gold	Hafnium	Iron	Lead	Lithium	Magnesium	Manganese
600	4.87	78.5	32.9			9.52	151
700	5.82		44.0			11.2	152
800	6.81		57.1			12.8	
900	7.86					14.4	

T/K	Molybdenum	Nickel	Palladium	Platinum	Potassium	Rubidium	Silver
1	0.00070	0.0032	0.0200	0.002	0.0008	0.0131	0.00100
10	0.00089	0.0057	0.0242	0.0154	0.0160	0.109	0.00115
20	0.00261	0.0140	0.0563	0.0484	0.117	0.444	0.0042
40	0.0457	0.068	0.334	0.409	0.480	1.21	0.0539
60	0.206	0.242	0.938	1.107	0.90	1.94	0.162
80	0.482	0.545	1.75	1.922	1.34	2.65	0.289
100	0.858	0.96	2.62	2.755	1.79	3.36	0.418
150	1.99	2.21	4.80	4.76	2.99	5.27	0.726
200	3.13	3.67	6.88	6.77	4.26	7.49	1.029
273	4.85	6.16	9.78	9.6	6.49	11.5	1.467
293	5.34	6.93	10.54	10.5	7.20	12.8	1.587
298	5.47	7.12	10.73	10.7	7.39	13.1	1.617
300	5.52	7.20	10.80	10.8	7.47	13.3	1.629
400	8.02	11.8	14.48	14.6			2.241
500	10.6	17.7	17.94	18.3			2.87
600	13.1	25.5	21.2	21.9			3.53
700	15.8	32.1	24.2	25.4			4.21
800	18.4	35.5	27.1	28.7			4.91
900	21.2	38.6	29.4	32.0			5.64

T/K	Sodium	Strontium	Tantalum	Tungsten	Vanadium	Zinc	Zirconium
1	0.0009	0.80	0.10	0.000016		0.0100	0.250
10	0.0015	0.80	0.102	0.000137	0.0145	0.0112	0.253
20	0.016	0.92	0.146	0.00196	0.039	0.0387	0.357
40	0.172	1.70	0.751	0.0544	0.304	0.306	1.44
60	0.447	2.68	1.65	0.266	1.11	0.715	3.75
80	0.80	3.64	2.62	0.606	2.41	1.15	6.64
100	1.16	4.58	3.64	1.02	4.01	1.60	9.79
150	2.03	6.84	6.19	2.09	8.2	2.71	17.8
200	2.89	9.04	8.66	3.18	12.4	3.83	26.3
273	4.33	12.3	12.2	4.82	18.1	5.46	38.8
293	4.77	13.2	13.1	5.28	19.7	5.90	42.1
298	4.88	13.4	13.4	5.39	20.1	6.01	42.9
300	4.93	13.5	13.5	5.44	20.2	6.06	43.3
400		17.8	18.2	7.83	28.0	8.37	60.3
500		22.2	22.9	10.3	34.8	10.82	76.5
600		26.7	27.4	13.0	41.1	13.49	91.5
700		31.2	31.8	15.7	47.2		104.2
800		35.6	35.9	18.6	53.1		114.9
900			40.1	21.5	58.7		123.1

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ELECTRICAL RESISTIVITY OF PURE METALS (continued)

Element	*T*/K	Electrical resistivity 10^{-8} Ω m
Antimony	273	39
Bismuth	273	107
Cadmium	273	6.8
Cerium (β, hex)	290—300	82.8
Cerium (γ, cub)	298	74.4
Cobalt	273	5.6
Dysprosium	290—300	92.6
Erbium	290—300	86.0
Europium	290—300	90.0
Gadolinium	290—300	131
Gallium	273	13.6
Holmium	290—300	81.4
Indium	273	8.0
Iridium	273	4.7
Lanthanum	290—300	61.5
Lutetium	290—300	58.2
Mercury	298	96.1
Neodymium	290—300	64.3
Niobium	273	15.2
Osmium	273	8.1
Polonium	273	40
Praseodymium	290—300	70.0
Promethium	290—300	75 est.
Protactinium	273	17.7
Rhenium	273	17.2
Rhodium	273	4.3
Ruthenium	273	7.1
Samarium	290—300	94.0
Scandium	290—300	56.2
Terbium	290—300	115
Thallium	273	15
Thorium	273	14.7
Thulium	290—300	67.6
Tin	273	11.5
Titanium	273	39
Uranium	273	28
Ytterbium	290—300	25.0
Yttrium	290—300	59.6

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ELECTRICAL RESISTIVITY OF SELECTED ALLOYS

These values were obtained by fitting all available measurements to a theoretical formulation describing the temperature and composition dependence of the electrical resistivity of metals. Some of the values listed here fall in regions of temperature and composition where no actual measurements exist. Details of the procedure may be found in the reference.

Values of the resistivity are given in units of 10^{-8} Ω m. General comments in the preceding table for pure metals also apply here.

REFERENCE

C.Y. Ho, et al., *J. Phys. Chem. Ref. Data*, 12, 183-322, 1983.

Aluminum-Copper

Wt % Al	100 K	273 K	293 K	300 K	350 K	400 K
99[a]	0.531	2.51	2.74	2.82	3.38	3.95
95[a]	0.895	2.88	3.10	3.18	3.75	4.33
90[b]	1.38	3.36	3.59	3.67	4.25	4.86
85[b]	1.88	3.87	4.10	4.19	4.79	5.42
80[b]	2.34	4.33	4.58	4.67	5.31	5.99
70[b]	3.02	5.03	5.31	5.41	6.16	6.94
60[b]	3.49	5.56	5.88	5.99	6.77	7.63
50[b]	4.00	6.22	6.55	6.67	7.55	8.52
40[c]		7.57	7.96	8.10	9.12	10.2
30[c]		11.2	11.8	12.0	13.5	15.2
25[f]		16.3	17.2	17.6	19.8	22.2
15[h]			12.3			
10[g]	8.71	10.8	11.0	11.1	11.7	12.3
5[c]	7.92	9.43	9.61	9.68	10.2	10.7
1[b]	3.22	4.46	4.60	4.65	5.00	5.37

Aluminum-Magnesium

Wt % Al	100 K	273 K	293 K	300 K	350 K	400 K
99[c]	0.958	2.96	3.18	3.26	3.82	4.39
95[c]	3.01	5.05	5.28	5.36	5.93	6.51
90[c]	5.42	7.52	7.76	7.85	8.43	9.02
10[b]	14.0	17.1	17.4	17.6	18.4	19.2
5[b]	9.93	13.1	13.4	13.5	14.3	15.2
1[a]	2.78	5.92	6.25	6.37	7.20	8.03

Copper-Gold

Wt % Cu	100 K	273 K	293 K	300 K	350 K	400 K
99[c]	0.520	1.73	1.86	1.91	2.24	2.58
95[c]	1.21	2.41	2.54	2.59	2.92	3.26
90[c]	2.11	3.29	4.42	3.46	3.79	4.12
85[c]	3.01	4.20	4.33	4.38	4.71	5.05
80[c]	3.95	5.15	5.28	5.32	5.65	5.99
70[c]	5.91	7.12	7.25	7.30	7.64	7.99
60[c]	8.04	9.18	9.13	9.36	9.70	10.05
50[c]	9.88	11.07	11.20	11.25	11.60	11.94
40[c]	11.44	12.70	12.85	12.90	13.27	13.65
30[c]	12.43	13.77	13.93	13.99	14.38	14.78
25[c]	12.59	13.93	14.09	14.14	14.54	14.94
15[c]	11.38	12.75	12.91	12.96	13.36	13.77
10[c]	9.33	10.70	10.86	10.91	11.31	11.72
5[c]	5.91	7.25	7.41	7.46	7.87	8.28
1[c]	2.00	3.40	3.57	3.62	4.03	4.45

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Copper-Nickel

Wt % Cu	100 K	273 K	293 K	300 K	350 K	400 K
99[c]	1.45	2.71	2.85	2.91	3.27	3.62
95[c]	6.19	7.60	7.71	7.82	8.22	8.62
90[c]	12.08	13.69	13.89	13.96	14.40	14.81
85[c]	18.01	19.63	19.83	19.90	20.32	20.70
80[c]	23.89	25.46	25.66	25.72	26.12	26.44
70[i]	35.73	36.67	36.72	36.76	36.85	36.89
60[i]	45.76	45.43	45.38	43.35	45.20	45.01
50[i]	50.22	50.19	50.05	50.01	49.73	49.50
40[c]	36.77	47.42	47.73	47.82	48.28	48.49
30[i]	26.73	40.19	41.79	42.34	44.51	45.40
25[c]	22.22	33.46	35.11	35.69	39.67	42.81
15[c]	13.49	22.00	23.35	23.85	27.60	31.38
10[c]	9.28	16.65	17.82	18.26	21.51	25.19
5[c]	5.20	11.49	12.50	12.90	15.69	18.78
1[c]	1.81	7.23	8.08	8.37	10.63	13.18

Copper-Palladium

Wt % Cu	100 K	273 K	293 K	300 K	350 K	400 K
99[c]	0.91	2.10	2.23	2.27	2.59	2.92
95[c]	2.99	4.21	4.35	4.40	4.74	5.08
90[c]	5.69	6.89	7.03	7.08	7.41	7.74
85[c]	8.30	9.48	9.61	9.66	10.01	10.36
80[c]	10.74	11.99	12.12	12.16	12.51	12.87
70[c]	15.67	16.87	17.01	17.06	17.41	17.78
60[c]	20.45	21.73	21.87	21.92	22.30	22.69
50[c]	26.07	27.62	27.79	27.86	28.25	28.64
40[c]	33.53	35.31	35.51	35.57	36.03	36.47
30[c]	45.03	46.50	46.66	46.71	47.11	47.47
25[c]	44.12	46.25	46.45	46.52	46.99	47.43
15[c]	31.79	36.52	36.99	37.16	38.28	39.35
10[c]	23.00	28.90	29.51	29.73	31.19	32.56
5[c]	13.09	20.00	20.75	21.02	22.84	24.54
1[c]	8.97	11.90	12.67	12.93	14.82	16.68

Copper-Zinc

Wt % Cu	100 K	273 K	293 K	300 K	350 K	400 K
99[b]	0.671	1.84	1.97	2.02	2.36	2.71
95[b]	1.54	2.78	2.92	2.97	3.33	3.69
90[b]	2.33	3.66	3.81	3.86	4.25	4.63
85[b]	2.93	4.37	4.54	4.60	5.02	5.44
80[b]	3.44	5.01	5.19	5.26	5.71	6.17
70[b]	4.08	5.87	6.08	6.15	6.67	7.19

Gold-Palladium

Wt % Au	100 K	273 K	293 K	300 K	350 K	400 K
99[c]	1.31	2.69	2.86	2.91	3.32	3.73
95[c]	3.88	5.21	5.35	5.41	5.79	6.17
90[i]	6.70	8.01	8.17	8.22	8.56	8.93
85[b]	9.14	10.50	10.66	10.72	11.10	11.48
80[b]	11.23	12.75	12.93	12.99	13.45	13.93
70[c]	16.44	18.23	18.46	18.54	19.10	19.67
60[b]	24.64	26.70	26.94	27.02	27.63	28.23

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Gold-Palladium (continued)

Wt % Au	100 K	273 K	293 K	300 K	350 K	400 K
50[a]	23.09	27.23	27.63	27.76	28.64	29.42
40[a]	19.40	24.65	25.23	25.42	26.74	27.95
30[b]	14.94	20.82	21.49	21.72	23.35	24.92
25[b]	12.72	18.86	19.53	19.77	21.51	23.19
15[a]	8.54	15.08	15.77	16.01	17.80	19.61
10[a]	6.54	13.25	13.95	14.20	16.00	17.81
5[a]	4.58	11.49	12.21	12.46	14.26	16.07
1[a]	3.01	10.07	10.85	11.12	12.99	14.80

Gold-Silver

Wt % Au	100 K	273 K	293 K	300 K	350 K	400 K
99[b]	1.20	2.58	2.75	2.80	3.22	3.63
95[a]	3.16	4.58	4.74	4.79	5.19	5.59
90[j]	5.16	6.57	6.73	6.78	7.19	7.58
85[j]	6.75	8.14	8.30	8.36	8.75	9.15
80[j]	7.96	9.34	9.50	9.55	9.94	10.33
70[j]	9.36	10.70	10.86	10.91	11.29	11.68
60[j]	9.61	10.92	11.07	11.12	11.50	11.87
50[j]	8.96	10.23	10.37	10.42	10.78	11.14
40[j]	7.69	8.92	9.06	9.11	9.46	9.81
30[a]	6.15	7.34	7.47	7.52	7.85	8.19
25[a]	5.29	6.46	6.59	6.63	6.96	7.30
15[a]	3.42	4.55	4.67	4.72	5.03	5.34
10[a]	2.44	3.54	3.66	3.71	4.00	4.31
5[i]	1.44	2.52	2.64	2.68	2.96	3.25
1[b]	0.627	1.69	1.80	1.84	2.12	2.42

Iron-Nickel

Wt % Fe	100 K	273 K	293 K	300 K	400 K
99[a]	3.32	10.9	12.0	12.4	18.7
95[c]	10.0	18.7	19.9	20.2	26.8
90[c]	14.5	24.2	25.5	25.9	33.2
85[c]	17.5	27.8	29.2	29.7	37.3
80[c]	19.3	30.1	31.6	32.2	40.0
70[b]	20.9	32.3	33.9	34.4	42.4
60[c]	28.6	53.8	57.1	58.2	73.9
50[d]	12.3	28.4	30.6	31.4	43.7
40[d]	7.73	19.6	21.6	22.5	34.0
30[c]	5.97	15.3	17.1	17.7	27.4
25[b]	5.62	14.3	15.9	16.4	25.1
15[c]	4.97	12.6	13.8	14.2	21.1
10[c]	4.20	11.4	12.5	12.9	18.9
5[c]	3.34	9.66	10.6	10.9	16.1
1[b]	1.66	7.17	7.94	8.12	12.8

Silver-Palladium

Wt % Ag	100 K	273 K	293 K	300 K	350 K	400 K
99[b]	0.839	1.891	2.007	2.049	2.35	2.66
95[b]	2.528	3.58	3.70	3.74	4.04	4.34
90[b]	4.72	5.82	5.94	5.98	6.28	6.59
85[k]	6.82	7.92	8.04	8.08	8.38	8.68
80[k]	8.91	10.01	10.13	10.17	10.47	10.78

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ELECTRICAL RESISTIVITY OF SELECTED ALLOYS (continued)

Silver-Palladium (continued)

Wt % Ag	100 K	273 K	293 K	300 K	350 K	400 K
70[k]	13.43	14.53	14.65	14.69	14.99	15.30
60[i]	19.4	20.9	21.1	21.2	21.6	22.0
50[k]	29.3	31.2	31.4	31.5	32.0	32.4
40[m]	40.8	42.2	42.2	42.2	42.3	42.3
30[b]	37.1	40.4	40.6	40.7	41.3	41.7
25[k]	32.4	36.67	37.06	37.19	38.1	38.8
15[i]	21.0	27.08	26.68	27.89	29.3	30.6
10[i]	14.95	21.69	22.39	22.63	24.3	25.9
5[b]	8.91	15.98	16.72	16.98	18.8	20.5
1[a]	3.97	11.06	11.82	12.08	13.92	15.70

[a] Uncertainty in resistivity is ± 2%.
[b] Uncertainty in resistivity is ± 3%.
[c] Uncertainty in resistivity is ± 5%.
[d] Uncertainty in resistivity is ± 7% below 300 K and ± 5% at 300 and 400 K.
[e] Uncertainty in resistivity is ± 7%.
[f] Uncertainty in resistivity is ± 8%.
[g] Uncertainty in resistivity is ± 10%.
[h] Uncertainty in resistivity is ± 12%.
[i] Uncertainty in resistivity is ± 4%.
[j] Uncertainty in resistivity is ± 1%.
[k] Uncertainty in resistivity is ± 3% up to 300 K and ± 4% above 300 K.
[m] Uncertainty in resistivity is ± 2% up to 300 K and ± 4% above 300 K.

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PERMITTIVITY (DIELECTRIC CONSTANT) OF INORGANIC SOLIDS

H. P. R. Frederikse

This table lists the permittivity ϵ, frequently called the dielectric constant, of a number of inorganic solids. When the material is not isotropic, the individual components of the permittivity are given. A superscript S indicates a measurement made under constant strain ("clamped" dielectric constant). If the constraint is removed, the measurement yields ϵ^T, the "unclamped" or free dielectric constant.

The temperature of the measurement is given when available; the symbol r.t. indicates a value at nominal room temperature. The frequency of the measurement is given in the last column (i.r. indicates a measurement in the infrared).

Substances are listed in alphabetical order by chemical formula.

REFERENCE

Young, K. F. and Frederikse, H. P. R., *J. Phys. Chem. Ref. Data*, 2, 313, 1973.

Formula	Name	ϵ_{ijk}	*T*/K	*ν*/Hz
Ag_3AsS_3	Silver thioarsenate (Proustite)	$\epsilon^T_{11} = 16.5$, $\epsilon^S_{11} = 14.5$	r.t.	2×10^7
		$\epsilon^T_{33} = 20.0$, $\epsilon^S_{33} = 18.0$	r.t.	2×10^7
AgBr	Silver bromide	12.50	r.t.	
AgCN	Silver cyanide	5.6	r.t.	10^6
AgCl	Silver chloride	11.15	r.t.	
$AgNO_3$	Silver nitrate	9.0	293	5×10^5
$AgNa(NO_2)_2$	Silver sodium nitrite	4.5 ± 0.5	r.t.	9.4×10^9
Ag_2O	Silver oxide	8.8	r.t.	
$(AlF)_2SiO_4$	Aluminum fluosilicate (topaz)	$\epsilon_{11} = 6.62$	297	7×10^3
		$\epsilon_{22} = 6.58$	297	7×10^3
		$\epsilon_{33} = 6.95$	297	7×10^3
Al_2O_3	Aluminum oxide (alumina)	$\epsilon_{11} = \epsilon_{22} = 9.34$	298	10^2—8×10^9
		$\epsilon_{33} = 11.54$	298	10^2—8×10^9
$AlPO_4$	Aluminum phosphate	$\epsilon^T_{11} = 6.05$	r.t.	10^3
AlSb	Aluminum antimonide	11.21	300	i.r.
AsF_3	Arsenic trifluoride	5.7	r.t.	
BN	Boron nitride	7.1	r.t.	i.r.
$BaCO_3$	Barium carbonate	8.53	291	2×10^5
$Ba(COOH)_2$	Barium formate	$\epsilon_{11} = 7.9$	r.t.	10^3
		$\epsilon_{22} = 5.9$	r.t.	10^3
		$\epsilon_{33} = 7.5$	r.t.	10^3
$BaCl_2$	Barium chloride	9.81	r.t.	
$BaCl_2 \cdot 2H_2O$	Barium chloride dihydrate	9.00	r.t.	10^3
BaF_2	Barium fluoride	7.32	292	5×10^2—10^{11}
$Ba(NO_3)_2$	Barium nitrate	4.95	292	2×10^5
$Ba_2NaNb_5O_{15}$	Barium sodium niobate ("Bananas")	$\epsilon^S_{11} = 222$, $\epsilon^T_{11} = 235$	296	10^4
		$\epsilon^S_{22} = 227$, $\epsilon^T_{22} = 247$	296	
		$\epsilon^S_{33} = 32$, $\epsilon^T_{33} = 51$	296	
BaO	Barium oxide (baria)	34 ± 1	248, 333	60×10^7
BaO_2	Barium peroxide	10.7	r.t.	2×10^6
BaS	Barium sulfide	19.23	r.t.	7.25×10^6
$BaSO_4$	Barium sulfate	11.4	288	10^8
$BaSnO_3$	Barium stannate	18	298	25×10^5
$BaTiO_3$	Barium titanate	$\epsilon^T_{11} = 3600$	298	10^5
		$\epsilon^S_{11} = 2300$	298	2.5×10^8
		$\epsilon^T_{33} = 150$	298	10^5
		$\epsilon^S_{33} = 80$	298	2.5×10^8
$Ba_6Ti_2Nb_8O_{30}$	Barium titanium niobate	$\epsilon_{11} = \epsilon_{22} \approx 190$	298	
		$\epsilon_{33} \approx 220$	298	
$BaWO_4$	Barium tungstate	$\epsilon_{11} = \epsilon_{22} = 35.5 \pm 0.2$	297.5	1.6×10^3
		$\epsilon_{33} = 37.2 \pm 0.2$	297.5	1.6×10^3
$BaZrO_3$	Barium zirconate	43	r.t.	

Formula	Name	ϵ_{ijk}	*T*/K	ν/Hz
$Be_3Al_2Si_6O_{18}$	Beryllium aluminum silicate (Beryl)	$\epsilon_{33} = 5.95$	297	7×10^3
		$\epsilon_{11} = \epsilon_{22} = 6.86$	297	7×10^3
$BeCO_3$	Beryllium carbonate	9.7	291	2×10^5
BeO	Beryllium oxide (beryllia)	7.35 ± 0.2	293	2×10^6
$BiFeO_3$	Bismuth iron oxide	40 ± 3	300	9.4×10^9
$Bi_{12}GeO_{20}$	Bismuth germanite	$\epsilon^S_{11} = 38$	r.t.	
$Bi(GeO_4)_3$	Bismuth germanate	16	293	
Bi_2O_3	Bismuth sesquioxide	18.2	r.t.	2×10^6
$Bi_4Ti_3O_{12}$	Bismuth titanate	112	r.t.	10^3
C	Diamond			
	Type I	5.87 ± 0.19	300	10^3
	Type IIa	5.66 ± 0.04	300	10^3
$C_4H_4O_6$	Tartaric acid	$\epsilon_{11} = \epsilon_{22} = 4.3$	298	
		$\epsilon_{33} = 4.5$	298	
		$\epsilon_{13} = 0.55$	298	
$C_6H_{14}N_2O_6$	Ethylene diamine tartrate (EDT)	$\epsilon^T_{11} = 5.0$	293	
		$\epsilon^T_{22} = 8.3$	293	
		$\epsilon^T_{33} = 6.0$	293	
		$\epsilon^T_{13} = 0.7$	293	
$C_6H_{12}O_6NaBr$	Dextrose sodium bromide	$\epsilon^T_{11} = 4.0$	r.t.	10^3
$(CH_3NH_3)Al(SO_4)_2 \cdot 2H_2O$	Methyl ammonium alum (MASD)	19	197	
$Ca_2B_6O_{11} \cdot 5H_2O$	Colemanite	$\epsilon_{11} = 20$	293	10^3
		$\epsilon_{33} = 25$	293	10^3
$CaCO_3$	Calcium carbonate	$\epsilon_{11} = 8.67$	r.t.	9.4×10^{10}
		$\epsilon_{22} = 8.69$	r.t.	9.4×10^{10}
		$\epsilon_{33} = 8.31$	r.t.	9.4×10^{10}
$CaCeO_3$	Calcium cerate	21	r.t.	
CaF_2	Calcium fluoride	6.81	300	5×10^2—10^{11}
$CaMoO_4$	Calcium molybdate	$\epsilon_{11} = \epsilon_{22} = 24.0 \pm 0.2$	297.5	<10
		$\epsilon_{33} = 20.0 \pm 0.2$	297.5	<10
$Ca(NO_3)_2$	Calcium nitrate	6.54	292	2×10^5
$CaNb_2O_6$	Calcium niobate	$\epsilon_{11} = 22.8 \pm 1.9$	r.t.	$(5—500) \times 10^3$
$Ca_2Nb_2O_7$	Calcium pyroniobate	~45	r.t.	5×10^7
CaO	Calcium oxide	11.8 ± 0.3	283	2×10^6
CaS	Calcium sulfide	6.699	r.t.	7.25×10^6
$CaSO_4 \cdot 2H_2O$	Calcium sulfate dihydrate	$\epsilon_{11} = 5.10$	r.t.	
		$\epsilon_{22} = 5.24$	r.t.	
		$\epsilon_{33} = 10.30$	r.t.	
$CaTiO_3$	Calcium titanate	165	r.t.	
$CaWO_4$	Calcium tungstate	$\epsilon_{11} = \epsilon_{22} = 11.7 \pm 0.1$	297.5	1.59×10^3
		$\epsilon_{33} = 9.5 \pm 0.2$	297.5	1.59×10^3
Cd_3As_2	Cadmium arsenide	$\epsilon_{33} = 18.5$	4	
$CdBr_2$	Cadmium bromide	8.6	293	5×10^5
CdF_2	Cadmium fluoride	8.33 ± 0.08	300	10^5—10^7
CdS	Cadmium sulfide	$\epsilon_{11} = \epsilon_{22} = 8.7$	300	i.r.
		$\epsilon_{33} = 9.25$	300	i.r.
		$\epsilon_{11} = \epsilon_{22} = 8.37$	8	i.r.
		$\epsilon_{33} = 9.00$	8	i.r.
		$\epsilon^T_{11} = 8.48$	77	10^4
		$\epsilon^T_{33} = 9.48$	77	10^4
		$\epsilon^S_{11} = 9.02$, $\epsilon^T_{11} = 9.35$	298	10^4
		$\epsilon^S_{33} = 9.53$, $\epsilon^T_{33} = 10.33$	298	10^4
CdSe	Cadmium selenide	$\epsilon^S_{11} = 9.53$, $\epsilon^T_{11} = 9.70$	298	10^4
		$\epsilon^S_{33} = 10.2$, $\epsilon^T_{33} = 10.65$	298	10^4
CdTe	Cadmium telluride	$\epsilon_{11} = \epsilon_{22} = 10.60 \pm 0.15$	297	i.r.
		$\epsilon_{33} = 7.05 \pm 0.05$	297	i.r.
$Cd_2Nb_2O_7$	Cadmium pyroniobate	500—580	293	10^3
CeO_2	Cerium oxide	7.0	r.t.	2×10^6

Formula	Name	ϵ_{ijk}	T/K	ν/Hz
$CoNb_2O_6$	Cobalt niobate	$\epsilon_{11} = 18.4 \pm 0.6$	r.t.	$(5—500) \times 10^3$
		$\epsilon_{22} = 21.4 \pm 1.1$	r.t.	$(5—500) \times 10^3$
		$\epsilon_{33} = 33.0 \pm 0.7$	r.t.	$(5—500) \times 10^3$
CoO	Cobalt oxide	12.9	298	$10^2—10^{10}$
Cr_2O_3	Chromic sesquioxide	$\epsilon_{11} = \epsilon_{22} = 13.3$	298.5	10^3
		$\epsilon_{33} = 11.9$	298.5	10^3
		8	315 (T_N)	6×10^{10}
$CsAl(SO_4)_2 \cdot 12H_2O$	Cesium alum	5.0	r.t.	$20—20 \times 10^3$
CsBr	Cesium bromide	6.38	298	1.6×10^3
Cs_2CO_3	Cesium carbonate	6.53	291	2×10^5
CsCl	Cesium chloride	7.2	298	
$Cs_2H_2AsO_4$	Cesium dihydrogen arsenate (CDA)	4.8	273	9.5×10^9
$Cs_2H_2PO_4$	Cesium dihydrogen phosphate (CDP)	6.15	285	9.5×10^9
$CsH_3(SeO_3)_2$	Cesium trihydrogen selenite	$\epsilon_{11} = 80$	273	10^5
		$\epsilon_{22} = 63$	273	10^5
		$\epsilon_{33} = 12$	273	10^5
CsI	Cesium iodide	6.31	298	1.6×10^3
$CsNO_3$	Cesium nitrate	$\epsilon_{11} = \epsilon_{22} = 9.4$	r.t.	5×10^5
		$\epsilon_{33} = 8.3$	r.t.	5×10^5
$CsPbCl_3$	Cesium lead chloride	14.37	300	$10^5—10^6$
CuBr	Cuprous bromide	8.0	293	5×10^5
CuCl	Cuprous chloride	9.8 ± 0.5	r.t.	10^3
CuO	Cupric oxide	18.1	r.t.	2×10^6
Cu_2O	Cuprous oxide (Cuprite)	7.60 ± 0.06	r.t.	10^5
$CuSO_4 \cdot 5H_2O$	Cupric sulfate pentahydrate	6.60	r.t.	
EuF_2	Europium fluoride	7.7 ± 0.2	298	$(1—300) \times 10^3$
$Eu_2(MoO_4)_3$	Europium molybdate	9.5	298	
EuS	Europium sulfide	13.10 ± 0.04	80	$5 \times 10^2—10^5$
FeO	Ferrous oxide	14.2	r.t.	2×10^6
Fe_2O_3	Ferric sesquioxide	4.5	r.t.	$10^5—10^7$
Fe_2O_3-α	Ferric sesquioxide (hematite)	12		6×10^{10}
Fe_3O_4	Ferrosoferric oxide (magnetite)	20	r.t.	$10^5—10^7$
GaAs	Gallium arsenide	13.13	300	
		12.90	4	i.r.
GaP	Gallium phosphide	11.1	r.t.	
		10.75 ± 0.1	1.6	i.r.
GaSb	Gallium antimonide	15.69	r.t.	
		15.7	4	i.r.
$Gd_2(MoO_4)_3$	Gadolinium molybdate	$\epsilon^T = 10$	298	
		$\epsilon^S = 9.5$	298	10^3
Ge	Germanium	16.0 ± 0.3	4	9.2×10^9
		15.8 ± 0.2	r.t.	$500—3 \times 10^{10}$
GeO_2	Germanium dioxide	$\epsilon_{11} = \epsilon_{22} = 7.44$	r.t.	i.r.
HIO_3	Iodic acid	$\epsilon_{11} = 7.5$	r.t.	10^3
		$\epsilon_{22} = 12.4$	r.t.	10^3
		$\epsilon_{33} = 8.1$	r.t.	10^3
$HNH_4(ClCH_2COO)_2$	Hydrogen ammonium dichloroacetate	$\epsilon_{[102]} = 5.9$	r.t.	10^5
H_2O	Ice I (P = 0 kbar)	99	243	
	Ice III (P = 3 kbar)	117	243	
	Ice V(P = 5 kbar)	114	243	
	Ice VI (P = 8 kbar)	193	243	
HgCl	Mercurous chloride (Calumel)	$\epsilon_{11} = \epsilon_{22} = 14.0$	r.t.	10^{12}
$HgCl_2$	Mercuric chloride	6.5	r.t.	10^{12}
HgS	Mercurous sulfide (Cinnabar)	$\epsilon_{11} = \epsilon_{22} = 18.0$	r.t.	i.r.
		$\epsilon_{33} = 32.5$	r.t.	i.r.
HgSe	Mercurous selenide	25.6	r.t.	$10^4—10^6$
I_2	Iodine	$\epsilon_{11} = 6$	r.t.	$5 \times 10^4—10^7$
		$\epsilon_{22} = 3$	r.t.	$5 \times 10^4—10^7$
		$\epsilon_{33} = 40$	r.t.	$5 \times 10^4—10^7$

Formula	Name	ϵ_{ijk}	T/K	ν/Hz
InAs	Indium arsenide	14.55 ± 0.3	r.t.	i.r.
		15.15	4	i.r.
InP	Indium phosphide	12.61	r.t.	i.r.
InSb	Indium antimonide	17.88	4	i.r.
$KAl(SO_4)_2 \cdot 12H_2O$	Potassium alum	6.5	r.t.	20—20 × 10^3
KBr	Potassium bromide	4.88	300	
		4.53	4.2	
$KBrO_3$	Potassium bromate	7.3	r.t.	2 × 10^6
KCN	Potassium cyanide	6.15	r.t.	2 × 10^6
K_2CO_3	Potassium carbonate	4.96	291	2 × 10^5
$K_2C_4H_4O_6 \cdot {}^1/_2\ H_2O$	Dipotassium tartrate (DKT)	ϵ_{11} = 6.44	r.t.	
		ϵ_{22} = 5.80	r.t.	
		ϵ_{33} = 6.49	r.t.	
		ϵ_{13} = 0.005	r.t.	
KCl	Potassium chloride	4.86 ± 0.02	r.t.	5 × 10^3
		4.50	4.2	
$KClO_3$	Potassium chlorate	5.1	r.t.	2 × 10^6
$KClO_4$	Potassium perchlorate	5.9	r.t.	2 × 10^6
K_2CrO_4	Potassium chromate	7.3	r.t.	6 × 10^7
$KCr(SO_4)_2 \cdot 12H_2O$	Potassium chrome alum	6.5	100—240	175 × 10^3
KD_2AsO_4	Potassium dideuterium arsenate (KDDA)	ϵ_{11} = 70	298	
		ϵ_{33} = 31	298	
KD_2PO_4	Potassium dideuterium phosphate (KDDP)	50 ± 2	297	10^3
KF	Potassium fluoride	6.05		2 × 10^6
KH_2AsO_4	Potassium dihydrogen arsenate (KDA)	ϵ_{11} = 60	298	
		ϵ_{33} = 24	298	
KH_2PO_4	Potassium dihydrogen phosphate (KDP)	46	298	10^3
		ϵ_{11} = 42	r.t.	
		ϵ_{33} = 21	r.t.	
K_2HPO_4	Dipotassium monohydrogen orthophosphate	9.05	r.t.	2 × 10^6
KI	Potassium iodide	5.00	r.t.	9.4 × 10^{10}
KIO_3	Potassium iodate	170	255	10^5
		10	293	10^5
		$\epsilon_{[101]}$ ≈ 40,70	r.t.	10^5
		16.85	r.t.	2 × 10^6
$(K,H)Al_3(SiO_4)_3$	Mica (muscovite)	5.4	299	10^2—3 × 10^9
$(K,H)Mg_3Al(SiO_4)_3$	Mica (Canadian)	ϵ_{11} = ϵ_{22} = 6.9	298	10^2—10^4
		ϵ_{33} = 7.3	298	10^4
KNO_2	Potassium nitrite	25	305	
KNO_3	Potassium nitrate	4.37	293	2 × 10^5
$KNbO_3$	Potassium niobate	700	r.t.	
K_3PO_4	Potassium orthophosphate	7.75	r.t.	2 × 10^6
KSCN	Potassium thiocyanate	7.9	r.t.	2 × 10^6
K_2SO_4	Potassium sulfate	6.4	r.t.	2 × 10^6
$K_2S_3O_6$	Potassium trithionate	5.7	293	1.8 × 10^6
$K_2S_4O_6$	Potassium tetrathionate	5.5	293	1.8 × 10^6
$K_2S_5O_6 \cdot H_2O$	Potassium pentathionate	7.8	293	1.8 × 10^6
$K_2S_6O_6$	Potassium hexathionate	7.8	293	1.8 × 10^6
K_2SeO_4	Potassium selenate	ϵ_{11} = 5.9	r.t.	10^3
		ϵ_{22} = 7.7	r.t.	10^3
$KSr_2Nb_5O_{15}$	Potassium strontium niobate	ϵ_{11} = ϵ_{11} ≈ 1200	298	
		ϵ_{33} ≈ 800	298	
$KTaNbO_3$	Potassium tantalate niobate (KTN)	34,000	273	10^4
		6,000	293	10^4
$KTaO_3$	Potassium tantalate	242	298	2 × 10^5
$LaScO_3$	Lanthanum scandate	30	r.t.	
LiBr	Lithium bromide	12.1	r.t.	2 × 10^6
Li_2CO_3	Lithium carbonate	4.9	291	2 × 10^5

Formula	Name	ϵ_{ijk}	*T*/K	*ν*/Hz
$LiCl$	Lithium chloride	11.05	r.t.	2×10^6
LiD	Lithium deuteride	14.0 ± 0.5	r.t.	i.r.
LiF	Lithium fluoride	9.00	298	10^2—10^7
		9.11	353	10^2—10^7
$LiGaO_2$	Lithium metagallate	$\epsilon^T_{11} = 7.0$, $\epsilon^T_{22} = 6.0$	r.t.	
		$\epsilon^T_{33} = 9.5$	r.t.	
		$\epsilon^S_{11} = 6.8$, $\epsilon^S_{22} = 5.8$	r.t.	
Li^6H	Lithium-6 hydride	13.2 ± 0.5	r.t.	
Li^7H	Lithium-7 hydride	12.9 ± 0.5	r.t.	
$LiH_3(SeO_3)_2$	Lithium trihydrogen selenite	29	298	10^4
		$\epsilon_{11} = 13.0$	r.t.	
		$\epsilon_{22} = 12.9$	r.t.	
		$\epsilon_{33} = 46$	r.t.	
LiI	Lithium iodide	11.03	r.t.	2×10^6
$LiIO_3$	Lithium iodate	$\epsilon_{11} = \epsilon_{22} = 65$	294.5	10^3
		$\epsilon_{33} = 554$	298	
$LiNH_4C_4H_4O_6 \cdot H_2O$	Lithium ammonium tartrate (LAT)	$\epsilon^T_{11} = 7.2$	298	
		$\epsilon^T_{22} = 8.0$	298	
		$\epsilon^T_{33} = 6.9$	298	
$LiNa_3CrO_4 \cdot 6H_2O$	Lithium trisodium chromate	8.0	r.t.	10^3
$LiNa_3MoO_4 \cdot 6H_2O$	Lithium trisodium molybdate	$\epsilon_{11} = 6.7$	r.t.	10^3
		$\epsilon_{33} = 5.3$	r.t.	10^3
$LiNbO_3$	Lithium niobate	$\epsilon_{11} = \epsilon_{22} = 82$	298	10^5
		$\epsilon_{33} = 30$	298	10^5
$Li_2SO_4 \cdot H_2O$	Lithium sulfate monohydrate	$\epsilon_{11} = 5.6$	298	
		$\epsilon_{22} = 10.3$	298	
		$\epsilon_{33} = 6.5$	298	
		$\epsilon_{13} = 0.07$	298	
$LiTaO_3$	Lithium tantalate	$\epsilon_{11} = \epsilon_{22} = 53$	r.t.	10^5
		$\epsilon_{33} = 46$	r.t.	10^5
		$\epsilon^S_{11} = \epsilon^S_{22} = 41$	r.t.	
		$\epsilon^S_{33} = 43$	r.t.	
		$\epsilon^T_{11} = \epsilon^T_{22} = 51$	r.t.	
		$\epsilon^T_{33} = 45$	r.t.	
$LiTlC_4H_4O_6 \cdot H_2O$	Lithium thallium tartrate (LTT)	$\epsilon_{11} \approx 20$	80	
$Mg_3B_7O_{13}Cl$	Magnesium borate monochloride (boracite)	$\epsilon_{11} = 14.1$	r.t.	5×10^5
$MgCO_3$	Magnesium carbonate	8.1	291	2×10^5
$MgNb_2O_6$	Magnesium niobate	$\epsilon_{11} = 16.4 \pm 0.5$	r.t.	$(5—500) \times 10^3$
		$\epsilon_{22} = 20.9 \pm 0.5$	r.t.	$(5—500) \times 10^3$
		$\epsilon_{33} = 32.4 \pm 0.5$	r.t.	$(5—500) \times 10^3$
MgO	Magnesium oxide (Periclase)	9.65	298	10^2—10^8
$(MgO)_xAl_2O_3$	Spinel	8.6	r.t.	
$MgSO_4$	Magnesium sulfate	8.2	r.t.	
$MgSO_4 \cdot 7H_2O$	Magnesium sulfate septa hydrate	5.46	r.t.	
$MgTiO_3$	Magnesium titanate	13.5	r.t.	
$MgWO_4$	Magnesium tungstate	$\epsilon_{11} = 18.0 \pm 1$	r.t.	$(5—500) \times 10^3$
		$\epsilon_{22} = 18.0 \pm 1$	r.t.	$(5—500) \times 10^3$
$MnNb_2O_6$	Manganese niobate	$\epsilon_{11} = 17.4 \pm 2$	r.t.	$(5—500) \times 10^3$
		$\epsilon_{22} = 16.1 \pm 0.5$	r.t.	$(5—500) \times 10^3$
		$\epsilon_{33} = 30.7 \pm 1$	r.t.	$(5—500) \times 10^3$
MnO	Manganese oxide (Pyrolusite)	12.8	r.t.	6×10^{10}
MnO_2	Manganese dioxide	$\sim 10^4$	298	10^4
Mn_2O_3	Manganese sesquioxide	8	r.t.	6×10^{10}
$MnWO_4$	Manganese tungstate	$\epsilon_{11} = 19.3 \pm 1.3$	r.t.	$(5—500) \times 10^3$
		$\epsilon_{22} = 14.3 \pm 0.5$	r.t.	$(5—500) \times 10^3$
		$\epsilon_{33} = 16.5 \pm 1.1$	r.t.	$(5—500) \times 10^3$
$N(CH_3)_4HgBr_3$	Tetramethylammonium tribromo mercurate (TTM)	~ 10	233—373	

Formula	Name	ϵ_{ijk}	T/K	ν/Hz
$N(CH_3)_4HgI_3$	Tetramethylammonium triiodo mercurate (TTM)	~10	233—373	
$N_4(CH_2)_6$	Hexamethylene tetramine (HMTA)	2.6 ± 0.2	r.t.	10^9—10^{10}
$(ND_4)_2BeF_4$	Deuteroammonium fluoberyllate	ϵ_{11} = 10	r.t.	
		ϵ_{22} = 9	r.t.	
		ϵ_{33} = 9	r.t.	
$(ND_4)_2SO_4$	Deuteroammonium sulfate	ϵ_{11} = 9	r.t.	
		ϵ_{22} = 10	r.t.	
		ϵ_{33} = 9	r.t.	
$(NH_2 \cdot CH_2COOH)_3 \cdot H_2SO_4$	Triglycine sulfate (TGS)	ϵ_{11} = 9	273	10^4
		ϵ_{22} = 30	273	10^4
		ϵ_{33} = 6.5	273	10^4
$(NH_2 \cdot CH_2COOH)_3 \cdot H_2SeO_4$	Triglycine selenate (TGSe)	200	293	1.6×10^3
$(NH_2 \cdot CH_2\ COOH)_3 \cdot H_2BeF_4$	Triglycine fluorberyllate (TGFB)	ϵ_{22} = 12	273	10^4
$NH_4Al(SO_4)_2 \cdot 12H_2O$	Ammonium alum	6	r.t.	10^{12}
$(NH_4)_2BeF_4$	Ammonium fluorberyllate	ϵ_{11} = ϵ_{22} = 7.8	123	10^5
		ϵ_{33} = 7.1	123	10^5
		ϵ_{11} = ϵ_{22} = 8.8	293	10^5
		ϵ_{33} = 9.2	293	10^5
NH_4Br	Ammonium bromide	7.1	r.t.	7×10^5
NH_4I	Ammonium iodide	9.8	r.t.	
$(NH_4)_2C_2H_6O_6$	Ammonium tartrate	ϵ_{11} = 6.45	r.t.	10^3
		ϵ_{22} = 6.8	r.t.	10^3
		ϵ_{33} = 6.0	r.t.	10^3
$(NH_4)_2Cd_2(SO_4)_3$	Ammonium cadmium sulfate	10.0	r.t.	10^4
NH_4Cl	Ammonium chloride	6.9	r.t.	7×10^5
$NH_4(ClCH_2COO)$	Ammonium monochloroacetate	5	r.t.	2×10^6
$NH_4Cr(SO_4)_2 \cdot 12H_2O$	Ammonium chrome alum	6.5	r.t.	175×10^3
NH_4HSO_4	Ammonium bisulfate	165	273	5×10^4
$NH_4H_2AsO_4$	Ammonium dihydrogen arsenate (ADA)	5.1	265	9.5×10^9
		ϵ_{11} = ϵ_{22} = 85	298	10^3
		ϵ_{33} = 22	298	
$NH_4H_2PO_4$	Ammonium dihydrogen phosphate (ADP)	ϵ_{11} = ϵ_{22} = 57.1 ± 0.6	294.5	10^5—35×10^9
		ϵ_{33} = 14.0 ± 0.3	294	10^5—36×10^9
$ND_4D_2PO_4$	Ammonium dideuterium phosphate (ADDP)	ϵ_{11} = ϵ_{22} = 74, ϵ_{33} = 24	300	
NH_4NO_3	Ammonium nitrate	10.7	322	$(5—50) \times 10^3$
$(NH_4)_2SO_4$	Ammonium sulfate	ϵ_{11} = ϵ_{22} = 8.0	123	10^5
		ϵ_{33} = 6.3	123	10^5
		ϵ_{11} = ϵ_{22} = 10.0	293	10^5
		ϵ_{33} = 9.3	293	10^5
$(NH_4)_2UO_2(C_2O_4)_2$	Ammonium uranyl oxalate	8.03	r.t.	10^4—3.3×10^5
$(NH_4)_2UO_2(C_2O_4)_2 \cdot 3H_2O$	Ammonium uranyl oxalate trihydrate	6.06	r.t.	10^4—3.3×10^5
$NaBr$	Sodium bromide	6.44	298	1.6×10^3
$NaBrO_3$	Sodium bromate	ϵ^T_{11} = 5.70	298	10^3
$NaCN$	Sodium cyanide	7.55	293	10^5
$NaCO_3$	Sodium carbonate	8.75	291	2×10^5
$NaCO_3 \cdot 10H_2O$	Sodium carbonate decahydrate	5.3	r.t.	6×10^7
$NaCl$	Sodium chloride	5.9	298	10^2—10^7
		5.45	4.2	
$NaClO_3$	Sodium chlorate	ϵ^T_{11} = 5.76	301	10^3
		5.28	r.t.	10^3
$NaClO_4$	Sodium perchlorate	5.76	r.t.	10^3
NaF	Sodium fluoride	5.08 ± 0.02	r.t.	5×10^3
$NaH_3(SeO_3)_2$	Sodium trihydrogen selenite	ϵ_{11} ≈ 75	273	2×10^5
$NaD_3(SeO_3)_2$	Sodium trideuterium selenite	ϵ_{11} ≈ 220	273	2×10^5
NaI	Sodium iodide	7.28 ± 0.03	r.t.	
$NaK(C_4H_2D_2O_6) \cdot 4D_2O$	Sodium potassium tartrate tetradeutrate	ϵ_{11} = 70	273	10^3
	(double deuterated Rochelle salt)	ϵ_{22} = 8.9	273	10^3

PERMITTIVITY (DIELECTRIC CONSTANT) OF INORGANIC SOLIDS (continued)

Formula	Name	ϵ_{ijk}	*T*/K	*ν*/Hz
$NaK(C_4H_4O_6) \cdot 4H_2O$	Sodium potassium tartrate tetrahydrate	ϵ_{11} = 170	273	10^3
	(Rochelle salt)	ϵ_{22} = 9.1	273	10^3
$NaNH_4(C_4H_4O_6) \cdot 4H_2O$	Sodium ammonium tartrate	ϵ_{11} = 8.4	298	
	(Ammonium Rochelle salt)	ϵ_{22} = 9.2	298	
		ϵ_{33} = 9.5	298	
$NaNbO_3$	Sodium niobate	ϵ_{33} = 670 ± 13	r.t.	
		ϵ_{11} = ϵ_{22} = 76 ± 2	r.t.	
$NaNO_2$	Sodium nitrite	ϵ_{11} = 7.4	r.t.	5 × 10^5
		ϵ_{22} = 5.5	r.t.	5 × 10^5
		ϵ_{33} = 5.0	r.t.	5 × 10^5
$NaNO_3$	Sodium nitrate	6.85	292	2 × 10^5
$NaSO_4$	Sodium sulfate	7.90	r.t.	
$NaSO_4 \cdot 10H_2O$	Sodium sulfate decahydrate	5.0	r.t.	
$Na_2S_2O_3 \cdot 5H_2O$	Sodium sulfate pentahydrate	7	250—290	300—10^4
$Na_2UO_2(C_2O_4)_2$	Sodium uranyl oxalate	5.18	r.t.	
$NdAlO_3$	Neodymium aluminate	17.5	r.t.	
$NdScO_3$	Neodymium scandate	27	r.t.	
$Ni_3B_7O_{13}I$	Nickel iodine boracite	ϵ_{11} = 14	260	
$NiNb_2O_6$	Nickel niobate	ϵ_{11} = 16.0 ± 0.5	r.t.	(5—500) × 10^3
		ϵ_{22} = 23.8 ± 1.8	r.t.	(5—500) × 10^3
		ϵ_{33} = 31.3 ± 2.5	r.t.	(5—500) × 10^3
NiO	Nickel oxide	11.9	298	10^5
$NiSO_4 \cdot 6H_2O$	Nickel sulfate hexahydrate	ϵ_{11} = 6.2	r.t.	
		ϵ_{33} = 6.8	r.t.	
$NiWO_4$	Nickel tungstate	ϵ_{11} = 17.4 ± 2.4	r.t.	(5—500) × 10^3
		ϵ_{22} = 13.6 ± 1.0	r.t.	(5—500) × 10^3
		ϵ_{33} = 19.7 ± 0.6	r.t.	(5—500) × 10^3
P	Phosphorous (red)	4.1	r.t.	10^8
	Phosphorous (yellow)	3.6	r.t.	10^8
$[P(CH_3)_4]HgBr_3$	Tetramethylphosphonium tribromo mercurate (TTM)	~10	233—373	
$PbBr_2$	Lead bromide	>30	293	(0.5—3) × 10^6
$PbCO_3$	Lead carbonate	18.6	288	10.8
$Pb(C_2H_3O_2)_2$	Lead acetate	2.6	290—295	10^6
$PbCl_2$	Lead chloride	33.5	273	(0.5—3) × 10^6
Pb_2CoWO_6	Lead cobalt tungstate	~250	r.t.	
PbF_2	Lead fluoride	26.3	r.t.	
$PbHfO_3$	Lead hafnate	390	300	10^5
		185	400	
PbI_2	Lead iodide	20.8	293	(0.5—3) × 10^6
$Pb_3MgNb_2O_9$	Lead magnesium niobate	10,000	297	
$PbMoO_4$	Lead molybdate	ϵ_{11} = 34.0 ± 0.4	297.5	1.6 × 10^3
		ϵ_{33} = 40.6 ± 0.2	297.5	1.6 × 10^3
$Pb(NO_3)_2$	Lead nitrate	16.8	r.t.	(0.5—3) × 10^6
$PbNb_2O_6$	Lead niobate	ϵ^T_{33} = 180	298	
PbO	Lead oxide	25.9	r.t.	2 × 10^6
PbS	Lead sulfide (Galena)	190	77	i.r.
		200 ± 35	r.t.	i.r.
$PbSO_4$	Lead sulfate	14.3	290—295	10^6
PbSe	Lead selenide	280	r.t.	i.r.
$PbTa_2O_6$	Lead metatantalate	ϵ_{11} = ϵ_{22} ≈ 300	r.t.	10^4
		ϵ_{33} = 150	r.t.	10^4
PbTe	Lead telluride	450	r.t.	i.r.
		40	77	10^4—15 × 10^4
		430	4.2	10^4—15 × 10^4
$PbTiO_3$	Lead titanate	~200	r.t.	10^3
$PbWO_4$	Lead tungstate	ϵ_{11} = ϵ_{22} = 23.6 ± 0.3	297.5	1.59 × 10^3
		ϵ_{33} = 31.0 ± 0.4	297.5	1.59 × 10^3
$Pb(Zn_{1/3}Nb_{2/3})O_3$	Lead zinc niobate	7	300	10^3, 300 × 10^3
$PbZrO_3$	Lead zirconate	200	400	

Formula	Name	ϵ_{ijk}	T/K	ν/Hz
$RbAl(SO_4)_2 \cdot 12H_2O$	Rubidium alum	5.1	r.t.	10^{12}
RbBr	Rubidium bromide	4.83	300	
Rb_2CO_3	Rubidium carbonate	4.87 ± 0.02	r.t.	5×10^3
RbCl	Rubidium chloride	4.91 ± 0.02	r.t.	5×10^3
$RbCr(SO_4)_2 \cdot 12H_2O$	Rubidium chrome alum	5.0	r.t.	10^{12}
RbF	Rubidium fluoride	5.91	r.t.	2×10^6
$RbHSO_4$	Rubidium bisulfate	$\epsilon_{11} = 7$	r.t.	10^5
		$\epsilon_{22} = 8$	r.t.	10^5
		$\epsilon_{33} = 10$	r.t.	10^5
RbH_2AsO_4	Rubidium dihydrogen arsenate (RDA)	3.90	273	9.5×10^9
RbH_2PO_4	Rubidium dihydrogen phosphate (RDP)	6.15	285	9.5×10^9
RbI	Rubidium iodide	4.94 ± 0.02	r.t.	5×10^3
$RbInSO_4$	Rubidium indium sulfate	6.85	r.t.	
$RbNO_3$	Rubidium nitrate	20—380	433—488	10^6
		30	488—538	10^6
S	Sulfur	$\epsilon_{11} = 3.75$	298	10^2—10^3
		$\epsilon_{22} = 3.95$	298	10^2—10^3
		$\epsilon_{33} = 4.44$	298	10^2—10^3
	sublimed	3.69	298	10^2—10^3
$SC(NH_2)_2$	Thiourea	$\epsilon_{11} = \epsilon_{33} \approx 3$	77—300	10^3
		$\epsilon_{22} = 35$	300	10^3
Sb_2O_3	Antimonous sesquioxide	12.8	r.t.	$(1.5—2) \times 10^3$
Sb_2S_3	Antimonous sulfide (stibnite)	$\epsilon_{11} = \epsilon_{22} = 15$	r.t.	10^3
		$\epsilon_{33} = 180$	r.t.	10^3
Sb_2Se_3	Antimonous selenide	~110	r.t.	$(10—16.5) \times 10^9$
SbSI	Antimonous sulfide iodide	2000	273	10^5
		$\epsilon_{11} = \epsilon_{22} \approx 25$	r.t.	10^3—10^5
		$\epsilon_{33} \approx 5 \times 10^4$	295	10^3—10^5
Se	Selenium (monocrystal)	$\epsilon_{11} = \epsilon_{22} = 11$	300	24×10^9
		$\epsilon_{33} = 21$	300	24×10^9
	(amorphous)	6.0	298	10^2—10^{10}
Si	Silicon	12.1	4.2	10^7—10^9
SiC	Silicon carbide			
	cubic	9.72	r.t.	i.r.
	6H	$\epsilon_{11} = \epsilon_{22} = 9.66$	r.t.	i.r.
		$\epsilon_{33} = 10.03$	r.t.	i.r.
		9.7 ± 0.1	1.8	i.r.
Si_3N_4	Silicon nitride	4.2 (film)	r.t.	10^3
SiO	Silicon monoxide	5.8	r.t.	10^3
SiO_2	Silicon dioxide	$\epsilon_{11} = 4.42$	r.t.	9.4×10^{10}
		$\epsilon_{22} = 4.41$	r.t.	9.4×10^{10}
		$\epsilon_{33} = 4.60$	r.t.	9.4×10^{10}
$Sm_2(MoO_4)_3$	Samarium molybdate	12	298	
SnO_2	Stannic dioxide	$\epsilon_{11} = \epsilon_{22} = 14 \pm 2$	r.t.	10^4—10^{10}
		$\epsilon_{33} = 9.0 \pm 0.5$	r.t.	10^4—10^{10}
SnSb	Tin antimonide	147	r.t.	10^4—10^6
SnTe	Tin telluride	1770 ± 300	r.t.	i.r.
$Sr(COOH)_2 \cdot 2H_2O$	Strontium formate dihydrate	6.1	r.t.	10^3
$SrCO_3$	Strontium carbonate	8.85	298	2×10^5
$SrCl_2$	Strontium chloride	9.19	r.t.	
$Sr_4Cl_2 \cdot 6H_2O$	Strontium chloride hexahydrate	8.52	r.t.	
SrF_2	Strontium fluoride	6.50	300	5×10^2—10^{11}
$SrMoO_4$	Strontium molybdate	$\epsilon_{11} = \epsilon_{22} = 31.7 \pm 0.2$	297.5	1.59×10^3
		$\epsilon_{33} = 41.7 \pm 0.2$	297.5	1.59×10^3
$Sr(NO_3)_2$	Strontium nitrate	5.33	292	2×10^5
$Sr_2Nb_2O_7$	Strontium niobate	$\epsilon_{11} = 75$	r.t.	10^3
		$\epsilon_{22} = 46$	r.t.	10^3
		$\epsilon_{33} = 43$	r.t.	10^3

Formula	Name	ϵ_{ijk}	*T*/K	ν/Hz
SrO	Strontium oxide	13.3 ± 0.3	273	2×10^6
SrS	Strontium sulfide	11.3	r.t.	7.25×10^6
$SrSO_4$	Strontium sulfate	11.5	r.t.	
$SrTiO_3$	Strontium titanate	332	298	10^3
		2080	78	10^3
$SrWO_4$	Strontium tungstate	$\epsilon_{11} = \epsilon_{22} = 25.7 \pm 0.2$	297.5	1.6×10^3
		$\epsilon_{33} = 34.1 \pm 0.2$	297.5	1.6×10^3
Ta_2O_5	Tantalum pentoxide (tantala)			
	α phase	$\epsilon_{11} = \epsilon_{22} = 30$	77	10^3
		$\epsilon_{33} = 65$	77	10^3
	β phase	24	292	10^3
$Tb(MoO_4)_3$	Terbium molybdate	11	298	
		$\epsilon_{11} = \epsilon_{22} = 33$	100—200	9.4×10^9
		$\epsilon_{33} = 53$	100—200	9.4×10^9
Te	Tellurium	$\epsilon_{11} = \epsilon_{22} = 33$	r.t.	
		$\epsilon_{33} = 54$	r.t.	
	polycrystalline	27.5	r.t.	i.r.
	monocrystalline	28.0	r.t.	i.r.
ThO_2	Thorium dioxide	18.9 ± 0.4	r.t.	3×10^5
TiO_2	Titanium dioxide (rutile)	$\epsilon_{11} = \epsilon_{22} = 86$	300	10^4—10^6
		$\epsilon_{33} = 170$	300	10^4—10^6
Ti_2O_3	Titanium sesquioxide	30	77	6×10^{10}
TlBr	Thallium bromide	30	293	10^3—10^7
TlCl	Thallous chloride	32.2 ± 0.2	293	10^3—10^5
TlI	Thallous iodide (orthorhombic)	20.7 ± 0.2	293	10^4
		37.3	193	10^7
$TlNO_3$	Thallous nitrate	16.5	293	5×10^5
$TlSO_4$	Thallous sulfate	25.5	293	5×10^5
UO_2	Uranium dioxide	24	r.t.	3×10^5
WO_3	Tungsten trioxide	300		
$YMnO_3$	Yttrium manganate	20	r.t.	2×10^7
Y_2O_3	Yttrium sesquioxide	10	r.t.	10^6
$YbMnO_3$	Ytterbium manganate	20	r.t.	2×10^7
Yb_2O_3	Ytterbium sesquioxide	5.0 (film)	r.t.	10^3
ZnO	Zinc monoxide	$\epsilon^S_{11} = 8.33$	r.t.	
		$\epsilon^S_{33} = 8.84$	r.t.	
		$\epsilon^T_{11} = 9.26$	r.t.	
		$\epsilon^T_{33} = 11.0$	r.t.	
		$\epsilon_{11} = 9.26$	r.t.	
		$\epsilon_{33} = 8.2$	r.t.	
		8.15	r.t.	i.r.
ZnS	Zinc sulfide	$\epsilon^S_{11} = 8.08 \pm 2\%$	77	10^4
		$\epsilon^S_{11} = 8.32 \pm 2\%$	298	10^4
		$\epsilon^T_{11} = 8.14 \pm 2\%$	77	10^4
		$\epsilon^T_{11} = 8.37 \pm 2\%$	298	10^4
ZnSe	Zinc selenide	$\epsilon^T_{11} = \epsilon^S_{11} = 9.12 \pm 2\%$	298	10^4
ZnTe	Zinc telluride	$\epsilon^T_{11} = \epsilon^S_{11} = 10.10 \pm 2\%$	r.t.	
$ZnWO_4$	Zinc tungstate	$\epsilon_{22} = 16.1 \pm 0.5$	r.t.	$(5—500) \times 10^3$
ZrO_2	Zirconium dioxide (zirconia)	12.5	r.t.	2×10^6

CURIE TEMPERATURE OF SELECTED FERROELECTRIC CRYSTALS

H. P. R. Frederikse

The following table lists the major ferroelectric crystals and their Curie temperatures, T_C.

REFERENCE

Young, K. F. and Frederikse, H. P. R., *J. Phys. Chem. Ref. Data*, 2, 313, 1973.

Name or acronym	Formula	T_C/K
Potassium dihydrogen phosphate group		
KDP	KH_2PO_4	123
KDA	KH_2AsO_4	97
KDDP	KD_2PO_4	213
KDDA	KD_2AsO_4	162
RDP	RbH_2PO_4	146
RDA	RbH_2AsO_4	111
RDDP	RbD_2PO_4	218
RDDA	RbD_2AsO_4	178
CDP	CsH_2PO_4	159
CDA	CsH_2AsO_4	143
CDDA	CsD_2AsO_4	212
Rochelle salt group		
Rochelle salt	$NaKC_4H_4O_6 \cdot 4H_2O$	255-297
Deuterated Rochelle salt	$NaKC_4H_2D_2O_6 \cdot 4H_2O$	251-308
Ammonium Rochelle salt	$NaNH_4C_4H_4O_6 \cdot 4H_2O$	109
LAT	$LiNH_4C_4H_4O_6 \cdot H_2O$	106
Triglycine sulfate group		
TGS	$(NH_2CH_2COOH)_3 \cdot H_2SO_4$	322
TGSe	$(NH_2CH_2COOH)_3 \cdot H_2SeO_4$	295
TGFB	$(NH_2CH_2COOH)_3 \cdot H_2BeF_4$	346
AFB	$(NH_4)_2BeF_4$	176
HADA	$HNH_4(ClCH_2COO)_2$	128
Perovskites and related compounds		
Barium titanate	$BaTiO_3$	406, 278, 193
Lead titanate	$PbTiO_3$	765
Potassium niobate	$KNbO_3$	712
Potassium tantalate niobate	$KTa_{2/3}Nb_{1/3}O_3$	241, 220, 170
Lithium niobate	$LiNBO_3$	1483
Lithium tantalate	$LiTaO_3$	891
Barium titanium niobate	$Ba_6Ti_2Nb_8O_{30}$	521
Ba-Na niobate (“Bananas”)	$Ba_2NaNb_5O_{15}$	833
Potassium iodate	KIO_3	485, 343, 257-263, 83
Lithium iodate	$LiIO_3$	529
Potassium nitrate	KNO_3	397
Sodium nitrate	$NaNO_3$	548
Rubidium nitrate	$RbNO_3$	437-487

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CURIE TEMPERATURE OF SELECTED FERROELECTRIC CRYSTALS (continued)

Name or acronym	Formula	T_C/K
Miscellaneous compounds		
Cesium trihydrogen selenite	$CsH_3(SeO_3)_2$	143
Lithium trihydrogen selenite	$LiH_3(SeO_3)_2$	$T_C > T_{mp}$
Potassium selenate	K_2SeO_4	93
Methyl ammonium alum (MASD)	$CH_3NH_3Al(SO_4)_2 \cdot 12H_2O$	177
Ammonium cadmium sulfate	$(NH_4)_2Cd_2(SO_4)_3$	95
Ammonium bisulfate	$(NH_4)HSO_4$	271
Ammonium sulfate	$(NH_4)_2SO_4$	224
Ammonium nitrate	NH_4NO_3	398, 357, 305, 255
Colemanite	$CaB_3O_4(OH)_3 \cdot H_2O$	266
Cadmium pyroniobite	$Cd_2Nb_2O_7$	185
Gadolinium molybdate	$Gd_2(MoO_4)_3$	432

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PROPERTIES OF ANTIFERROELECTRIC CRYSTALS

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Some important antiferroelectric crystals are listed here with their Curie Temperatures T_C. The last column gives the constant T_0 which appears in the Curie-Weiss law describing the dielectric constant of these materials above the Curie Temperature:

$$\varepsilon = \text{const.}/(T - T_0)$$

Name or acronym	Formula	T_C/K	T_0/K
ADP	$NH_4H_2PO_4$	148	
ADA	$NH_4H_2AsO_4$	216	
ADDP	$NH_4D_2PO_4$	242, 245	
ADDA	$NH_4D_2AsO_4$	299	
A_dDDP	$ND_4D_2PO_4$	243	
A_dDDA	$ND_4D_2AsO_4$	304	
Sodium niobate	$NaNbO_3$	911, 793	
Lead hafnate	$PbHfO_3$	476	378
Lead zirconate	$PbZrO_3$	503	475
Lead metaniobate	$PbNb_2O_6$	843	530
Lead metatantalate	$PbTa_2O_6$	543	533
Tungsten trioxide	WO_3	1010	
Potassium strontium niobate	$KSr_2Nb_5O_{15}$	427	413
Sodium nitrite	$NaNO_2$	437	437
Sodium trihydrogen selenite	$NaH_3(SeO_3)_2$	193	192
Sodium trideuterium selenite	$NaD_3(SeO_3)_2$	271	245
Ammonium trihydrogen periodate	$(NH_4)_2H_3IO_6$	245	

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DIELECTRIC CONSTANTS OF GLASSES

Type	Dielectric constant at 100 MHz (20°C)	Volume resistivity (350°C megohm-cm)	Loss factor[a]
Corning 0010	6.32	10	0.015
Corning 0080	6.75	0.13	0.058
Corning 0120	6.65	100	0.012
Pyrex 1710	6.00	2,500	0.025
Pyrex 3320	4.71	—	0.019
Pyrex 7040	4.65	80	0.013
Pyrex 7050	4.77	16	0.017
Pyrex 7052	5.07	25	0.019
Pyrex 7060	4.70	13	0.018
Pyrex 7070	4.00	1,300	0.0048
Vycor 7230	3.83	—	0.0061
Pyrex 7720	4.50	16	0.014
Pyrex 7740	5.00	4	0.040
Pyrex 7750	4.28	50	0.011
Pyrex 7760	4.50	50	0.0081
Vycor 7900	3.9	130	0.0023
Vycor 7910	3.8	1,600	0.00091
Vycor 7911	3.8	4,000	0.00072
Corning 8870	9.5	5,000	0.0085
G. E. Clear (silica glass)	3.81	4,000—30,000	0.00038
Quartz (fused)	3.75 4.1 (1 MHz)	—	0.0002 (1 MHz)

[a] Power factor × dielectric constant equals loss factor.

PROPERTIES OF SUPERCONDUCTORS

L. I. Berger and B. W. Roberts

The following tables include superconductive properties of selected elements, compounds, and alloys. Individual tables are given for thin films, elements at high pressures, superconductors with high critical magnetic fields, and high critical temperature superconductors.

The historically first observed and most distinctive property of a superconductive body is the near total loss of resistance at a critical temperature (T_c) that is characteristic of each material. Figure 1(a) below illustrates schematically two types of possible transitions. The sharp vertical discontinuity in resistance is indicative of that found for a single crystal of a very pure element or one of a few well annealed alloy compositions. The broad transition, illustrated by broken lines, suggests the transition shape seen for materials that are not homogeneous and contain unusual strain distributions. Careful testing of the resistivity limit for superconductors shows that it is less than 4×10^{-23} ohm cm, while the lowest resistivity observed in metals is of the order of 10^{-13} ohm cm. If one compares the resistivity of a superconductive body to that of copper at room temperature, the superconductive body is at least 10^{17} times less resistive.

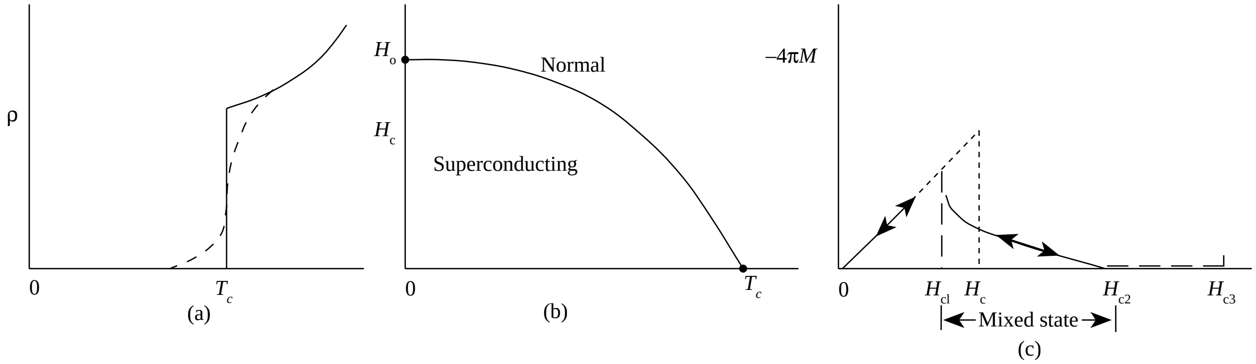

FIGURE 1. Physical properties of superconductors. (a) Resistivity vs. temperature for a pure and perfect lattice (solid line); impure and/or imperfect lattice (broken line). (b) Magnetic-field temperature dependence for Type-I or "soft" superconductors. (c) Schematic magnetization curve for "hard" or Type-II superconductors.

The temperature interval ΔT_c, over which the transition between the normal and superconductive states takes place, may be of the order of as little as 2×10^{-5} K or several K in width, depending on the material state. The narrow transition width was attained in 99.9999% pure gallium single crystals.

A Type-I superconductor below T_c, as exemplified by a pure metal, exhibits perfect diamagnetism and excludes a magnetic field up to some critical field H_c, whereupon it reverts to the normal state as shown in the *H-T* diagram of Figure 1(b).

The magnetization of a typical high-field superconductor is shown in Figure 1(c). The discovery of the large current-carrying capability of Nb_3Sn and other similar alloys has led to an extensive study of the physical properties of these alloys. In brief, a high-field superconductor, or Type-II superconductor, passes from the perfect diamagnetic state at low magnetic fields to a mixed state and finally to a sheathed state before attaining the normal resistive state of the metal. The magnetic field values separating the four stages are given as H_{c1}, H_{c2}, and H_{c3}. The superconductive state below H_{c1} is perfectly diamagnetic, identical to the state of most pure metals of the "soft" or Type-I superconductor. Between H_{c1} and H_{c2} a "mixed superconductive state" is found in which fluxons (a minimal unit of magnetic flux) create lines of normal flux in a superconductive matrix. The volume of the normal state is proportional to $-4\pi M$ in the "mixed state" region. Thus at H_{c2} the fluxon density has become so great as to drive the interior volume of the superconductive body completely normal. Between H_{c2} and H_{c3} the superconductor has a sheath of current-carrying superconductive material at the body surface, and above H_{c3} the normal state exists. With several types of careful measurement, it is possible to determine H_{c1}, H_{c2}, and H_{c3}. Table 6 contains some of the available data on high-field superconductive materials.

High-field superconductive phenomena are also related to specimen dimension and configuration. For example, the Type-I superconductor, Hg, has entirely different magnetization behavior in high magnetic fields when contained in the very fine sets of filamentary tunnels found in an unprocessed Vycor glass. The great majority of superconductive materials are Type-II. The elements in very pure form and a very few precisely stoichiometric and well annealed compounds are Type I with the possible exceptions of vanadium and niobium.

Metallurgical Aspects. The sensitivity of superconductive properties to the material state is most pronounced and has been used in a reverse sense to study and specify the detailed state of alloys. The mechanical state, the homogeneity, and the presence of impurity atoms and other electron-scattering centers are all capable of controlling the critical temperature and the current-carrying capabilities in high-magnetic fields. Well annealed specimens tend to show sharper transitions than those that are strained or inhomogeneous. This sensitivity to mechanical state underlines a general problem in the tabulation of properties for superconductive materials. The occasional divergent values of the critical temperature and of the critical fields quoted for a Type-II superconductor may lie in the variation in sample preparation. Critical temperatures of materials studied early in the history of superconductivity must be evaluated in light of the probable metallurgical state of the material, as well as the availability of less pure starting elements. It has been noted that recent work has given extended consideration to the metallurgical aspects of sample preparation.

Symbols in tables: T_c: Critical temperature; H_o: Critical magnetic field in the $T = 0$ limit; θ_D: Debye temperature; and γ: Electronic specific heat.

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TABLE 1
Selective Properties of Superconductive Elements

Element	T_c(K)	H_o(oersted)	θ_D(K)	γ(mJ mol^{-1}K^{-1})
Al	1.175 ± 0.002	104.9 ± 0.3	420	1.35
Am* (α,?)	0.6			
Am* (β,?)	1.0			
Be	0.026			0.21
Cd	0.517 ± 0.002	28 ± 1	209	0.69
Ga	1.083 ± 0.001	58.3 ± 0.2	325	0.60
Ga (β)	5.9, 6.2	560		
Ga (γ)	7	950, HF[a]		
Ga (Δ)	7.85	815, HF		
Hf	0.128	12.7		2.21
Hg (α)	4.154 ± 0.001	411 ± 2	87, 71.9	1.81
Hg (β)	3.949	339	93	1.37
In	3.408 ± 0.001	281.5 ± 2	109	1.672
Ir	0.1125 ± 0.001	16 ± 0.05	425	3.19
La (α)	4.88 ± 0.02	800 ± 10	151	9.8
La (β)	6.00 ± 0.1	1096, 1600	139	11.3
Lu	0.1 ± 0.03	350 ± 50		
Mo	0.915 ± 0.005	96 ± 3	460	1.83
Nb	9.25 ± 0.02	2060 ± 50, HF	276	7.80
Os	0.66 ± 0.03	70	500	2.35
Pa	1.4			
Pb	7.196 ± 0.006	803 ± 1	96	3.1
Re	1.697 ± 0.006	200 ± 5	4.5	2.35
Ru	0.49 ± 0.015	69 ± 2	580	2.8
Sn	3.722 ± 0.001	305 ± 2	195	1.78
Ta	4.47 ± 0.04	829 ± 6	258	6.15
Tc	7.8 ± 0.1	1410, HF	411	6.28
Th	1.38 ± 0.02	1.60 ± 3	165	4.32
Ti	0.40 ± 0.04	56	415	3.3
Tl	2.38 ± 0.02	178 ± 2	78.5	1.47
U	0.2			
V	5.40 ± 0.05	1408	383	9.82
W	0.0154 ± 0.0005	1.15 ± 0.03	383	0.90
Zn	0.85 ± 0.01	54 ± 0.3	310	0.66
Zr	0.61 ± 0.15	47	290	2.77
Zr (ω)	0.65, 0.95			

TABLE 2
Range of Critical Temperatures Observed for Superconductive Elements in Thin Films Condensed Usually at Low Temperatures

Element	T_c Range (K)	Comments	Element	T_c Range (K)	Comments
Al	1.15—5.7	HF[a]	Nb	2.0—10.1	
Be	5—9.75	HF	Pb	1.8—7.5	
Bi	6.17—6.6		Re	1.7—7	
Cd			Sn	3.5—6	
(Disordered)	0.79—0.91		Ta	<1.7—4.51	HF[a]
(Ordered)	0.53—0.59		Tc	4.6—7.7	
Ga	2.5—8.5	HF	Ti	1.3 Max	
Hg	3.87—4.5		Tl	2.33—2.96	
In	2.2—5.6	HF	V	1.8—6.02	
La	3.55—6.74		W	<1.0—4.1	
Mo	3.3—8.0		Zn	0.77—1.9	

[a] HF denotes high magnetic field superconductive properties.

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TABLE 3
Elements Exhibiting Superconductivity Under or After Application of High Pressure

Element	T_c Range (K)	Pressure (kbar)
Al	1.98—0.075	0—62
As	0.31—0.5	220—140
	0.2—0.25	140—100
Ba II	1—1.8	55—85
III	1.8—5	85—144
IV	4.5—5.4	144—190
Bi II	3.9	25—27
III	6.55—7.25	28—38
IV	7.0, 8.7—6.0	43, 43—62
V	6.7, 8.3	48—80
VI	8.55	90, 92—101
VII(?)	8.2	30
Ce (α)	0.020—0.045	20—35
Ce (α′)	1.9—1.3	45—125
Cs V	1.5	>125
Ga II	6.38	≥35
II′	7.5	≥35 then P removed
Ge	5.35	115
La	5.5—12.9	0—210
Lu	0.022—1.0	45—190
P	5.8	170
Pb II	3.55	160
Re II	2.3 Max.	"Plastic" compression
Sb (prepared 120 kbar, held below 77K)	2.6—2.7	
Sb II	3.55—3.40	85—150
Se II	6.75, 6.95	130
Si	6.7—7.1	120—130
Sn II	5.2—4.85	125—160
III	5.30	113
Te II	2.4—5.1	38—55
	4.1—4.2	53—62
IV	4.72—4	63—80
( )	3.3—2.8	100—260
Tl (cubic form)	1.45	35
(hexagonal form)	1.95	35
U	2.4—0.4	10—85
Y	1.7—2.5	110—160
Zr (omega form, metastable)	1—1.7	60—130

TABLE 4
Superconductive Compounds and Alloys

All compositions are denoted on an atomic basis, i.e., AB, AB_2, or AB_3 for compounds, unless noted. Solid solutions or odd compositions may be denoted as A_zB_{1-z} or A_zB. A series of three or more alloys is indicated as A_xB_{1-x} or by actual indication of the atomic fraction range, such as $A_{0—0.6}B_{1—0.4}$. The critical temperature of such a series of alloys is denoted by a range of values or possibly the maximum value.

The selection of the critical temperature from a transition in the effective permeability, or the change in resistance, or possibly the incremental changes in frequency observed by certain techniques is not often obvious from the literature. Most authors choose the mid-point of such curves as the probable critical temperature of the idealized material, while others will choose the highest temperature at which a deviation from the normal state property is observed. In view of the previous discussion concerning the variability of the superconductive properties as a function of purity and other metallurgical aspects, it is recommended that appropriate literature be checked to determine the most probable critical temperature or critical field of a given alloy.

A very limited amount of data on critical fields, H_o, is available for these compounds and alloys; these values are given at the end of the table.

A. SUPERCONDUCTORS WITH T_c< 10 K

Substance	T_c, K	Crystal structure type
$Ag_{3.3}Al$	0.34	A12-cI58 (Mn)
$Ag_xAl_yZn_{1-x-y}$	0.15	Cubic
$AgBi_2$	2.87—3.0	
$Ag_7F_{0.25}N_{0.75}O_{10.25}$	0.85—0.90	
Ag_2F	0.0.066	
Ag_7FO_8	0.3	Cubic
$Ag_{0.8—0.3}Ga_{0.2—0.7}$	6.5—8	
Ag_4Ge	0.85	Hex., c.p.
$Ag_{0.438}Hg_{0.562}$	0.64	$D8_2$
$AgIn_2$	~2.4	C16

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
$Ag_{0.1}In_{0.9}Te$ (n = 1.4 × 10^{22})*	1.2—1.89	B1
$Ag_{0.2}In_{0.8}Te$ (n = 1.07 × 10^{22})	0.77—1.00	B1
AgLa	0.94	B2-cP2 (CsCl)
AgLa (9.5 kbar)	1.2	B2
AgLu	0.33	B2-cP2
$AgMo_4S_5$	9.1	hR15 (Mo_6PbS_8)
$Ag_{1.2}Mo_6Se_8$	5.9	Same
Ag_7NO_{11}	1.04	Cubic
Ag_xPb_{1-x}	7.2 max.	
Ag_4Sn	0.1	h**
Ag_xSn_{1-x}	1.5—3.7	
Ag_xSn_{1-x} (film)	2.0—3.8	
$AgTe_3$	2.6	Cubic
AgTh	2.2	C16-tI12 (Al_2Cu)
$AgTh_2$	2.26	C16
$Ag_{0.03}Tl_{0.97}$	2.67	
$Ag_{0.94}Tl_{0.06}$	2.32	
AgY	0.33	B2-cP2 (CsCl)
Ag_xZn_{1-x}	0.5—0.845	
$AlAu_4$	0.4—0.7	Like A13
Al_2Au	0.1	C1-cF12 (CaF_2)
Al_2CMo_3	9.8—10.2	A13+trace 2nd. phase)
Al_2CaSi	5.8	
$Al_{0.131}Cr_{0.088}V_{0.781}$	1.46	Cubic
$AlGe_2$	1.75	
Al_2Ge_2U	1.6	LI_2-cP4 (Cu_3Au)
$AlLa_3$	5.57	DO_{19}
Al_2La	3.23	C15
Al_2Lu	1.02	C15-cF24 (Cu_2Mg)
Al_3Mg_2	0.84	F.C.C.
$AlMo_3$	0.58	A15
$AlMo_6Pd$	2.1	
AlN	1.55	B4
Al_2NNb_3	1.3	A13
Al_3Nb	0.64	tI8 (Al_3Ti)
AlOs	0.39	B2
Al_3Os	5.90	
AlPb (film)	1.2—7	
Al_2Pt	0.48—0.55	C1
Al_5Re_{24}	3.35	A12
AlSb	2.8	B4-tI4 (Sn)
Al_2Sc	1.02	C15-cF24 (Cu_2Mg)
Al_2Si_2U	1.34	LI_2-cP4 (Cu_3Au)
$AlTh_2$	0.1	C16-tI12 (Al_2Cu)
Al_3Th	0.75	DO_{19}
$Al_xTi_yV_{1-x-y}$	2.05—3.62	Cubic
$Al_{0.108}V_{0.892}$	1.82	Cubic
Al_2Y	0.35	C15-cF24 (Cu_2Mg)
Al_3Yb	0.94	LI_2-cP4 (Cu_3Au)
Al_xZn_{1-x}	0.5—0.845	
$AlZr_3$	0.73	LI_2
AsBiPb	9.0	
AsBiPbSb	9.0	
AsHfOs	3.2	C22-hP9 (Fe_2P)
AsHfRu	4.9	same

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
$As_{0.33}InTe_{0.67}$ ($n = 1.24 \times 10^{22}$)	0.85—1.15	B1
$As_{0.5}InTe_{0.5}$ ($n = 0.97 \times 10^{22}$)	0.44—0.62	B1
As_4La_3	0.6	cI28 (Th_3P_4)
$AsNb_3$	0.3	$L1_2$-tP32
$As_{0.50}Ni_{0.06}Pd_{0.44}$	1.39	C2
$AsNi_{0.25}Pd_{0.75}$	1.6	$B8_1$-hP4 (NiAs)
AsOsZr	8.0	C22-hP9 (Fe_2P)
AsPb	8.4	
$AsPd_2$ (low-temp. phase)	0.60	Hexagonal
$AsPd_2$ (high-temp. phase)	1.70	C22
$AsPd_5$	0.46	Complex
As_3Pd_5	1.9	
AsRh	0.58	B31
$AsRh_{1.4—1.6}$	< 0.03—0.56	Hexagonal
AsSn	4.10	
AsSn ($n = 2.14 \times 10^{22}$)	3.41—3.65	B1
$As_{\sim 2}Sn_{\sim 3}$	3.5—3.6; 1.21—1.17	
As_3Sn_4 ($n = 0.56 \times 10^{22}$)	1.16—1.19	Rhombohedral
AsV_3	0.20	A15-cP8 (Cr_3Si)
Au_5Ba	0.4—0.7	$D2_d$
AuBe	2.64	B20
Au_2Bi	1.80	C15
Au_5Ca	0.34—0.38	$C15_b$
$AuGa_2$	1.6	C1-cF12 (CaF_2)
AuGa	1.2	B31
$Au_{0.40—0.92}Ge_{0.60—0.08}$	<0.32—1.63	Complex
$AuIn_2$	0.2	C1-cF12
AuIn	0.4—0.6	Complex
AuLu	<0.35	B2
$AuNb_3$	1.2	A2
$AuPb_2$	3.15	
$AuPb_2$ (film)	4.3	
$AuPb_3$	4.40	
$AuPb_3$ (film)	4.25	
Au_2Pb	1.18; 6—7	C15
$AuSb_2$	0.58	C2
AuSn	1.25	$B8_1$
Au_xSn_{1-x} (film)	2.0—3.8	
Au_5Sn	0.7—1.1	A3
$AuTa_{4.3}$	0.55	A15-cP8 (Cr_3Si)
Au_3Te_5	1.62	Cubic
$AuTh_2$	3.08	C16
AuTl	1.92	
AuV_3	0.74	A15
Au_xZn_{1-x}	0.50—0.845	
$AuZn_3$	1.21	Cubic
Au_xZr_y	1.7—2.8	A3
$AuZr_3$	0.92	A15
$B_2Ba_{0.67}Pt_3$	5.60	hP12 (B_2BaPt_3)
$BCMo_2$	5.4	Orthorhombic
$BCMo_2$	5.3—7.0	Same
$B_2Ca_{0.67}Pt_3$	1.57	hP12
B_4ErIr_4	2.1	tP18 (B_4CeCo_4)
B_4ErRh_4	4.3	oC108 (B_4LuRh_4)
B_4ErRh_4	8.7	tP18 (B_4CeCo_4)

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
BHf	3.1	Cubic
B_4HoIr_4	2.0	tP18
B_4HoRh_4	1.4	oC108
B_2Ir_3La	1.65	hP6 ($CaCu_5$)
B_2Ir_3Th	2.09	Same
B_4Ir_4Tm	1.6	tP18
B_6La	5.7	
B_2LaRh_3	2.82	hP6
$B_{12}Lu$	0.48	
B_2LuOs	2.66	oP16 (B_2LuRu)
B_2LuOs_3	4.62	hP6
B_4LuRh_4	6.2	oC108
B_2LuRu	9.86	oP16
B_4LuRu_4	2.0	tI72 (B_4LuRu_4)
BMo	0.5 (extrapol.)	
BMo_2	4.74	C16
BNb	8.25	B_f
B_4NdRh_4	5.3	tP18
B_2OsSc	1.34	oP16
B_2OsY	2.22	oP16
$B_2Pt_3Sr_{0.67}$	2.78	hP12 (B_2BaPt_3)
BRe_2	2.80; 4.6	
$B_4Rh_{3.4}Ru_{0.6}$	8.38	tI72
B_4Rh_4Sm	2.7	tP18
B_4Rh_4Th	4.3	Same
B_4Rh_4Tm	9.8	Same
B_4Rh_4Tm	5.4	oC108
$B_{0.3}Ru_{0.7}$	2.58	$D10_2$
B_4Ru_4Sc	7.2	tI72
B_2Ru_3Th	1.79	hP6
B_2Ru_3Y	2.85	Same
B_2Ru Y	7.80	oP16
B_4Ru_4Y	1.4	tI72
$B_{12}Sc$	0.39	
BTa	4.0	B_f
BTa_2	3.12	C16-tI12 (Al_2Cu)
B_6Th	0.74	
BW_2	3.1	C16
B_6Y	6.5—7.1	
$B_{12}Y$	4.7	
BZr	3.4	Cubic
$B_{12}Zr$	5.82	
$BaBi_3$	5.69	Tetragonal
$Ba_2Mo_{15}Se_{19}$	2.75	hP15 (Mo_6PbS_8)
$Ba_xO_3Sr_{1-x}Ti$ ($n = 4.2 \times 10^{19}$)	<0.1—0.55	
$Ba_{0.13}O_3W$	1.9	Tetragonal
$Ba_{0.14}O_3W$	<1.25—2.2	Hexagonal
$BaRh_2$	6.0	C15
$Be_{22}Mo$	2.51	Cubic ($Be_{22}Re$)
$Be_8Nb_5Zr_2$	5.2	
$Be_{0.98—0.92}Re_{0.02—0.08}$ (quenched)	9.5—9.75	Cubic
$Be_{0.957}Re_{0.043}$	9.62	Cubic ($Be_{22}Re$)
BeTc	5.21	Cubic
$Be_{22}W$	4.12	Cubic ($Be_{22}Re$)

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
$Be_{13}W$	4.1	Tetragonal
Bi_3Ca	2.0	
$Bi_{0.5}Cd_{0.13}Pb_{0.25}Sn_{0.12}$ (weight fractions)	8.2	
BiCo	0.42—0.49	
Bi_2Cs	4.75	C15
Bi_xCu_{1-x} (electrodeposited)	2.2	
BiCu	1.33—1.40	
Bi_3Fe	1.0	m**
$Bi_{0.019}In_{0.981}$	3.86	
$Bi_{0.05}In_{0.95}$	4.65	α-phase
$Bi_{0.10}In_{0.90}$	5.05	Same
$Bi_{0.15—0.30}In_{0.85—0.70}$	5.3—5.4	α- and β-phases
$Bi_{0.34—0.48}In_{0.66—0.52}$	4.0—4.1	
Bi_3In_5	4.1	
$BiIn_2$	5.65	β-phase
Bi_2Ir	1.7—2.3	
Bi_2Ir (quenched)	3.0—3.96	
BiK	3.6	
Bi_2K	3.58	C15
BiLi	2.47	$L1_o$, α-phase
$Bi_{4—9}Mg$	0.7—~1.0	
Bi_3Mo	3—3.7	
BiNa	2.25	$L1_o$
$BiNb_3$	4.5	A15-cP8 (Cr_3Si)
$BiNb_3$ (high pressure and temperature)	3.05	A15
BiNi	4.25	$B8_1$
Bi_3Ni	4.06	Orthorhombic
$BiNi_{0.5}Rh_{0.5}$	3.0	$B8_1$-hP4 (AsNi)
$Bi_{0.5}NiSb_{0.5}$	2.0	Same
$Bi_{1-0}Pb_{0-1}$	7.26—9.14	
$Bi_{1-0}Pb_{0-1}$ (film)	7.25—8.67	
$Bi_{0.05—0.40}Pb_{0.95—0.60}$	7.35—8.4	H.C.P. to ε-phase
Bi_2Pb	4.25	t**
BiPbSb	8.9	
$Bi_{0.5}Pb_{0.31}Sn_{0.19}$ (weight fractions)	8.5	
$Bi_{0.5}Pb_{0.25}Sn_{0.25}$	8.5	
$BiPd_2$	4.0	
$Bi_{0.4}Pd_{0.6}$	3.7—4	Hexagonal, ordered
BiPd	3.7	Orthorhombic
Bi_2Pd	1.70	Monoclinic, α-phase
Bi_2Pd	4.25	Tetragonal, β-phase
$BiPd_{0.45}Pt_{0.55}$	3.7	$B8_1$-hP4 (NiAs)
BiPdSe	1.0	C2
BiPdTe	1.2	C2
BiPt	1.21	$B8_1$
$Bi_{0.1}PtSb_{0.9}$	2.05; 1.5	$B8_1$-hP4 (NiAs)
BiPtSe	1.45	C2
BiPtTe	1.15	C2
Bi_2Pt	0.155	Hexagonal
Bi_2Rb	4.25	C15
$BiRe_2$	1.9—2.2	
BiRh	2.06	$B8_1$

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
Bi_3Rh	3.2	Orthorhombic (NiB_3)
Bi_4Rh	2.7	Hexagonal
BiRu	5.7	m**
Bi_3Sn	3.6—3.8	
BiSn	3.8	
Bi_xSn_y	3.85—4.18	
Bi_3Sr	5.62	$L1_2$
Bi_3Te	0.75—1.0	
Bi_5Tl_3	6.4	
$Bi_{0.26}Tl_{0.74}$	4.4	Cubic, disordered
$Bi_{0.26}Tl_{0.74}$	4.15	$L1_2$, ordered (?)
Bi_2Y_3	2.25	
Bi_3Zn	0.8—0.9	
$Bi_{0.3}Zr_{0.7}$	1.51	
$BiZr_3$	2.4—2.8	
$BrMo_6Se_7$	7.1	hP15 (Mo_6PbS_8)
$Br_3Mo_6Se_5$	7.1	Same
CCs_x	0.020—0.135	Hexagonal
CFe_3	1.30	DO_{11}-oP16 (Fe_3C)
$CGaMo_2$	3.7—4.1	Hexagonal
$CHf_{0.5}Mo_{0.5}$	3.4	B1
$CHf_{0.3}Mo_{0.7}$	5.5	B1
$CHf_{0.25}Mo_{0.75}$	6.6	B1
$CHf_{0.7}Nb_{0.3}$	6.1	B1
$CHf_{0.6}Nb_{0.4}$	4.5	B1
$CHf_{0.5}Nb_{0.5}$	4.8	B1
$CHf_{0.4}Nb_{0.6}$	5.6	B1
$CHf_{0.25}Nb_{0.75}$	7.0	B1
$CHf_{0.2}Nb_{0.8}$	7.8	B1
$CHf_{0.9—0.1}Ta_{0.1—0.9}$	5.0—9.0	B1
CK (excess K)	0.55	Hexagonal
C_8K	0.39	Hexagonal
C_2La	1.66	tI6 (CaC_2)
C_2Lu	3.33	Same
$C_{0.40—0.44}Mo_{0.60—0.56}$	9—13	
C_3MoRe	3.8	B1-cF8
$C_{0.6}Mo_{4.8}Si_3$	7.6	$D8_8$
$CMo_{0.2}Ta_{0.8}$	7.5	B1
$CMo_{0.5}Ta_{0.5}$	7.7	B1
$CMo_{0.75}Ta_{0.25}$	8.5	B1
$CMo_{0.8}Ta_{0.2}$	8.7	B1
$CMo_{0.85}Ta_{0.15}$	8.9	B1
CMo_xV_{1-x}	2.9—9.3	B1
CMo_xZr_{1-x}	9.8	B1
$C_{0.984}Nb$	9.8	B1
CNb_2	9.1	
CNb_xTi_{1-x}	<4.2—8.8	B1
$CNb_{0.1—0.9}Zr_{0.9—0.1}$	4.2—8.4	B1
CRb_x (Au)	0.023—0.151	Hexagonal
$CRe_{0.06}W$	5.0	
CRu	2.00	hP2 (CW)
$C_{0.98}7Ta$	9.7	
$C_{0.848—0.987}$	2.04—9.7	
CTa (film)	5.09	B1
CTa_2	3.26	L'_3

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
$CTa_{0.4}Ti_{0.6}$	4.8	B1
$Cta_{1—0.4}W_{0—0.6}$	8.5—10.5	B1
$CTa_{0.2—0.9}Zr_{0.8—0.1}$	4.6—8.3	B1
CTc (excess C)	3.85	Cubic
$CTi_{0.5—0.7}W_{0.5—0.3}$	6.7—2.1	B1
CW	1.0	
CW_2	2.74	L'_3
CW_2	5.2	F.C.C.
C_2Y	3.88	tI6 (CaC_2)
$Ca_3Co_4Sn_{13}$	5.9	cP40 ($Pr_3Rh_2Sn_{13}$)
$Ca_3Ge_{13}Rh_4$	2.1	Same
CaHg	1.6	B2-cP2 (CsCl)
$CaHg_3$	1.6	hP8 (Ni_3Sn)
$CaIr_2$	6.15	C15
$Ca_3Ir_4Sn_{13}$	7.1	cP40
$Ca_xO_3Sr_{1-x}Ti$ ($n = 3.7—11 \times 10^{19}$)	<0.1—0.55	
$Ca_{0.1}O_3W$	1.4—3.4	Hexagonal
CaPb	7.0	
$CaRh_2$	6.40	C15
$CaRh_{1.2}Sn_{4.5}$	8.7	cP40
$CaTl_3$	2.0	B2-cP2
$Cd_{0.3—0.5}Hg_{0.7—0.5}$	1.70—1.92	
CdHg	1.77; 2.15	Tetragonal
$Cd_{0.0075—0.05}In_{0.9925—0.95}$	3.24—3.36	Tetragonal
$Cd_{0.97}Pb_{0.03}$	4.2	
CdSn	3.65	
$Cd_{0.17}Tl_{0.83}$	2.3	
$Cd_{0.18}Tl_{0.82}$	2.54	
$CeCo_2$	0.84	C15
$CeCo_{1.67}Ni_{0.33}$	0.46	C15
$CeCo_{1.67}Rh_{0.33}$	0.47	C15
$Ce_xGd_{1-x}Ru_2$	3.2—5.2	C15
$CeIr_3$	3.34	
$CeIr_5$	1.82	
$Ce_{0.005}La_{0.995}$	4.6	
Ce_xLa_{1-x}	1.3—6.3	
$Ce_xPr_{1-x}Ru_2$	1.4—5.3	C15
Ce_xPt_{1-x}	0.7—1.55	
$CeRu_2$	6.0	C15
$Ce_3Mo_6Se_5$	5.7	hR15 (Mo_6PbS_8)
$Ce_2Mo_6Te_6$	1.7	Same
$Co_xFe_{1-x}Si_2$	1.4 (max.)	C1
$CoHf_2$	0.56	$E9_3$
$CoLa_3$	4.28	
$Co_4La_3Sn_{13}$	2.8	cP40
$CoLu_3$	~0.35	
Co_xLuSn_y	1.5	cP40
$Co_{0—0.01}Mo_{0.8}Re_{0.2}$	2—10	
$Co_{0.02—0.10}Nb_3Rh_{0.98—0.90}$	2.28—1.90	A15
$Co_xNi_{1-x}Si_2$	1.4 (max.)	C1
$Co_{0.5}Rh_{0.5}Si_2$	2.5	
$Co_xRh_{1-x}Si_2$	3.65 (max.)	
$Co_{\sim0.3}So_{\sim0.7}$	~0.35	
$Co_4Sc_5Si_{10}$	5.0	tP38 ($Co_4Sc_5Si_{10}$)
$CoSi_2$	1.40; 1.22	C1

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
Co_xSn_yYb	2.5	cP40
Co_3Th_7	1.83	$D10_2$
Co_xTi_{1-x}	2.8 (max.)	Co in α-Ti
Co_xTi_{1-x}	3.8 (max.)	Co in β-Ti
$CoTi_2$	3.44	$E9_3$
CoTi	0.71	A2
CoU	1.7	B2, distorted
CoU_6	2.29	$D2_c$
$Co_{0.28}Y_{0.72}$	0.34	
CoY_3	<0.34	
$CoZr_2$	6.3	C16
$Co_{0.1}Zr_{0.9}$	3.9	A3
$Cr_{0.6}Ir_{0.4}$	0.4	H.C.P.
$Cr_{0.65}Ir_{0.35}$	0.59	H.C.P.
$Cr_{0.7}Ir_{0.3}$	0.76	H.C.P.
$Cr_{0.72}Ir_{0.28}$	0.83	
Cr_3Ir	0.45	A15
$Cr_{0—0.1}Nb_{1—0.9}$	4.6—9.2	A2
$Cr_{0.80}Os_{0.20}$	2.5	Cubic
Cr_3Os	4.68	A15-cP8 (Cr_3Si)
Cr_xRe_{1-x}	1.2—5.2	
$Cr_{0.4}Re_{0.6}$	2.15	$D8_b$
$Cr_{0.8—0.6}Rh_{0.2—0.4}$	0.5—1.10	A3
Cr_3Rh	0.3	A15-cP8
Cr_3Ru (annealed)	3.3	A15
Cr_2Ru	2.02	$D8_b$
Cr_3Ru_2	2.10	$D8_b$-tP30 (CrFe)
$Cr_{0.1—0.5}Ru_{0.9—0.5}$	0.34—1.65	A3
Cr_xTi_{1-x}	3.6 (max.)	Cr in α-Ti
Cr_xTi_{1-x}	4.2 (max.)	Cr in β-Ti
$Cr_{0.1}Ti_{0.3}V_{0.6}$	5.6	
$Cr_{0.0175}U_{0.9825}$	0.75	β-phase
$Cs_{0.32}O_3W$	1.12	Hexagonal
$Cu_{0.15}In_{0.85}$ (film)	3.75	
$Cu_{0.04—0.08}In_{0.94—0.92}$	4.4	
CuLa	5.85	
$Cu_2Mo_6O_2S_6$	9	hR15 (Mo_6PbS_8)
$Cu_2Mo_6Se_8$	5.9	Same
Cu_xPb_{1-x}	5.7—7.7	
CuS	1.62	B18
CuS_2	1.48—1.53	C18
CuSSe	1.5—2.0	C18
$CuSe_2$	2.3—2.43	C18
CuSeTe	1.6—2.0	C18
Cu_xSn_{1-x}	3.2—3.7	
Cu_xSn_{1-x} (film, made at 10K)	3.6—7	
Cu_xSn_{1-x} (film, made at 300K)	2.8—3.7	
$CuTe_2$	<1.25—1.3	C18
$CuTh_2$	3.49	C16
$Cu_{0—0.027}V$	3.9—5.3	A2
CuY	0.33	B2-cP2 (CsCl)
Cu_xZn_{1-x}	0.5—0.845	
$DyMo_6S_8$	2.1	hR15
Er_xLa_{1-x}	1.4—6.3	
$ErMo_6S_8$	2.2	hR15

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
$ErMo_6Se_8$	6.2	hR15
$Fe_3Lu_2Si_5$	6.1	tP40 ($Fe_3Sc_2Si_5$)
$Fe_{0—0.04}Mo_{0.8}Re_{0.2}$	1—10	
$Fe_{0.05}Ni_{0.05}Zr_{0.90}$	~3.9	
Fe_3Re_2	6.55	$D8_b$-tP30 (FeCr)
$Fe_3Sc_2Si_5$	4.52	tP40
Fe_3Si_5Tm	1.3	Same
$Fe_3Si_5Y_2$	2.4	Same
Fe_3Th_7	1.86	D10
Fe_xTi_{1-x}	3.2 (max.)	Fe in α-Ti
Fe_xTi_{1-x}	3.7 (max.)	Fe in β-Ti
$Fe_xTi_{0.6}V_{1-x}$	6.8 (max.)	
FeU_6	3.86	$D2_c$
$Fe_{0.1}Zr_{0.9}$	1.0	A3
$Ga_{0.5}Ge_{0.5}Nb_3$	7.3	A15
Ga_2Ge_2U	0.87	B2-cP2
$GaHf_2$	0.21	C16-tI12 (Al_2Cu)
$GaLa_3$	5.84	
Ga_3Lu	2.3	B2-cP2
Ga_2Mo	9.5	
$GaMo_3$	0.76	A15
GaN (black)	5.85	B4
$Ga_{0.7}Pt_{0.3}$	2.9	C1
GaPt	1.74	B20
GaSb (120kbar, 77K, annealed)	4.24	A5
GaSb (unannealed)	~5.9	
$Ga_{0—1}Sn_{1—0}$ (quenched)	3.47—4.18	
$Ga_{0—1}Sn_{1—0}$ (annealed)	2.6—3.85	
GaTe	0.17	mC24 (GaTe)
Ga_5V_2	3.55	Tetragonal (Mn_2Hg_5)
$GaV_{4.5}$	9.15	
Ga_3Zr	1.38	
Ga_3Zr_5	3.8	$D8_b$-hP16 (Mn_5Si_3)
Gd_xLa_{1-x}	< 1.0—5.5	
$GdMo_6S_8$	3.5	hR15
$GdMo_6Se_8$	5.6	hR15
$Gd_xOs_2Y_{1-x}$	1.4—4.7	
$Gd_xRu_2Th_{1-x}$	3.6 (max.)	C15
$Ge_{10}As_4Y_5$	9.06	tP38 ($C0_4Sc_5Si_{10}$)
GeIr	4.7	B31
GeIrLa	1.64	tI12 (LaPtSi)
$Ge_{10}Ir_4Lu_5$	2.60	tP38
$Ge_{10}Ir_4Y_5$	2.62	tP38
Ge_2La	1.49; 2.2	Orthorhombic, distorted (Mn_2Hg_5)
GeLaPt	3.53	tI12
$Ge_{13}Lu_3Os_4$	3.6	cP40 ($Pr_3Rh_2Sn_{13}$)
$Ge_{10}Lu_5Rh_4$	2.79	tP38
$Ge_{13}Lu_3Ru_4$	2.3	cP40
$GeMo_3$	1.43	A15
$GeNb_2$	1.9	
$Ge_{0.29}Nb_{0.71}$	6	A15
GePt	0.40	B31
Ge_3Rh_5	2.12	Orthorhombic, related to $InNi_2$

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
GeRh	0.96	B31-oP8 (MnP)
$Ge_{13}Rh_4Sc_3$	1.9	c P40
$Ge_{10}Rh_4Y_5$	1.35	tP38
$Ge_{13}Ru_4Y_3$	1.7	cP40
Ge_2So	1.3	
$GeTa_3$	8.0	A15-cP8 (Cr_3Si)
Ge_3Te_4 ($n = 1.06 \times 10^{22}$)	1.55—1.80	Rhombohedral
Ge_xTe_{1-x} ($n = 8.5—64 \times 10^{20}$)	0.07—0.41	R1
GeV_3	6.01	A15
Ge_2Y	3.80	C_c
$Ge_{1.62}Y$	2.4	
Ge_2Zr	0.30	oC12 ($ZrSi_2$)
$GeZr_3$	0.4	$L1_2$-tP32 (Ti_3P)
$H_{0.33}Nb_{0.67}$	7.28	B.C.C.
$H_{0.1}Nb_{0.9}$	7.38	Same
$H_{0.05}Nb_{0.95}$	7.83	Same
$H_{0.12}Ta_{0.88}$	2.81	B.C.C.
$H_{0.08}Ta_{0.92}$	3.26	Same
$H_{0.04}Ta_{0.96}$	3.62	Same
HfIrSi	3.50	C37-cP12 (Co_2Si)
$HfMo_2$	0.05	hP24 (Ni_2Mn)
$HfN_{0.989}$	6.6	B1
$Hf_{0—0.5}Nb_{1—0.5}$	8.3—9.5	A2
$Hf_{0.75}Nb_{0.25}$	>4.2	
$HfOs_2$	2.69	C14
HfOsP	6.1	C22-hP9 (Fe_2P)
HfPRu	9.9	Same
$HfRe_2$	4.80	C14
$Hf_{0.14}Re_{0.86}$	5.86	A12
$Hf_{0.99—0.96}Rh_{0.01—0.04}$	0.85—1.51	
$Hf_{0—0.55}Ta_{1—0.45}$	4.4—6.5	A2
HfV_2	8.9—9.6	C15
Hg_xIn_{1-x}	3.14—4.55	
HgIn	3.81	
Hg_2K	1.20	Orthorhombic
Hg_3K	3.18	
Hg_4K	3.27	
Hg_8K	3.42	
Hg_3Li	1.7	Hexagonal
$HgMg_3$	0.17	hP8 (Na_3As)
Hg_2Mg	4.0	tI6 ($MoSi_2$)
Hg_3Mg_5	0.48	$D8_b$-hP16 (Mn_5Si_3)
Hg_2Na	1.62	Hexagonal
Hg_4Na	3.05	
Hg_xPb_{1-x}	4.14—7.26	
HgSn	4.2	
Hg_xTl_{1-x}	2.30—4.19	
Hg_5Tl_2	3.86	
Ho_xLa_{1-x}	1.3—6.3	
$Ho_{1.2}Mo_6Se_8$	6.1	$D10_2$-hR12 (Be_3Nb)
$In_{1—0.86}Mg_{0—0.14}$	3.395—3.363	
$In_2Mo_6Te_6$	2.6	hR15 (Mo_6PbS_8)
$InNb_3$ (high pressure and temp.)	4—8; 9.2	A15
$In_{0.5}Nb_3Zr_{0.5}$	6.4	
$In_{0.11}O_3W$	< 1.25—2.8	Hexagonal

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
$In_{0.95—0.85}Pb_{0.05—0.15}$	3.6—5.05	
$In_{0.98—0.91}Pb_{0.02—0.09}$	3.45—4.2	
InPb	6.65	
InPd	0.7	B2
InSb (quenched from 170 kbar into liquid N_2)	4.8	Like A5
InSb	2.1	B4
$(InSb)_{0.95—0.10}Sn_{0.05—0.90}$ (various heat treatments)	3.8—5.1	
$(InSb)_{0—0.07}Sn_{1—0.93}$	3.67—3.74	
In_3Sn	~5.5	
In_xSn_{1-x}	3.4—7.3	
$In_{0.82—1}Te$ ($n = 0.83—1.71 \times 10^{22}$)	1.02—3.45	B1
$In_{1.000}Te_{1.002}$	3.5—3.7	B1
In_3Te_4 ($n = 4.7 \times 10^{21}$)	1.15—1.25	Rhombohedral
In_xTl_{1-x}	2.7—3.374	
$In_{0.8}Tl_{0.2}$	3.223	
$In_{0.62}Tl_{0.38}$	2.760	
$In_{0.78—0.69}Tl_{0.22—0.31}$	3.18—3.32	Tetragonal
$In_{0.69—0.62}Tl_{0.31—0.38}$	2.98—3.3	F.C.C.
Ir_2La	0.48	C15
Ir_3La	2.32	$D10_2$
Ir_3La_7	2.24	$D10_2$
Ir_5La	2.13	
$IrLaSi_2$	2.03	oC16 ($CeNiSi_2$)
$IrLaSi_3$	2.7	tI10 ($BaNiSn_3$)
Ir_2Lu	2.47	C15
Ir_3Lu	2.89	C15
$Ir_4Lu_5Si_{10}$	3.9	tP38 ($Co_4Sc_5Si_{10}$)
IrMo	< 1.0	A3
$IrMo_3$	9.6	A15
$IrMo_3$	6.8	$D8_b$
$IrNb_3$	1.9	A15
$Ir_{0.4}Nb_{0.6}$	9.8	$D8_b$
$Ir_{0.37}Nb_{0.63}$	2.32	$D8_b$
IrNb	7.9	$D8_b$
$Ir_{1.15}Nb_{0.85}$	4.6	oP12 (IrTa)
$Ir_{0.02}Nb_3Rh_{0.98}$	2.43	A15
$Ir_{0.05}Nb_3Rh_{0.95}$	2.38	A15
$Ir_{0.287}O_{0.14}Ti_{0.573}$	5.5	$E9_3$
$Ir_{0.265}O_{0.035}Ti_{0.65}$	2.30	$E9_3$
Ir_xOs_{1-x}	0.3—0.98	
$Ir_{1.5}Os_{0.5}$	2.4	C14
IrOsY	2.6	C15
IrSiY	2.70	C37-oP12 (Co_2Si)
IrSiZr	2.04	Same
Ir_2Sc	2.07	C15
$Ir_{2.5}Sc$	2.46	C15
$Ir_4Sc_5Si_{10}$	8.46	tP38
Ir_2Si_2Th	2.14	tI10
$IrSi_3Th$	1.75	tI10
IrSiTh	6.50	tI12 (LaPtSi)
Ir_2Si_2Y	2.60	tI10 (Al4Ba)
$Ir_4Si_{10}Y_5$	3.10	tP38
$Ir_3Si_5Y_2$	2.83	oI40

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
$IrSn_2$	0.65—0.78	C1
Ir_2Sr	5.70	C15
Ir_7Ta_{13}	1.2	$D8_b$-tP30 (FeCr)
$Ir_{0.5}Te_{0.5}$	~3	
$IrTe_3$	1.18	C2
IrTh	< 0.37	B_f
Ir_2Th	6.50	C15
Ir_3Th	4.71	
Ir_3Th_7	1.52	$D10_2$
Ir_5Th	3.93	$D2_d$
$IrTi_3$	5.40	A15
IrV_2	1.39	A15
IrW_3	3.82	
$Ir_{0.28}W_{0.72}$	4.49	
Ir_2Y	2.18; 1.38	C15
$Ir_{0.69}Y_{0.31}$	1.98; 1.44	C15
$Ir_{0.70}Y_{0.30}$	2.16	C15
Ir_2Y_3	1.61	
Ir_3Y	3.50	$D10_2$-hR13 (Be_3Nb)
Ir_xY_{1-x}	0.3—3.7	
Ir_2Zr	4.10	C15
$Ir_{0.1}Zr_{0.9}$	5.5	A3
$K_2Mo_{15}S_{19}$	3.32	hR15
$K_{0.27—0.31}O_3W$	0.50	Hexagonal
$K_{0.40—0.57}O_3W$	1.5	Tetragonal
$La_{0.55}Lu_{0.45}$	2.2	Hexagonal, La type
$La_{0.8}Lu_{0.2}$	3.4	Same
$LaMg_2$	1.05	C15
$LaMo_6S_8$	7.1	hR15
LaN	1.35	
$LaOs_2$	6.5	C15
$LaPt_2$	0.46	C15
$La_{0.28}Pt_{0.72}$	0.54	C15
LaPtSi	3.48	tI12
$LaRh_3$	2.60	
$LaRh_5$	1.62	
La_7Rh_3	2.58	$D10_2$
$LaRhSi_2$	3.42	oC16 ($CeNiSi_2$)
$La_2Rh_3Si_5$	4.45	oI40 ($Co_3Si_5U_2$)
$LaRhSi_3$	2.7	tl10 ($BaNiSn_3$)
$LaRh_2Si_2$	3.90	tl10 (Al_4Ba)
$LaRu_2$	1.63	C15
La_3S_4	6.5	$D7_3$
La_3Se_4	8.6	$D7_3$
$LaSi_2$	2.3	C_c
La_xY_{1-x}	1.7—5.4	
LaZn	1.04	B2
$Li_2Mo_6S_8$	4.2	hR15
LiPb	7.2	
$LuOs_2$	3.49	C14
$Lu_{0.275}Rh_{0.725}$	1.27	C15
$LuRh_5$	0.49	
$Lu_5Rh_4Si_{10}$	3.95	tP38 ($Co_4So_5Si_{10}$)
$LuRu_2$	0.86	C14
$Mg_{1.14}Mo_{6.6}S_8$	3.5	hR15

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
Mg2Nb	5.6	
$Mg_{\sim0.47}Tl_{\sim0.53}$	2.75	B2
MgZn	0.9	A3-oP4 (AuCd)
Mn_xTi_{1-x}	2.3 (max.)	Mn in -Ti
Mn_xTi_{1-x}	1.1—3.0	Mn in -Ti
MnU_6	2.32	$D2_c$
Mo_2N	5.0	F.C.C.
$Mo_6Na_2S_8$	8.6	hR15
Mo_xNb_{1-x}	0.016—9.2	
$Mo_{5.25}Nb_{0.75}Se_8$	6.2	hR15
Mo_6NdSa_8	8.2	hR15
Mo_3Os	7.2	A15
$Mo_{0.62}Cs_{0.38}$	5.65	$D8_b$
Mo_3P	5.31	DO_e
$Mo_6Pb_{1.2}Se_8$	6.75	hR15
$Mo_{0.5}Pd_{0.5}$	3.52	A3
Mo_6PrSe_8	9.2	hR15
MoRe	7.8	$D8_b$-tP30
$MoRe_3$	9.25; 9.89	A12
Mo_xRe_{1-x}	1.2—12.2	
$Mo_{0.42}Re_{0.58}$	6.35	$D8_b$
MoRh	1.97	A3
Mo_xRh_{1-x}	1.5—8.2	B.C.C.
MoRu	9.5—10.5	A3
$Mo_{0.61}Ru_{0.39}$	7.18	$D8_b$
$Mo_{0.2}Ru_{0.8}$	1.66	A3
Mo_3Ru_2	7.0	$D8_b$-tP30
$Mo_4Ru_2Te_8$	1.7	hR15
Mo_6S_8	1.85	hR15
Mo_6S_8Sc	3.6	hR15
$Mo_6S_8Sm_{1.2}$	2.9	hR15
Mo_6S_8Tb	2.0	hR15
Mo_6S_8Tl	8.7	hR15
$Mo_6S_8Tm_{1.2}$	2.1	hR15
$Mo_6S_8Y_{1.2}$	3.0	hR15
Mo_6S_8Yb	9.2	hR15
$Mo_{6.6}S_8Zn_{11}$	3.6	hR15
Mo_3Sb_4	2.1	
Mo_6Se_8	6.3	hR15
$Mo_6Se_8Sm_{1.2}$	6.8	hR15
$Mo_6Se_8Sn_{1.2}$	6.8	hR15
Mo_6Se_8Tb	5.7	hR15
Mo_3Se_3Tl	4.0	hP14
$Mo_6Se_8Tm_{1.2}$	6.3	hR15
Mo_6Se_8Yb	6.2	hR15
Mo_3Si	1.30	A15
$MoSi_{0.7}$	1.34	
Mo_xSiV_{3-x}	4.54—16.0	A15
$Mo_{5.25}Ta_{0.75}Te_8$	1.7	hR15
Mo_6Te_8	1.7	hR15
$Mo_{0.16}Ti_{0.84}$	4.18; 4.25	
$Mo_{0.913}Ti_{0.087}$	2.95	
$Mo_{0.04}Ti_{0.96}$	2.0	Cubic
$Mo_{0.025}Ti_{0.975}$	1.8	
Mo_xU_{1-x}	0.7—2.1	

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
Mo_xV_{1-x}	0—~5.3	
Mo_2Zr	4.25—4.75	C15
NNb (film)	6—9	B1
$N_xO_yTi_z$	2.9—5.6	Cubic
$N_xO_yV_z$	5.8—8.2	Cubic
$N_{0.34}Re$	4—5	F.C.C.
NTa (film)	4.84	B1
$N_{0.6—0.987}Ti$	<1.17—5.8	B1
$N_{0.82—0.99}V$	2.9—7.9	B1
NZr	9.8	B1
$N_{0.906—0.984}Zr$	3.0—9.5	B1
$Na_{0.28—0.35}O_3W$	0.56	Tetragonal
$Na_{0.28}Pb_{0.72}$	7.2	
NbO	1.25	
$NbOs_2$	2.52	A12
Nb_3Os	1.05	A15
$Nb_{0.6}Os_{0.4}$	1.89; 1.78	$D8_b$
$Nb_3Os_{0.02—0.10}Rh_{0.98—0.90}$	2.42—2.30	A15
Nb_3P	1.8	$L1_2$tP32 (Ti_3P)
NbPRh	4.08	C37-oP12 (Co_2Si)
$Nb_{0.6}Pd_{0.4}$	1.60	$D8_f$ plus cubic
$Nb_3Pd_{0.02—0.10}Rh_{0.92—0.90}$	2.49—2.55	A15
$Nb_{0.62}Pt_{0.38}$	4.21	$D8_b$
Nb_5Pt_3	3.73	$D8_b$
$Nb_3Pt_{0.02—0.98}Rh_{0.98—0.02}$	2.52—9.6	A15
$NbRe_3$	5.27	$D8_b$-tP30 (FeCr)
$Nb_{0.38—0.18}Re_{0.62—0.82}$	2.43—9.70	A15
NbRe	3.8	$D8_b$-tP30
NbReSi	5.1	oI36 (FeTiSi)
Nb_3Rh	2.64	A15
$Nb_{0.6}Rh_{0.40}$	4.21	$D8_b$ plus other
$Nb_{0.9}Rh_{1.1}$	3.07	A3-oP4 (AuCd)
$Nb_3Rh_{0.98—0.90}Ru_{0.02—0.10}$	2.42—2.44	A15
Nb_xRu_{1-x}	1.2—4.8	
NbRuSi	2.65	oI36
NbS_2	6.1—6.3	Hexagonal, $NbSe_2$ type
NbS_2	5.0—5.5	Hexagonal, three-layer type
Nb_3Sb	0.2	$L1_2$-tP32 (Ti_3P)
$Nb_3Sb_{0—0.7}Sn_{1—0.3}$	6.8—18	A15
$NbSe_2$	5.15—5.62	Hexagonal
$Nb_{1—1.05}Se_2$	2.2—7.0	Same
Nb_3Se_4	2.0	hP14
Nb_3Si	1.5	$L1_2$
Nb_3SiSnV_3	4.0	
$NbSn_2$	2.60	Orthorhombic
Nb_6Sn_5	2.8	oI44 (Sn_5Ti_6)
NbSnTaV	6.2	A15
$NbSnV_2$	5.5	A15
Nb_2SnV	9.8	A15
Nb_xTa_{1-x}	4.4—9.2	A2
Nb_3Te_4	1.8	hP14
Nb_xTi_{1-x}	0.6—9.8	
$Nb_{0.6}Ti_{0.4}$	9.8	
Nb_xU_{1-x}	1.95 (max.)	
$Nb_{0.88}V_{0.12}$	5.7	A2

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
$Nb_{0.5}V_{1.5}Zr$	4.3	C15-hP12 ($MgZn_2$)
$Ni_{0.3}Th_{0.7}$	1.98	$D10_2$
$NiZr_2$	1.52	
$Ni_{0.1}Zr_{0.9}$	1.5	A3
$O_3Rb_{0.27—0.29}W$	1.98	Hexagonal
OSn	3.81	tP4 (PbO)
O_3SrTi (n = 1.7—12.0 $\times 10^{19}$)	0.12—0.37	
O_3SrTi (n = 10^{18}—10^{21})	0.05—0.47	
O_3SrTi (n = 10^{20})	0.47	
$O_3Sr_{0.08}W$	2—4	Hexagonal
OTi	0.58	
$O_3Tl_{0.30}W$	2.0—2.14	Hexagonal
OV_3Zr_3	7.5	$E9_3$
OW_3 (film)	3.35; 1.1	A15
OsPti	1.2	C22-hP9 (Fe_2P)
OsPZr	7.4	Same
OsReY	2.0	C14
Os_2Sc	4.6	C14
OsTa	1.95	A12
Os_3Th_7	1.51	$D10_2$
Os_xW_{1-x}	0.9—4.1	
OsW_3	~3	
Os_2Y	4.7	C14
Os_2Zr	3.0	C14
Os_xZr_{1-x}	1.5—5.6	
PPb	7.8	
OsW_2	3.81	$D8_b$-tP30 (FeCr)
$PPd_{3.0—3.2}$	<0.35—0.7	DO_{11}
P_3Pd_7 (high temperature)	1.0	Rhombohedral
P_3Pd_7 (low temperature)	0.70	Complex
PRh	1.22	
PRh_2	1.3	C1
P_4Rh_5	1.22	oP28 ($CaFe_2O_4$)
PRhTa	4.41	C37-oP12 (Co_2Si)
PRhZr	1.55	Same
PRuTi	1.3	C22-hP9 (Fe_2P)
PRuZr	3.46	C37-oP12
PW_3	2.26	DO_e
Pb_2Pd	2.95	C16
Pb_4Pt	2.80	Related to C16
Pb_2Rh	2.66	C16
PbSb	6.6	
PbTe (plus 0.1 w/o Pb)	5.19	
PbTe (plus 0.1 w/o Te)	5.24—5.27	
$PbTl_{0.27}$	6.43	
$PbTl_{0.17}$	6.73	
$PbTl_{0.12}$	6.88	
$PbTl_{0.075}$	6.98	
$PbTl_{0.04}$	7.06	
$Pb_{1—0.26}Tl_{0—0.74}$	7.20—3.68	
$PbTl_2$	3.75—4.1	
Pb_3Zr_5	4.60	$D8_8$
$PbZr_3$	0.76	A15
$Pd_{0.9}Pt_{0.1}Te_2$	1.65	C6
$Pd_{0.05}Ru_{0.05}Zr_{0.9}$	~9	

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structure type
$Pd_{2.2}S$ (quenched)	1.63	Cubic
$PdSb_2$	1.25	C2
PdSb	1.5	$B8_1$
PdSbSe	1.0	C2
PdSbTe	1.2	C2
Pd_4Se	0.42	Tetragonal
$Pd_{6–7}Se$	0.66	Like Pd_4Te
$Pd_{2.8}Se$	2.3	
Pd_xSe_{1-x}	2.5 (max.)	
PdSi	0.93	B31
PdSn	0.41	B31
$PdSn_2$	3.34	
Pd_2Sn	0.41	C37
Pd_3Sn	0.47—0.64	$B8_2$
Pd_2SnTm	1.77	DO_3-cF16 (BiF_3)
Pd_2SnY	4.92	Same
Pd_2SnYb	1.79	Same
PdTe	2.3; 3.85	$B8_1$
$PdTe_{1.02—1.08}$	2.56—1.88	$B8_1$
$PdTe_2$	1.69	C6
$PdTe_{2.1}$	1.89	C6
$PdTe_{2.3}$	1.85	C6
$Pd_{1.1}Te$	4.07	$B8_1$
Pd_3Te	0.76	cI2 (W)
$PdTh_2$	0.85	C16
$Pd_{0.1}Zr_{0.9}$	7.5	A3
PtSb	2.1	$B8_1$
PtSi	0.88	B31
PtSn	0.37	$B8_1$
$PtSn_4$	2.38	C16-oC20 ($PdSn_4$)
Pt_3Ta_7	1.5	$D8_b$-tP30
$PtTa_3$	0.4	A15-cP8 (Cr_3Si)
PtTe	0.59	Orthorhombic
PtTh	0.44	B_f
Pt_3Th_7	0.98	$D10_2$
Pt_5Th	3.13	
$PtTi_3$	0.58	A15
$Pt_{0.02}U_{0.98}$	0.87	β-phase
$PtV_{2.5}$	1.36	A15
PtV_3	2.87—3.20	A15
$PtV_{3.5}$	1.26	A15
$Pt_{0.5}W_{0.5}$	1.45	A1
Pt_xW_{1-x}	0.4—2.7	
Pt_2Y_3	0.90	
Pt_2Y	1.57; 1.70	C15
Pt_3Y_7	0.82	$D10_2$
PtZr	3.0	A3
Re_2Sc	4.2	C15-hP12 ($MgZn_2$)
$Re_{24}Sc_5$	2.2	A12-cI58 (Mg)
ReSiTa	4.4	oI36 (FeTiSi)
$Re_3Si_5Y_2$	1.76	tP40 ($Fe_3Sc_2Si_5$)
Re_3Ta_2	1.4	$D8_b$-tP30 (FeCr)
$Re_{0.64}Ta_{0.36}$	1.46	A12
Re_3Ta	6.78	A12-cI58 (Mn)
$Re_{24}Ti_5$	6.60	A12

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structue type
Re_xTi_{1-x}	6.6 (max.)	
$Re_{0.76}V_{0.24}$	4.52	$D8_b$
Re_3V	6.26	$D8_b$-tP30
$Re_{0.92}V_{0.08}$	6.8	A3
$Re_{0.6}W_{0.4}$	6.0	
$Re_{0.5}W_{0.5}$	5.12	$D8_b$
$Re_{13}W_{12}$	5.2	$D8_b$-tP30
Re_3W	9.0	A12-cI58
Re_2Y	1.83	C14
Re_2Zr	5.9	C14
Re_3Zr	7.40	A12-cI58
Re_6Zr	7.40	Same
$Rh_{17}S_{15}$	5.8	Cubic
$Rh_{\sim 0.24}Sc_{\sim 0.76}$	0.88; 0.92	
$Rh_4Sc_5Si_{10}$	8.54	tP38
$Rh_4Sc_3Sn_{13}$	4.5	cP40
Rh_xSe_{1-x}	6.0 (max.)	
$RhSi_3Th$	1.76	tI10
$Rh_{0.86}Sc_{1.04}Th$	6.45	tI12
Rh_2Si_2Y	3.11	tI10
$Rh_3Si_5Y_2$	2.70	oI40
$Rh_4Sn_{13}Sr_3$	4.3	cP40
Rh_xSn_yTh	1.9	cI2 (W)
Rh_xSn_yTm	2.3	cP40
$Rh_4Sn_{13}Y_3$	3.2	cP40
Rh_2Sr	6.2	C15
$Rh_{0.4}Ta_{0.6}$	2.35	$D8_b$
$RhTe_2$	1.51	C2
$Rh_{0.67}Te_{0.33}$	0.49	
Rh_xTe_{1-x}	1.51 (max.)	
RhTh	0.36	B_f
Rh_3Th_7	2.15	$D10_2$
Rh_5Th	1.07	
Rh_xTi_{1-x}	2.25—3.95	
$Rh_{0.02}U_{0.98}$	0.96	
RhV_3	0.38	A15
RhW	~3.4	A3
RhY_3	0.65	
Rh_2Y_3	1.48	
Rh_3Y	1.07	C15
Rh_5Y	0.56	
Rh_3Y_7	0.32	hP20 (Fe_3Th_7)
$Rh_{0.005}Zr$ (annealed)	5.8	
$Rh_{0—0.45}Zr_{1—0.55}$	2.1—10.8	
$Rh_{0.1}Zr_{0.9}$	9.0	H.C.P.
Ru_2Sc	1.67	C14
RuSiTa	3.15	oI36
Ru_3Si_2Th	3.98	hP12
Ru_3Si_2Y	3.51	hP12
$Ru_{1.1}Sn_{3.1}Y$	1.3	cP40
Ru_2Th	3.56	C15
RuTi	1.07	B2
$Ru_{0.05}Ti_{0.95}$	2.5	
$Ru_{0.1}Ti_{0.9}$	3.5	
$Ru_xTi_{0.6}V_y$	6.6 (max.)	

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c, K	Crystal structue type
Ru_3U	0.15	$L1_2$-cP4
$Ru_{0.45}V_{0.55}$	4.0	B2
RuW	7.5	A3
Ru_2Y	1.52	C14
Ru_2Zr	1.84	C14
$Ru_{0.1}Zr_{0.9}$	5.7	A3
STh	0.5	B1-cF8 (NaCl)
SbSn	1.30—1.42	B1 or distorted
$SbTa_3$	0.72	A15-cP8 (Cr_3Si)
$SbTi_3$	5.8	Same
Sb_2Ti_7	5.2	
$Sb_{0.01—0.03}V_{0.99—0.97}$	3.76—2.63	A2
SbV_3	0.80	A15
SeTh	1.7	B1-cF8
$SiMo_3$	1.4	A15-cP8
Si_2Th	3.2	C_c, α-phase
Si_2Th	2.4	C32, β-phase
$SiV_{2.7}Ru_{0.3}$	2.9	A15
Si_2W_3	2.8; 2.84	
$SiZr_3$	0.5	$L1_2$-tP32 (Ti_3P)
$Sn_{0.174—0.104}Ta_{0.826—0.896}$	6.5—< 4.2	A15
$SnTa_3$	8.35	A15, highly ordered
$SnTa_3$	6.2	A15, partially ordered
$SnTaV_2$	2.8	A15
$SnTa_2V$	3.7	A15
Sn_xTe_{1-x} ($n = 10.5—20 \times 10^{20}$)	0.07—0.22	B1
Sn_3Th	3.33	$L1_2$-cP4
$SnTi_3$	5.80	A15-cP8
Sn_xTl_{1-x}	2.37—5.2	
SnV_3	3.8	A15
$Sn_{0.02—0.057}V_{0.98—0.943}$	2.87—~1.6	A2
$SnZr_3$	0.92	A15-cP8
$Ta_{0.025}Ti_{0.975}$	1.3	Hexagonal
$Ta_{0.05}Ti_{0.95}$	2.9	Hexagonal
$Ta_{0.05—0.75}V_{0.95—0.25}$	4.30—2.65	A2
$Ta_{0.8—1}W_{0.2—0}$	1.2—4.4	A2
$Tc_{0.1—0.4}W_{0.9—0.6}$	1.25—7.18	Cubic
$Tc_{0.50}W_{0.50}$	7.52	α plus
$Tc_{0.60}W_{0.40}$	7.88	plus α
Tc_6Zr	9.7	A12
TeY	1.02	B1-cF8
$ThTl_3$	0.87	$L1_2$-cP4
$Th_{0—0.55}Y_{1—0.45}$	1.2—1.8	
$Ti_{0.70}V_{0.30}$	6.14	Cubic
Ti_xV_{1-x}	0.2—7.5	
$Ti_{0.5}Zr_{0.5}$ (annealed)	1.23	
$Ti_{0.5}Zr_{0.5}$ (quenched)	2.0	
Tl_3Y	1.52	$L1_2$-cP4
V_2Zr	8.80	C15
$V_{0.26}Zr_{0.74}$	5.9	
W_2Zr	2.16	C15
YZn	0.33	B2-cP2 (CsCl)

* n denotes current carriers concentration in cm^{-3}.

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TABLE 4
Superconductive Compounds and Alloys (continued)

B. SUPERCONDUCTORS WITH $T_c > 10K$

Substance	T_c,K	Crystal structure type	
Al_2CMo_3	10.0	A13	
$Al_{0.5}Ge_{0.5}Nb$	12.6	A15	
$Al_{\sim0.8}Ge_{\sim0.2}Nb_3$	20.7	A15	
$AlNb_3$	18.0	A15	(Cr_3Si)
$AlNb_3$	12.0		(FeCr)
$A1_xNb_{1-x}$	<4.2—13.5	$D8_b$	
$A1_xNb_{1-x}$	12—17.5	A15	
$A1_{0.27}Nb_{0.73—0.48}V_{0—0.25}$	14.5—17.5	A15	
$A1\ Nb_xV_{1-x}$	4.4—13.5		
$A1_{0.1}Si_{0.9}V_3$	14.05		
$A1V_3$	11.8	A15	(Cr_3Si)
$AuNb_3$	11.5	A15	
$Au_{0—0.3}Nb_{1—0.7}$	1.1—11.0		
$Au_{0.02—0.98}Nb_3Rh_{0.98—0.02}$	2.53—10.9	A15	
$AuNb_{3(1-x)}V_{3x}$	1.5—11.0	A15	
$B_{0.03}C_{0.51}Mo_{0.47}$	12.5		
B_4LuRh_4	11.7		(B_4CeCo_4)
B_2LuRu	10		
B_4Rh_4Y	11.3		(B_4CeCo_4)
$B_{0.1}Si_{0.9}V_3$	15.8	A15	
$BaBi_{0.2}O_3Pb_{0.8}$	13.2		
$Ba_2CaCu_2O_8T1_2$	120		
$Ba_2Cu_3LaO_6$	80		
$Ba_2Cu_3O_7Tm$	101		
$Ba_2Cu_3O_7Y$	90		
$(Ba,La)_2CuO_4$	36	A15	(K_2NiF_4)
$Bi_2CaCu_2O_8Sr_2$	110		
$Br_2Mo_6S_6$	13.8		(Mo_6PbS_8)
C_3La	11.0		(C_3Pu_2)
CMo	14.3	B1	(NaC1)
CMo_2	12.2		o**
$C_{0.5}Mo_xNb_{1-x}$	10.8—12.5	B1	
CMo_xTi_{1-x}	10.2(max)	B1	
$CMo_{0.83}Ti_{0.17}$	10.2	B1	
$C_{0—0.38}N_{1—0.62}Ta$	10.0—11.3		
CNb (whiskers)	7.5—10.5		
CNb	11.5	B1	
$C_{0.7—1.0}Nb_{0.3—0}$	6—11	B1	
CNb_xTa_{1-x}	8.2—13.9		
$CNb_{0.6—0.9}W_{0.4—0.1}$	12.5—11.6	B1	
$C_{0.1}Si_{0.9}V_3$	16.4	A15	
CTa	10.3	B1	
$CTa_{1—0.4}W_{0—0.6}$	8.5—10.5	B1	
$C_{0.66}Th_{0.13}Y_{0.21}$	17		(C_3Pu_2)
C_3Y_2	11.5		(C_3Pu_2)
CW	10	B1	
$(Ca,La)_2CuO_4$	18		(K_2NiF_4)
$Cu(La,Sr)_2O_4$	39		
$Cu_{1.8}Mo_6S_8$	10.8		(Mo_6PbS_8)
$Cr_{0.3}SiV_{2.7}$	11.3	A15	
$GaNb_3$	14.5	A15	(Cr_3Si)
$Ga_xNb_3Sn_{1-x}$	14—18.37	A15	

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c,K	Crystal structure type	
GaV_3	16.8	A15	
$GaV_{2.1—3.5}$	6.3—14.45	A15	
$GeNb_3$	23.2	A15	
$GeNb_3$ (quenched)	6—17	A15	
$Ge_xNb_3Sn_{1-x}$	17.6—18.0	A15	
$Ge_{0.5}Nb_3Sn_{0.5}$	11.3		
$Ge_{0.1}Si_{0.9}V_3$	14.0	A15	
GeV_3	11	A15	
$InLa_3$	9.83; 10.4	LI_2	($AuCu_3$)
$InLa_3$ (0—35 kbar)	9.75—10.55		
$In_{0—0.3}Nb_3Sn_{1—0.7}$	18.0—18.19	A15	
InV_3	13.9	A15	
$Ir_{0.4}Nb_{0.6}$	10		(FeCr)
$LaMo_6Se_8$	11.4		(Mo_6PbS_8)
LiO_4Ti_2	13.7		($A1_2MgO_4$)
MoN	12; 14.8		h*
Mo_3Os	12.7	A15	
$Mo_6Pb_{0.9}S_{7.5}$	15.2		(Mo_6PbS_8)
Mo_3Re	10.0; 15	A15	
Mo_xRe_{1-x}	1.2—12.2		
$Mo_{0.52}Re_{0.48}$	11.1		
$Mo_{0.57}Re_{0.43}$	14.0		
$Mo_{\sim 0.60}Re_{0.395}$	10.6		
MoRu	9.5—10.5	A3	
Mo_3Ru	10.6	A15	
Mo_6Se_8T1	12.2		(Mo_6PbS_8)
$Mo_{0.3}SiV_{2.7}$	11.7	A15	
Mn_3Si	12.5	A15	
Mo_3Tc	15	A15	
$Mo_{0.3}Tc_{0.7}$	12.0	A15	
Mo_xTc_{1-x}	10.8—15.8		
$MoTc_3$	15.8		
NNb (whiskers)	10—14.5		
NNb (diffusion wires)	16.10		
$N_{0.988}Nb$	14.9; 17.3	B1	
$N_{0.824—0.988}Nb$	14.4—15.3	B1	
$N_{0.7—0.795}Nb$	11.3—12.9		
NNb_xO_y	13.5—17.0	B1	
NNb_xO_y	6.0—11		
$N_{100—42w/o}Nb_{0—58w/o}Ti$	15—16.8		
$N_{100—75w/o}Nb_{0—25w/o}Zr$	12.5—16.35		
NNb_xZr_{1-x}	9.8—13.8	B1	
$N_{0.93}Nb_{0.85}Zr_{0.15}$	13.8	B1	
NTa	12—14	B1	
NZr	10.7	B1	
Nb_3Pt	10.9	A15	
$Nb_{0.18}Re_{0.82}$	10		(Mn)
Nb_3Si	19	A15	
$Nb_{0.3}SiV_{2.7}$	12.8	A15	
Nb_3Sn	18.05	A15	
$Nb_{0.8}Sn_{0.2}$	18.18; 18.5	A15	
Nb_xSn_{1-x} (film)	2.6—18.5		o*
Nb_3Sn_2	16.6		t*
$NbSnTa_2$	10.8	A15	
Nb_2SnTa	16.4	A15	

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TABLE 4
Superconductive Compounds and Alloys (continued)

Substance	T_c,K	Crystal structure type
$Nb_{2.5}SnTa_{0.5}$	17.6	A15
$Nb_{2.75}SnTa_{0.25}$	17.8	A15
$Nb_{3x}SnTa_{3(1-x)}$	6.0—18.0	
$Nb_2SnTa_{0.5}V_{0.5}$	12.2	A15
$NbTc_3$	10.5	A12
$Nb_{0.75}Zr_{0.25}$	10.8	
$Nb_{0.66}Zr_{0.33}$	10.8	
$PbTa_3$	17	A15
$RhTa_3$	10	A15
$RhZr_2$	10.8; 11.3	C16 ($A1_2Cu$)
$Rh_{0-0.45}Zr_{1-0.55}$	2.1—10.8	
$SiTi_{0.3}V_{2.7}$	10.9	A15
SiV_3	17.1	A15
$SiV_{2.7}Zr_{0.3}$	13.2	A15

TABLE 5
Critical Field Data

Substance	H_o oersteds	Substance	H_o oersteds
Ag_2F	2.5	InSb	1100
Ag_7NO_{11}	57	In_xTl_{1-x}	252—284
Al_2CMo_3	1700	$In_{0.8}Tl_{0.2}$	252
$BaBi_3$	740	$Mg_{0.47}Tl_{0.53}$	220
Bi_2Pt	10	$Mo_{0.16}Ti_{0.84}$	<985
Bi_3Sr	530	$NbSn_2$	620
Bi_5Tl_3	>400	$PbTl_{0.27}$	756
CdSn	>266	$PbTl_{0.17}$	796
$CoSi_2$	105	$PbTl_{0.12}$	849
$Cr_{0.1}Ti_{0.3}V_{0.6}$	1360	$PbTl_{0.075}$	880
$In_{1-0.86}Mg_{0-0.14}$	272.4—259.2	$PbTl_{0.04}$	864

TABLE 6
High Critical Magnetic-Field Superconductive Compounds and Alloys

Substance	T_c, K	H_{c1}, kOe	H_{c2}, kOe	H_{c3}, kOe	T_{obs}, K[a]
Al_2CMo_3	9.8—10.2	0.091	156		1.2
$AlNb_3$		0.375			
$Ba_xO_3Sr_{1-x}Ti$	<0.1—0.55	0.0039 max.			
$Bi_{0.5}Cd_{0.1}Pb_{0.27}Sn_{0.13}$			>24		3.06
Bi_xPb_{1-x}	7.35—8.4	0.122 max.	30 max.		4.2
$Bi_{0.56}Pb_{0.44}$	8.8		15		4.2
$Bi_{7.5w/o}Pb_{92.5w/o}$[b]			2.32		
$Bi_{0.099}Pb_{0.901}$		0.29	2.8		
$Bi_{0.02}Pb_{0.98}$		0.46	0.73		
$Bi_{0.53}Pb_{0.32}Sn_{0.16}$			>25		3.06
$Bi_{1-0.93}Sn_{0-0.07}$			0—0.032		3.7
Bi_5Tl_3	6.4		>5.6		3.35
C_8K (excess K)	0.55		0.160 (H⊥c)		0.32
			0.730 (H||c)		0.32

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TABLE 6
High Critical Magnetic-Field Superconductive Compounds and Alloys (continued)

Substance	T_c, K	H_{c1}, kOe	H_{c2}, kOe	H_{c3}, kOe	T_{obs}, K[a]
C_8K	0.39		0.025 (H⊥c)		0.32
			0.250 (H∥c)		0.32
$C_{0.44}Mo_{0.56}$	12.5—13.5	0.087	98.5		1.2
CNb	8—10	0.12	16.9		4.2
$CNb_{0.4}Ta_{0.6}$	10—13.6	0.19	14.1		1.2
CTa	9—11.4	0.22	4.6		1.2
$Ca_xO_3Sr_{1-x}Ti$	<0.1—0.55	0.002—0.004			
$Cd_{0.1}Hg_{0.9}$ (by weight)		0.23	0.34		2.04
$Cd_{0.05}Hg_{0.95}$		0.28	0.31		2.16
$Cr_{0.10}Ti_{0.30}V_{0.60}$	5.6	0.071	84.4		0
GaN	5.85	0.725			4.2
Ga_xNb_{1-x}			>28		4.2
GaSb (annealed)	4.24		2.64		3.5
$GaV_{1.95}$	5.3		73[e]		
$GaV_{2.1\text{-}3.5}$	6.3—14.45		230—300[d]		0
GaV_3		0.4	350[e]		0
			500[d]		
$GaV_{4.5}$	9.15		121[c]		0
Hf_xNb_y			>52—>102		1.2
Hf_xTa_y			>28—>86		1.2
$Hg_{0.05}Pb_{0.95}$		0.235	2.3		
$Hg_{0.101}Pb_{0.899}$		0.23	4.3		4.2
$Hg_{0.15}Pb_{0.85}$	6.75		>13		2.93
$In_{0.98}Pb_{0.02}$	3.45	0.1		0.12	2.76
$In_{0.96}Pb_{0.04}$	3.68	0.1	0.12	0.25	2.94
$In_{0.94}Pb_{0.06}$	3.90	0.095	0.18	0.35	3.12
$In_{0.913}Pb_{0.087}$	4.2	~l0.17	0.55	2.65	
$In_{0.316}Pb_{0.684}$		0.155	3.7		4.2
$In_{0.17}Pb_{0.83}$			2.8	5.5	4.2
$In_{1.000}Te_{1.002}$	3.5—3.7		1.2[c]		0
$In_{0.95}Tl_{0.05}$		0.263	0.263		3.3
$In_{0.90}Tl_{0.10}$		0.257	0.257		3.25
$In_{0.83}Tl_{0.17}$		0.242	0.39		3.21
$In_{0.75}Tl_{0.25}$		0.216	0.50		3.16
LaN	1.35	0.45			0.76
La_3S_4	6.5	≈0.15	>25		1.3
La_3Se_4	8.6	≈0.2	>25		1.25
$Mo_{0.52}Re_{0.48}$	11.1		14—21	22—33	4.2
			18—28	37—43	1.3
$Mo_{0.6}Re_{0.395}$	10.6		14—20	20—37	4.2
			19—26	26—37	1.3
$Mo_{0.5}Ti_{0.5}$			75[c]		0
$Mo_{0.16}Ti_{0.84}$	4.18	0.028	98.7[c]		0
			36—38		3.0
$Mo_{0.913}Ti_{0.087}$	2.95	0.060	15		4.2
$Mo_{0.1\text{-}0.3}U_{0.9\text{-}0.7}$	1.85—2.06		>25		
$Mo_{0.17}Zr_{0.83}$			30		
$N_{(12.8\ w/o)}Nb$	15.2		>9.5		13.2
NNb (wires)	16.1		153[c]		0
			132		4.2
			95		8
			53		12
NNb_xO_{1-x}	13.5—17.0		38		

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TABLE 6
High Critical Magnetic-Field Superconductive Compounds and Alloys (continued)

Substance	T_c, K	H_{c1}, kOe	H_{c2}, kOe	H_{c3}, kOe	T_{obs}, K[a]
NNb_xZr_{1-x}	9.8—13.8		4- >130		4.2
$N_{0.93}Nb_{0.85}Zr_{0.15}$	13.8		>130		4.2
$Na_{0.086}Pb_{0.914}$		0.19	6.0		
$Na_{0.016}Pb_{0.984}$		0.28	2.05		
Nb	9.15		2.020		1.4
			1.710		4.2
Nb		0.4—1.1	3—5.5		4.2
Nb (unstrained)		1.1—1.8	3.40	6—9.1	4.2
Nb (strained)		1.25—1.92	3.44	6.0—8.7	4.2
Nb (cold-drawn wire)		2.48	4.10	≈10	4.2
Nb (film)			>25		4.2
NbSc			>30		
Nb_3Sn		0.170	221		4.2
			70		14.15
			54		15
			34		16
			17		17
$Nb_{0.1}Ta_{0.9}$		0.084	0.154		4.195
$Nb_{0.2}Ta_{0.8}$			10		4.2
$Nb_{0.65\text{-}0.73}Ta_{0.02\text{-}0.10}Zr_{0.25}$			>70—>90		4.2
Nb_xTi_{1-x}			148 max.		1.2
			120 max.		4.2
$Nb_{0.222}U_{0.778}$		1.98	23		1.2
Nb_xZr_{1-x}			127 max.		1.2
			94 max.		4.2
O_3SrTi	0.43	0.0049[c]	0.504[c]		0
O_3SrTi	0.33	0.00195[c]	0.420[c]		0
$PbSb_{1\ w/o}$(quenched)			>1.5		4.2
$PbSb_{1\ w/o}$(annealed)			>0.7		4.2
$PbSb_{2.8\ w/o}$(quenched)			>2.3		4.2
$PbSb_{2.8\ w/o}$(annealed)			>0.7		4.2
$Pb_{0.871}Sn_{0.129}$		0.45	1.1		
$Pb_{0.965}Sn_{0.035}$		0.53	0.56		
$Pb_{1\text{-}0.26}Tl_{0\text{-}0.74}$	7.20—3.68		2—6.9[c]		0
$PbTl_{0.17}$	6.73		4.5[c]		0
$Re_{0.26}W_{0.74}$			>30		
$Sb_{0.93}Sn_{0.07}$			0.12		3.7
SiV_3	17.0	0.55	156[e]		
Sn_xTe_{1-x}		0.00043—0.00236	0.005—0.0775		0.012—0.079
Ta (99.95%)		0.425	1.850		1.3
		0.325	1.425		2.27
		0.275	1.175		2.66
		0.090	0.375		3.72
$Ta_{0.5}Nb_{0.5}$			3.55		4.2
$Ta_{0.65\text{-}0}Ti_{0.35\text{-}1}$	4.4—7.8		>14—138		1.2
$Ta_{0.5}Ti_{0.5}$			138		1.2
Te	3.3	0.25[c]			0
Tc_xW_{1-x}	5.75—7.88		8—44		4.2
Ti				2.7	4.2
$Ti_{0.75}V_{0.25}$	5.3	0.029[c]	199[c]		0
$Ti_{0.775}V_{0.225}$	4.7	0.024[c]	172[c]		0
$Ti_{0.615}V_{0.385}$	7.07	0.050	34		4.2
$Ti_{0.516}V_{0.484}$	7.20	0.062	28		4.2
$Ti_{0.415}V_{0.585}$	7.49	0.078	25		4.2

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TABLE 6
High Critical Magnetic-Field Superconductive Compounds and Alloys (continued)

Substance	T_c, K	H_{c1}, kOe	H_{c2}, kOe	H_{c3}, kOe	T_{obs}, K[a]
$Ti_{0.12}V_{0.88}$			17.3	28.1	4.2
$Ti_{0.09}V_{0.91}$			14.3	16.4	4.2
$Ti_{0.06}V_{0.94}$			8.2	12.7	4.2
$Ti_{0.03}V_{0.97}$			3.8	6.8	4.2
Ti_xV_{1-x}			108 max.		1.2
V	5.31	0.8	3.4		1.79
		0.75	3.15		2
		0.45	2.2		3
		0.30	1.2		4
$V_{0.26}Zr_{0.74}$	≈5.9	0.238			1.05
		0.227			1.78
		0.185			3.04
		0.165			3.5
W (film)	1.7—4.1		>34		1

[a] Temperature of critical field measurement.
[b] w/o denotes weight percent.
[c] Extrapolated.
[d] Linear extrapolation.
[e] Parabolic extrapolation.

REFERENCES

1. B. W. Roberts, in *Superconductive Materials and Some of Their Properties. Progress in Cryogenics*, Vol. IV, 1964, pp. 160—231.
2. B. W. Roberts, Superconductive Materials and Some of Their Properties, NBS Technical Notes 408 and 482, U.S. Government Printing Office, 1966 and 1969; B. W. Roberts, *J. Phys. Chem. Ref. Data*, 5, 581, 1976.
3. B. W. Roberts, Properties of Selected Superconductive Materials, 1978 Supplement, NBS Technical Note 983, 1978.
4. T. Claeson, *Phys. Rev.*, 147, 340, 1966.
5. C. J. Raub, W. H. Zachariasen, T. H. Geballe, and B. T. Matthias, *J. Phys. Chem. Solids*, 24, 1093, 1963.
6. T. H. Geballe, B. T. Matthias, V. B. Compton, E. Corenzwit, G. W. Hull, Jr., and L. D. Longinotti, *Phys. Rev.*, 1A, 119, 1965.
7. C. J. Raub, V. B. Compton, T. H. Geballe, B. T. Matthias, J. P. Maita, and G. W. Hull, Jr., *J. Phys. Chem. Solids*, 26, 2051, 1965.
8. R. D. Blaugher, J. K. Hulm, and P. N. Yocom, *J. Phys. Chem. Solids*, 26, 2037, 1965.
9. T. Claeson and H. L. Luo, *J. Phys. Chem. Solids*, 27, 1081, 1966.
10. S. C. Ng and B. N. Brockhouse, *Solid State Comm.*, 5, 79, 1967.
11. O. I. Shulishova and I. A. Shcherbak, *Izv. AN SSSR, Neorg. Materials*, 3, 1495, 1967.
12. T. F. Smith and H. L. Luo, *J. Phys. Chem. Solids*, 28, 569, 1967.
13. A. C. Lawson, *J. Less–Common Metals*, 23, 103, 1971.
14. R. Chevrel, M. Sergent, and J. Prigent, *J. Solid State Chem.*, 3, 515, 1971.
15. M. Marezio, P. D. Dernier, J. P. Remeika, and B. T. Matthias, *Mat. Res. Bull.*, 8, 657, 1973.
16. J. K. Hulm and R. D., *Blaugher in Superconductivity in d– and f–Band Metals*, D. H. Douglass,Ed., American Institute of Physics, 4, 1, 1972.
17. R. N. Shelton, A. C. Lawson, and D. C. Johnston, *Mat. Res. Bull.*, 10, 297, 1975.
18. H. D. Wiesinger, *Phys. Status Sol.*, 41A, 465, 1977.
19. O. Fisher, *Applied Phys.*, 16, 1, 1978.
20. D. C. Johnston, *Solid State Comm.*, 24, 699, 1977.
21. H. C. Ku and R. H. Shelton, *Mat. Res. Bull.*, 15, 1441, 1980.
22. H. Barz, *Mat. Res. Bull.*, 15, 1489, 1980.
23. G. P. Espinosa, A. S. Cooper, H. Barz, and J. P. Remeika, *Mat. Res. Bull.*, 15, 1635, 1980.
24. E. M. Savitskii, V. V. Baron, Yu. V. Efimov, M. I. Bychkova, and L. F. Myzenkova, in *Superconducting Materials*, Plenum Press, 1981, p. 107.
25. R. Fluckiger and R. Baillif, in Topics in *Current Physics*, O. Fischer and M. B. Maple, Eds., Springer Verlag, 34, 113, 1982.
26. R. N. Shelton, in *Superconductivity in d– and f–Band Metals*, W. Buckel and W. Weber, Eds., Kernforschungszentrum, Karlsruhe, 1982, p. 123.
27. D. C. Johnston and H. F. Braun, *Topics in Current Phys.*, 32, 11, 1982.
28. R. Chevrel and M. Sergent, *Topics in Current Phys.*, 32, 25, 1982.

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29. G. P. Espinosa, A. S. Cooper, and H. Barz, *Mat. Res. Bull.*, 17, 963, 1982.
30. R. Muller, R. N. Shelton, J. W. Richardson, Jr., and R. A. Jacobson, *J. Less–Comm. Met.*, 92, 177, 1983.
31. You–Xian Zhao and Shou–An He, in *High Pressure in Science and Technology*, North Holland, 22, 51, 1983.
32. You–Xian Zhao and Shou–An He, *Solid State Comm.*, 24, 699, 1983.
33. G. P. Meisner and H. C. Ku, *Appl. Phys.*, A31, 201, 1983.
34. R. J. Cava, D. W. Murphy, and S. M. Zahurak, *J. Electrochem. Soc.*, 130, 2345, 1983.
35. R. N. Shelton, *J. Less–Comm. Met.*, 94, 69, 1983.
36. B. Chevalier, P. Lejay, B. Lloret, Wang Xian–Zhong, J. Etourneau, and P. Hagenmuller, *Annales de Chemie*, 9, 191, 1984.
37. G. Venturini, M. Meot–Meyer, E. McRae, J. F. Mareche, and B. Rogues, *Mat. Res. Bull.*, 19, 1647, 1984.
38. J. M. Tarascon, F. G. DiSalvo, D. W. Murphy, G. Hull, and J. V. Waszczak, *Phys. Rev.*, 29B, 172, 1984.
39. G. V. Subba and G. Balakrishnan, *Bull. Mat. Sci.*, 6, 283, 1984.
40. B. Batlog, *Physica*, 126B, 275, 1984.
41. M. J. Johnson, Ames Lab (USA) Report IS-T-1140, 1984.
42. I. M. Chapnik, *J. Mat. Sci. Lett.*, 4, 370, 1985.
43. W. Rong–Yao, L. Qi–Guang, and Z. Xiao, *Phys. Status Sol.*, 90A, 763, 1985.
44. W. Xian–Zhong, B. Chevalier, J. Etourneau, and P. Hagenmuller, *Mat. Res. Bull.*, 20, 517, 1985.
45. H. R. Ott, F. Hulliger, H. Rudigier, and Z. Fisk, *Phys. Rev.*, 31B, 1329, 1985.
46. P. Villars and L. D. Calver, *Pearson's Handbook of Crystallographic Data for Intermetallic Phases*, Vol. 1—3, ASM, 1985.
47. G. V. Subba Rao, K. Wagner, G. Balakhrishnan, J. Jakani, W. Paulus, and R. Scollhorn, *Bull. Mat. Sci.*, 7, 215, 1985.
48. J. G. Bednorz and K. A. Muller, *Zs. Physik*, B64, 189, 1986.
49. W. Rong–Yao, *Phys. Status Sol.*, 94A, 445, 1986.
50. H. D. Yang, R. N. Shelton, and H. F. Braun, *Phys. Rev.*, 33B, 5062, 1986.
51. G. Venturini, M. Kanta, E. McRae, J. F. Mareche, B. Malaman, and B. Roques, *Mat. Res. Bull.*, 21, 1203, 1986.
52. W. Rong–Yao, *J. Mat. Sci. Lett.*, 5, 87, 1986.
53. M. K. Wu, J. R. Ashburn, C. J. Torng, P. H. Hor, R. L. Meng, L. Gao, Z. J. Huang, Y. Q. Wang, and C. W. Chu, *Phys. Rev. Lett.*, 58, 908, 1987.
54. R. J. Cava, R. B. Van Dover, B. Batlog, and E. A. Rietman, *Phys. Rev. Lett.*, 58, 408, 1987.
55. L. C. Porter, T. J. Thorn, U. Geiser, A. Umezawa, H. H. Wang, W. K. Kwok, H–C. I. Kao, M. R. Monaghan, G. W. Crabtree, K. D. Carlson, and J. M. Williams, *Inorg. Chem.*, 26, 1645, 1987.
56. A. M. Kini, U. Geiser, H–C. I. Kao, K. D. Carlson, H. H. Wang, M. R. Monaghan, and K. M. Williams, *Inorg. Chem.*, 26, 1834, 1987.
57. T. Penney, S. von Molnar, D. Kaiser, F. Holtzberg, and A. W. Kleinsasser, *Phys. Rev.*, B38, 2918, 1988.
58. Y. K. Tao, J. S. Swinnea, A. Manthiram, J. S. Kim, J. B. Goodenoug, and H. Steinfink, *J. Mat. Res.*, 3, 248, 1988.
59. G. G. Peterson, B. R. Weinberger, L. Lynds, and H. A. Krasinski, *J. Mat. Res.*, 3, 605, 1988.
60. J. B. Torrance, Y. Tokura, A. Nazzai, and S. S. P. Parkin, *Phys. Rev. Lett.*, 60, 542, 1988.
61. K. Kourtakis, M. Robbins, P. K. Gallagher, and T. Teifel, *J. Mat. Res.*, 4, 1289, 1989.
62. J. C. Phillips, *Physics of High-T_c Superconductors*, Academic Press, 1989, p. 336.
63. Shui Wai Lin and L. I. Berger, *Rev. Sci. Instrum.*, 60, 507, 1989.
64. M. Tinkham, *Introduction to Superconductivity*, McGraw–Hill, New York, 1975.
65. O. Fischer and M.B. Maple, Eds., *Topics in Current Physics*, Volume 32: Superconductivity in Ternary Compounds I; Volume 34: Superconductivity in Ternary Compounds II, Springer–Verlag, Berlin, 1982.
66. K. J. Dunn and F. P. Bundy, *Phys. Rev.*, B25, 194, 1982.
67. A. Barone and G. Paterno, *Physics and Applications of the Josephson Effect*, Wiley, New York, 1982.
68. D. H. Douglass, Ed., *Superconductivity in d- and f-band Metals*, Plenum Press, New York, 1976.
69. D. M. Ginsberg, Ed., *Physical Properties of High Temperature Superconductors*, (Volume II, 1990; Volume III, 1992; Volume V, 1996), World Scientific, Singapore.
70. T. Ishiguro and K. Yamji, *Organic Superconductors*, Springer Verlag, Berlin, 1990.
71. Sh. Okada, K. Shimizu, T. C. Kobayashi, K. Amaya, and Sh. Endo., *J. Phys. Soc. Jpn.*, 65, 1924, 1996.
72. A. Bourdillon and N. X. Tan Bourdillon, *High Temperature Superconductors: Processing and Science*, Academic Press, 1994.
73. J. M. Williams, J. R. Ferraro, R. J. Thorn, K. Carlson, U. Geiser, H. H. Wang, A. M. Kini, and M.-H. Whangbo, *Organic Superconductors (Including Fullerenes): Synthesis, structure, Properties, and Theory*, Prentice–Hall, 1992.

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HIGH TEMPERATURE SUPERCONDUCTORS

C. N. R. Rao and A. K. Raychaudhuri

The following tables give properties of a number of high temperature superconductors. Table 1 lists the crystal structure (space group and lattice constants) and the critical transition temperature T_c for the more important high temperature superconductors so far studied. Table 2 gives energy gap, critical current density, and penetration depth in the superconducting state. Table 3 gives electrical and thermal properties of some of these materials in the normal state. The tables were prepared in November 1992 and updated in November 1994.

REFERENCES

1. Ginsburg, D.M., Ed., *Physical Properties of High-Temperature Superconductors*, Vols. I—III, World Scientific, Singapore, 1989—1992.
2. Rao, C.N.R., Ed., *Chemistry of High-Temperature Superconductors*, World Scientific, Singapore, 1991.
3. Shackelford, J.F., *The CRC Materials Science and Engineering Handbook*, CRC Press, Boca Raton, 1992, 98—99 and 122—123.
4. Kaldis, E., Ed., *Materials and Crystallographic Aspects of HT$_c$-Superconductivity*, Kluwer Academic Publ., Dordrecht, The Netherlands, 1992.
5. Malik, S.K. and Shah, S.S., Ed., *Physical and Material Properties of High Temperature Superconductors*, Nova Science Publ., Commack, N.Y., 1994.
6. Chmaissem, O. et. al., *Physica*, C230, 231—238, 1994.
7. Antipov, E.V. et. al., *Physica*, C215, 1—10, 1993.

Table 1
Structural Parameters and Approximate T_c Values of High-Temperature Superconductors

Material	Structure	T_c/K (maximum value)
$La_2CuO_{4+\delta}$	Bmab; a = 5.355, b = 5.401, c = 13.15 Å	39
$La_{2-x}Sr_x(Ba_x)CuO_4$	I4/mmm; a = 3.779, c = 13.23 Å	35
$La_2Ca_{1-x}Sr_xCu_2O_6$	I4/mmm; a = 3.825, c = 19.42 Å	60
$YBa_2Cu_3O_7$	Pmmm; a = 3.821, b = 3.885, c = 11.676 Å	93
$YBa_2Cu_4O_8$	Ammm; a = 3.84, b = 3.87, c = 27.24 Å	80
$Y_2Ba_4Cu_7O_{15}$	Ammm; a = 3.851, b = 3.869, c = 50.29 Å	93
$Bi_2Sr_2CuO_6$	Amaa; a = 5.362, b = 5.374, c = 24.622 Å	10
$Bi_2CaSr_2Cu_2O_8$	A_2aa; a = 5.409, b = 5.420, c = 30.93 Å	92
$Bi_2Ca_2Sr_2Cu_3O_{10}$	A_2aa; a = 5.39, b = 5.40, c = 37 Å	110
$Bi_2Sr_2(Ln_{1-x}Ce_x)_2Cu_2O_{10}$	P4/mmm; a = 3.888, c = 17.28 Å	25
$Tl_2Ba_2CuO_6$	A_2aa; a = 5.468, b = 5.472, c = 23.238 Å;	
	I4/mmm; a = 3.866, c = 23.239 Å	92
$Tl_2CaBa_2Cu_2O_8$	I4/mmm; a = 3.855, c = 29.318 Å	119
$Tl_2Ca_2Ba_2Cu_3O_{10}$	I4/mmm; a = 3.85, c = 35.9 Å	128
$Tl(BaLa)CuO_5$	P4/mmm; a = 3.83, c = 9.55 Å	40
$Tl(SrLa)CuO_5$	P4/mmm; a = 3.7, c = 9 Å	40
$(Tl_{0.5}Pb_{0.5})Sr_2CuO_5$	P4/mmm; a = 3.738, c = 9.01 Å	40
$TlCaBa_2Cu_2O_7$	P4/mmm; a = 3.856, c = 12.754 Å	103
$(Tl_{0.5}Pb_{0.5})CaSr_2Cu_2O_7$	P4/mmm; a = 3.80, c = 12.05 Å	90
$TlSr_2Y_{0.5}Ca_{0.5}Cu_2O_7$	P4/mmm; a = 3.80, c = 12.10 Å	90
$TlCa_2Ba_2Cu_3O_8$	P4/mmm; a = 3.853, c = 15.913 Å	110
$(Tl_{0.5}Pb_{0.5})Sr_2Ca_2Cu_3O_9$	P4/mmm; a = 3.81, c = 15.23 Å	120
$TlBa_2(La_{1-x}Ce_x)_2Cu_2O_9$	I4/mmm; a = 3.8, c = 29.5 Å	40
$Pb_2Sr_2La_{0.5}Ca_{0.5}Cu_3O_8$	Cmmm; a = 5.435, b = 5.463, c = 15.817 Å	70
$Pb_2(Sr,La)_2Cu_2O_6$	$P22_12$; a = 5.333, b = 5.421, c = 12.609 Å	32
$(Pb,Cu)Sr_2(La,Ca)Cu_2O_7$	P4/mmm; a = 3.820, c = 11.826 Å	50
$(Pb,Cu)(Sr,Eu)(Eu,Ce)Cu_2O_x$	I4/mmm; a = 3.837, c = 29.01 Å	25
$Nd_{2-x}Ce_xCuO_4$	I4/mmm; a = 3.95, c = 12.07 Å	30
$Ca_{1-x}Sr_xCuO_2$	P4/mmm; a = 3.902, c = 3.35 Å	110
$Sr_{1-x}Nd_xCuO_2$	P4/mmm; a = 3.942, c = 3.393 Å	40
$Ba_{0.6}K_{0.4}BiO_3$	Pm3m; a = 4.287 Å	31
Rb_2CsC_{60}	a = 14.493 Å	31
$NdBa_2Cu_3O_7$	Pmmm; a = 3.878, b = 3.913, c = 11.753	58

Table 1
Structural Parameters and Approximate T_c Values of High-Temperature Superconductors (continued)

Material	Structure	T_c/K (maximum value)
$SmBaSrCu_3O_7$	I4/mmm; a = 3.854, c = 11.62	84
$EuBaSrCu_3O_7$	I4/mmm; a = 3.845, c = 11.59	88
$GdBaSrCu_3O_7$	I4/mmm; a = 3.849, c = 11.53	86
$DyBaSrCu_3O_7$	Pmmm; a = 3.802, b = 3.850, c = 11.56	90
$HoBaSrCu_3O_7$	Pmmm; a = 3.794, b = 3.849, c = 11.55	87
$ErBaSrCu_3O_7$ (multiphase)	Pmmm; a = 3.787, b = 3.846, c = 11.54	82
$TmBaSrCu_3O_7$ (multiphase)	Pmmm; a = 3.784, b = 3.849, c = 11.55	88
$YBaSrCu_3O_7$	Pmmm; a = 3.803, b = 3.842, c = 11.54	84
$HgBa_2CuO_4$	I4/mmm; a = 3.878, c = 9.507	94
$HgBa_2CaCu_2O_6$ (annealed in O_2)	I4/mmm; a = 3.862, c = 12.705	127
$HgBa_2Ca_2Cu_3O_8$	Pmmm; a = 3.85, c = 15.85	133
$HgBa_2Ca_3Cu_4O_{10}$	Pmmm; a = 3.854, c = 19.008	126

Table 2
Superconducting Properties

J_c (0): Critical current density extrapolated to 0 K
λ_{ab}: Penetration depth in a-b plane
k_B: Boltzmann constant

Material	Form	Energy gap (Δ)		$10^{-6} \times J_c$ (0)/A cm^{-2}	λ_{ab}/Å
		$2\Delta_{pp}/k_BT_c$*	$2\Delta_{fit}/k_BT_c$†		
$Y\ Ba_2Cu_3O_7$	Single Crystal	5–6	4–5	30 (film)	1400
$Bi_2Sr_2CaCu_2O_8$	Single Crystal	8–9	5.5–6.5	2	2700
$Tl_2Ba_3CaCu_2O_8$	Ceramic	6–7	4–6	10 (film, 80 K)	2000
$La_{2-x}Sr_xCuO_4$, x = 0.15	Ceramic	7–9	4–6		
$Nd_{2-x}Ce_xCuO_4$	Ceramic	8	4–5	0.2 (film)	

* Obtained from peak to peak value.
† Obtained from fit to BCS-type relation.

Table 3
Normal State Properties

ρ_{ab}:	Resistivity in the *a-b* plane
ρ_c:	Resistivity along the *c* axis
+ve:	ρ_c has positive temperature coefficient of resistivity
–ve:	ρ_c has negative temperature coefficient of resistivity
n_H:	Hall density
k:	Thermal conductivity
in plane:	Along *a-b* plane
out of plane:	Perpendicular to *a-b* plane

		$\rho_{ab}/\mu\Omega$ cm		ρ_c/mΩ cm		$10^{-21} \times n_H/cm^{-3}$		*k*/(mW/cm K) at 300 K	
Material	**Form**	**300 K**	**100 K**	**300 K**	**dρ_c/d*T***	**300 K**	**100 K**	**in plane**	**out of plane**
$YBa_2Cu_3O_7$	Single Crystal	110	35	5	+ve	11–16	4–6	120	3
	film	200–300	60–100			5–9	2–3		
$YBa_2Cu_4O_8$	Single Crystal	75	20	10	–ve	14			
	film	100–200	20–50			22	17		
$Bi_2Sr_2CuO_6$	Single Crystal	300	150	5000	–ve	6	5		
$Bi_2Sr_2CaCu_2O_8$	Single Crystal	150	50	>1000	–ve	4	3	60	8
$Tl_2Ba_2CuO_6$	Single Crystal	300–400	50–75	200–300	+ve	3.1	2.5		
$Tl_2Ba_2Ca_2Cu_3O_{10}$	Ceramic	***	**				≈ 2*		
$La_{2-x}Sr_xCuO_4$, $x = 0.12$	Single Crystal	900	350	200	+ve for T >225 K	2.5			
$La_{2-x}Sr_xCuO_4$, $x = 0.20$	Single Crystal	400	200	80	+ve for T >150 K	10		50 (for $x = 0.04$)	20
	film	400	160			8.4	6.3		
$Nd_{2-x}Ce_xCuO_4$, $x = 0.17$	Single Crystal	500	275			53	17		
$x = 0.15$	film	140–180	35			32	11	250 (for $x = 0.15$)	

* At 200 K
** ρ ~0.4 mΩ cm at 120 K
*** ρ ~1.5 mΩ cm at 300 K

ORGANIC SUPERCONDUCTORS

H.P.R. Frederikse

Although the vast majority of organic compounds are insulators, a small number of organic solids show considerable electrical conductivity. Some of these materials appear to be superconductors. The superconducting organics fall primarily into two groups: those containing fulvalenes (pentagonal rings containing sulfur or selenium) and those based on fullerenes, involving the nearly spherical cluster C_{60}.

The transition temperatures T_c of the fulvalene derivatives are shown in Table 1. The abbreviations of the various molecular groups are listed in Table 2 and their chemical structures are depicted in Figure 1. Most of the T_c's are between 1 and 12 K. Several of the compounds only show superconductivity under pressure.

The fullerenes are A_3C_{60} compounds, where A represents a single or a combination of alkali atoms. The C_{60} cluster is shown in Figure 2a, while Figure 2b illustrates how the alkali atoms fit into the A_3C_{60} molecule to form the A15 crystallographic structure. Their superconducting transition temperatures range from 8 to 31.3 K (see Table 3).

REFERENCES

1. Ishigura, T. and Yamaji, K., *Organic Superconductors*, Springer-Verlag, Berlin, 1990.
2. Williams, Jack M. et al., *Organic Superconductors (Including Fullerenes)*, Prentice Hall, Englewood Cliffs, N.J., 1992.
3. *The Fullerenes*, Ed.: Krato, H.W., Fisher, J.E., and Cox, D.E., Pergamon Press, Oxford, 1993.
4. Schluter, M. et al., in *The Fullerenes* (Ref. 3), p. 303.

Table 1
Critical Pressure and Maximum Critical Temperature of Organic Superconductors

Material	P_c/kbar	T_c/K	Material	P_c/kbar	T_c/K
$(TMTSF)_2PF_6$	6.5	1.2	β-$(ET)_2IBr_2$	0	2.8
$(TMTSF)_2AsF_6$	9	1.3	β-$(ET)_2AuI_2$	0	4.8
$(TMTSF)_2SbF_6$	11	0.4	$(ET)_4Hg_{2.89}Cl_8$	0	4.2
$(TMTSF)_2TaF_6$	12	1.4	$(ET)_4Hg_{2.89}Br_8$	12	1.8
$(TMTSF)_2ClO_4$	0	1.4	$(ET)_3Cl_2(H_2O)_2$	16	2
$(TMTSF)_2ReO_4$	9.5	1.3	κ-$(ET)_2Cu(NCS)_2$	0	10.4
$(TMTSF)_2FSO_3$	5	3	κ-$(d\text{-}ET)_2Cu(NCS)_2$	0	11.4
$(ET)_4(ReO_4)_2$	4.5	2	$(DMET)_2Au(CN)_2$	1.5	0.9
β_L-$(ET)_2I_3$	0	1.4	$(DMET)_2AuI_2$	5	0.6
β_H-$(ET)_2I_3$	0	8.1	$(DMET)_2AuBr_2$	0	1.9
γ-$(ET)_3I_{2.5}$	0	2.5	$(DMET)_2AuCl_2$	0	0.9
ε-$(ET)_2I_3(I_8)_{0.5}$	0	2.5	$(DMET)_2I_3$	0	0.6
α-$(ET)_2I_3I_2$-doped	0	3.3	$(DMET)_2IBr_2$	0	0.7
α_t-$(ET)_2I_3$	0	8	$(MDT\text{-}TTF)_2AuI_2$	0	3.5
ε→β-$(ET)_2I_3$[a]	0	6	$TTF[Ni(dmit)_2]_2$	2	1.6[b]
θ-$(ET)_2I_3$	0	3.6	$TTF[Pd(dmit)_2]_2$	20	6.5
κ-$(ET)_2I_3$	0	3.6	$(CH_3)_4N[Ni(dmit)_2]_2$	7	5

[a] Converted form ε-type to β-type by thermal treatment.
[b] For 7 kbar.

From Ishigura, T. and Yamaji, K., *Organic Superconductors*, Springer-Verlag, Berlin, 1990. With permission.

Table 2
List of Symbols and Abbreviations

TTF	tetrathiafulvalene
TMTSF	tetramethyltetraselenafulvalene
BEDT-TTF or “ET”	bis(ethylenedithio)tetrathiafulvalene
MDT-TTF	methylenedithiotetrathiafulvalene
DMET	[dimethyl(ethylenedithio)diselenadithiafulvalene]
dmit	4,5-dimercapto-1,3-dithiole-2-thione
T_c	transition temperature to superconducting state
P_c	minimum pressure required for superconducting transition

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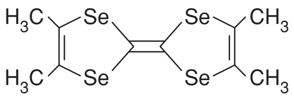
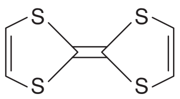
ORGANIC SUPERCONDUCTORS (continued)



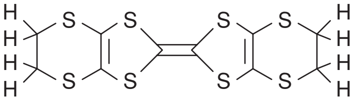
TMTSF

Tetramethyltetraselenafulvalene



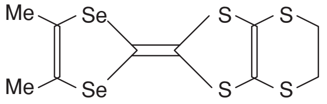
TTF

Tetrathiafulvalene



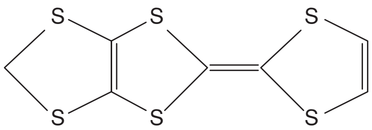
BEDT – TTF or ET

Bis(ethylenedithio)tetrathiafulvalene



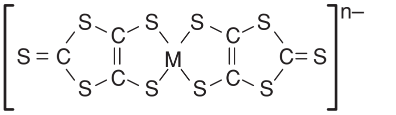
DMET

Dimethyl(ethylenedithio)diselenadithiafulvalene



MDT – TTF

Methylenedithiotetrathiafulvalene

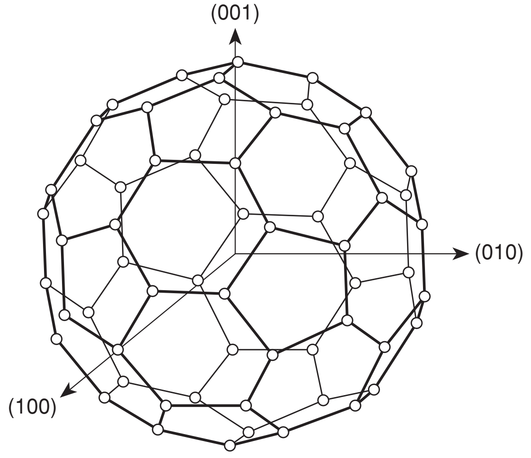


M=Ni, Pd, Pt

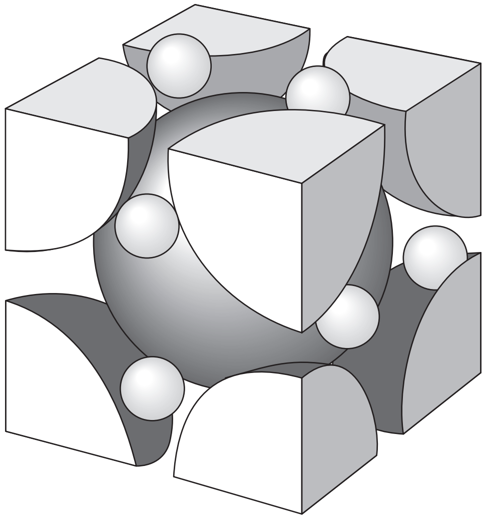
$M(dmit)_2^{2-}$

Ligand is 4,5-dimercapto-1.3-dithiole-2-thione

FIGURE 1. Structures of various donor molecules and acceptor species.



a



b

FIGURE 2. (a) C_{60} cluster placed in a fcc lattice. Each crystal axis crosses a double bond shared by two hexagons. (b) A hypothetical A_3C_{60} with the A15 structure. The structure can be seen to be an ordered defect structure of A_6C_{60}.

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Table 3
Unit Cell and T_c for FCC-A_3 C_{60}

	Lattice parameter(s) (Å)	T_c/K
$Na_2Rb_{0.5}Cs_{0.5}C_{60}$	14.148(3)	8.0
Na_2CsC_{60} No. 1[a]	14.132(2)	10.5
Na_2CsC_{60} No. 2[a]	14.176(9)	14.0
K_3C_{60}	14.253(3)	19.3
K_2RbC_{60}	14.299(2)	21.8
Rb_2KC_{60} No. 1[a]	14.336(1)	24.4
Rb_2KC_{60} No. 2[a]	14.364(5)	26.4
Rb_3C_{60}	14.436(2)	29.4
Rb_2CsC_{60}	14.493(2)	31.3

[a] Samples labeled No. 1 and No. 2 have the same nominal composition.

From Schluter, M et. al., *The Fullerenes*, Ed.: Krato, H.W., Fisher, J.E., and Cox, D.E., Pergamon Press, Oxford, 1993. With permission.

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PROPERTIES OF SEMICONDUCTORS

L. I. Berger and B. R. Pamplin

The term "semiconductor" is applied to a material in which electric current is carried by electrons or holes and whose electrical conductivity, when extremely pure, rises exponentially with temperature and may be increased from its low "intrinsic" value by many orders of magnitude by "doping" with electrically active impurities.

Semiconductors are characterized by an energy gap in the allowed energies of electrons in the material which separates the normally filled energy levels of the *valence band* (where "missing" electrons behave like positively charged current carriers "holes") and the *conduction band* (where electrons behave rather like a gas of free negatively charged carriers with an effective mass dependent on the material and the direction of the electrons' motion). This energy gap depends on the nature of the material and varies with direction in anisotropic crystals. It is slightly dependent on temperature and pressure, and this dependence is usually almost linear at normal temperatures and pressures.

Data are presented in three tables. Table I "General Properties of Semiconductors" lists the main crystallographic and semiconducting properties of a large number of semiconducting materials in three main categories: "Tetrahedral Semiconductors" in which every atom is tetrahedrally co-ordinated to four nearest neighbor atoms (or atomic sites) as for example in the diamond structure; "Octahedral Semiconductors" in which every atom is octahedrally co-ordinated to six nearest neighbor atoms — as for examples the halite structure; and "Other Semiconductors."

Table II gives more detailed information about some better known semiconductors, while Table III gives some information about the electronic energy band structure parameters of the best known materials.

Table I
PHYSICO-CHEMICAL PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE)

Substance	Molecular mass	Average atomic mass	Lattice parameters (Å, room temp.)	Density (g/cm^3)	Melting point (K)	Microhardness, N/mm^2 (M-Mohs Scale)	Specific heat, J/kg·K (300 K)	Debye temp. (K)	Coefficient of thermal linear expansion [10^{-6} K^{-1} (300K)]	Thermal conductivity [mW/cm·K (300K)]
PART A. ADAMANTINE SEMICONDUCTORS										
§A1. Diamond Structure Elements (Strukturbericht symbol A4, Space Group Fd3m-O_h^7)										
C		12.01	3.56683	3.51	≈3850 Transition to graphite > 980	10(M)	471.5	2340	1.18	9900(I) 23200(IIA) 13600(IIB)
Si		28.09	5.43072	2.3283	1685 ± 2	11270	702	645	2.49	1240
Ge		72.59	5.65754	5.3234	1231	7644	321.9	374	6.1	640
α-Sn		118.69	6.4912	5.765 (281 K)	505.2 (Tr. 286.4)		213	230	5.4 (220 K)	
§A2. Sphalerite (Zinc Blende) Structure Compounds (Strukturbericht symbol B3 Space Group F $\bar{4}$ 3m-T_d^2)										
I VII Compounds										
CuF	82.54	41.27	4.255		1181					
CuCl	98.99	49.49	5.4057	3.53	695	2.3 (M)	490	240	12.1	8.4
CuBr	143.36	71.73	5.6905	4.98	770	2.5(M)	381	207	15.4	12.5
CuI	190.46	95.23	6.60427	5.63	878	192	276	181	19.2	16.8
AgBr	187.78	93.89		6.473	>1570 (Tr. 410)	2.5(M)	270			
AgI	234.77	117.39	6.502	5.67	831	2.5(M)	232	134	−2.5	4.2
II VI Compounds										
BeS	41.08	20.54	4.865	2.36						
BeSe	87.97	43.99	5.139	4.315						
BeTe	136.61	68.31	5.626	5.090						
BePo	(218)	(109)	5.838	7.3						
ZnO	81.37	40.69	4.63	5.675	2248	5.0 (M)	494	416	2.9	234
ZnS	97.43	48.72	5.4093	4.079	2100 (Tr. 1295)	1780	472	530	6.36	251
ZnSe	144.34	72.17	5.6676	5.42	1790	1350	339	400	7.2	140
ZnTe	192.99	96.5	6.101	6.34	1568	900	264	223	8.19	108
ZnPo	(274)	(137)	6.309							
CdS	144.46	72.23	5.832	4.826	1750	1250	330	219	4.7	200
CdSe	191.36	95.68	6.05	5.674	1512	1300	255	181	3.8	90
CdTe	240.00	120.00	6.477	5.86	1365	600	205	200	4.9	58.5
CdPo	(321)	(161)	6.665							
HgS	232.65	116.33	5.8517	7.73	1820	3(M)	210			
HgSe	279.55	139.78	6.084	8.25	1070	2.5(M)	178	151	5.46	10
HgTe	328.19	164.10	6.4623	8.17	943	300	164	242	4.6	20
III V Compounds										
BN	24.82	12.41	3.615	3.49	≈3300	10(M)	793	≈1900		200
BP(L.T.)	41.78	20.87	4.538	2.9	≈2800	37000		≈980		
BAs	85.73	42.87	4.777		≈2300	19000		≈625		

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Table I
PHYSICO-CHEMICAL PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE) (continued)

Substance	Molecular mass	Average atomic mass	Lattice parameters (Å, room temp.)	Density (g/cm^3)	Melting point (K)	Microhardness, N/mm^2 (M-Mohs Scale)	Specific heat, J/kg·K (300 K)	Debye temp. (K)	Coefficient of thermal linear expansion $[10^{-6} K^{-1}$ (300K)]	Thermal conductivity [mW/cm·K (300K)]
AlP	57.95	28.98	5.451	2.42	≈2100	5.5(M)		588		920
AlAs	101.90	50.95	5.6622	3.81	2013	5000		417	3.5	840
AlSb	148.73	74.37	6.1355	4.218	1330	4000		292	4.2	600
GaP	100.69	50.35	5.4505	4.13	1750	9450		446	5.3	752
GaAs	144.64	72.32	5.65315	5.316	1510	7500		344	5.4	560
GaSb	191.47	95.74	6.0954	5.619	980	4480	320	265	6.1	270
InP	145.79	72.90	5.86875	4.787	1330	4100		321	4.6	800
InAs	189.74	94.87	6.05838	5.66	1215	3300	268	249	4.7	290
InSb	236.57	118.29	6.47877	5.775	798	2200	144	202	4.7	160
Other sphalerite structure compounds										
MnS	87.0	43.5	5.011							
MnSe	133.9	66.95	5.82							
β-SiC	40.1	20.1	4.348	3.21	3070					
Ga_2Se_3	376.32	75.26	5.429	4.92	1020	3160			8.9	50
Ga_2Te_3	522.24	104.45	5.899	5.75	1063	2370				47
In_2Te_3(H.T.)	608.44	121.7	6.150	5.8	940	1660				69
$MgGeP_2$	158.84	39.71	5.652							
$ZnSnP_2$	246.00	61.5	5.65		1200					
$ZnSnAs_2$(H.T.)	333.90	82.38	5.851	5.53	1050					76
$ZnSnSb_2$	427.56	106.89	6.281	5.67	870	2500				76

§A3. Wurtzite (Zincite) Structure Compounds (Strukturbericht symbol B4, Space Group P $6_3mc-C^4_{6v}$)

Substance	Molecular mass	Average atomic mass	Lattice parameters (Å, room temp.)		Density (g/cm^3)	Melting point (K)	Microhardness	Specific heat	Debye temp. (K)	Coefficient of thermal linear expansion	Thermal conductivity
I VII Compounds											
CuCl	99.0	49.5	3.91	6.42		T_c680K					
CuBr	143.46	71.73	4.06	6.66		T_c658K					
CuI	190.46	95.23	4.31	7.09							
AgI	234.80	117.40	4.580	7.494							
II VI Compounds											
BeO	25.01	12.51	2.698	4.380		2800					
MgTe	151.9	76.0	4.54	7.39	3.85	≈2800					
ZnO	81.37	40.69	3.24950	5.2069	5.66	2250					600
ZnS	97.43	48.72	3.8140	6.2576	4.1	2100					460
ZnTe	192.99	46.50	4.27	6.99		1568					
CdS	144.46	72.23	4.1348	6.7490	4.82	1748					401
CdSe	191.36	95.68	4.299	7.010	5.66	1512					316
CdTe	240.00	120.00	4.57	7.47							
III V Compounds											
BP(H.T.)	41.79	20.90	3.562	5.900							
AlN	40.99	20.50	3.111	4.978	3.26	≈2500					823
GaN	83.73	41.87	3.190	5.189	6.10	1500					656
InN	128.83	64.42	3.533	5.693	6.88	1200					556
Other wurtzite structure compounds											
MnS	87.0	43.5	3.985	6.45	3.248						
MnSe	133.9	66.95	4.12	6.72							
SiC	40.1	20.1	3.076	5.048							
MnTe	182.54	91.27	4.078	6.701							
Al_2S_3	150.14	30.03	3.579	5.829	2.55	1400					
Al_2Se_3	290.84	58.17	3.890	6.30	3.91	1250					

§A4. Chalcopyrite Structure Compounds (Strukturbericht symbol $E1_1$, Space Group I $\bar{4}$ $2d-D^{12}_{2d}$)

Substance	Molecular mass	Average atomic mass	Lattice parameters (Å, room temp.)		Density (g/cm^3)	Melting point (K)	Microhardness	Specific heat	Debye temp. (K)	Coefficient of thermal linear expansion	Thermal conductivity
I III VI_2 Compounds											
$CuAlS_2$	154.65	38.66	5.323	10.44	3.47	2500					
$CuAlSe_2$	248.45	62.11	5.617	10.92	4.70	2260					
$CuAlTe_2$	345.73	86.43	5.976	11.80	5.50	2550					
$CuGaS_2$	197.39	49.35	5.360	10.49	4.35	2300					
$CuGaSe_2$	291.19	72.80	5.618	11.01	5.56	1970	4200		275	5.4	42
$CuGaTe_2$	388.47	97.12	6.013	11.93	5.99	2400	3500			6.9	27
$CuInS_2$	242.49	60.62	5.528	11.08	4.75	1400	2550				
$CuInSe_2$	336.29	84.07	5.785	11.56	5.77	1600	2050			6.6	37
$CuInTe_2$	433.57	108.39	6.179	12.365	6.10	1660	400		195	7.1	49
$CuTlS_2$	332.05	83.01	5.580	11.17	6.32						
$CuTlSe_2$(L.T.)	425.85	106.46	5.844	11.65	7.11	900					
$CuFeS_2$	183.51	45.88	5.25	10.32	4.088						
$CuFeSe_2$	277.31	69.33				850					

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Table I
PHYSICO-CHEMICAL PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE) (continued)

Substance	Molecular mass	Average atomic mass	Lattice parameters (Å, room temp.)		Density (g/cm^3)	Melting point (K)	Microhardness, N/mm^2 (M-Mohs Scale)	Specific heat, J/kg·K (300 K)	Debye temp. (K)	Coefficient of thermal linear expansion [10^{-6} K^{-1} (300K)]	Thermal conductivity [mW/cm·K (300K)]
$CuLaS_2$	266.58	66.65	5.65	10.86							
$AgAlS_2$	198.97	49.74	5.707	10.28	3.94						
$AgAlSe_2$	292.77	73.19	5.968	10.77	5.07	1220					
$AgAlTe_2$	390.05	97.51	6.309	11.85	6.18	1000					
$AgGaS_2$	241.71	60.43	5.755	10.28	4.72						
$AgGaSe_2$	335.51	83.88	5.985	10.90	5.84	1120	4400				
$AgGaTe_2$	432.79	108.2	6.301	11.96	6.05	990	1800		212		10
$AgInS_2$(L.T.)	286.87	71.70	5.828	11.19	5.00		2250				
$AgInSe_2$	380.61	95.15	6.102	11.69	5.81	1053	1850				30
$AgInTe_2$	477.89	119.47	6.42	12.59	6.12	965				9.49, 0.69	
$AgFeS_2$	227.83	56.96	5.66	10.30	4.53						
II IV V_2 Compounds											
$ZnSiP_2$	155.40	38.85	5.400	10.441	3.39	1640	11000				
$ZnGeP_2$	199.90	49.98	5.465	10.771	4.17	1295	8100				180
$ZnSnP_2$	246.00	61.5					6500				
$CdSiP_2$	202.43	50.61	5.678	10.431	4.00	≈1470	10500		282		
$CdGeP_2$	246.94	61.74	5.741	10.775	4.48	1049	5650				110
$CdSnP_2$	243.03	73.26	5.900	11.518			5000		195		140
$ZnSiAs_2$	242.20	60.55	5.61	10.88	4.70	1311	9200				
$ZnGeAs_2$	287.80	71.95	5.672	11.153	5.32	1150	6800		263		110
$ZnSnAs_2$	333.90	83.48	5.8515	11.704	5.53	1048	4550		271		150
$CdSiAs_2$	290.34	72.58	5.884	10.882			6850				
$CdGeAs_2$	334.83	83.71	5.9427	11.2172	5.60	938	4700				48
$CdSnAs_2$	380.93	95.23	6.0944	11.9182	5.72	880	3450				40

§A5. Other Ternary Semiconductors with Tetrahedral Coordination

Substance	Molecular mass	Average atomic mass	Lattice parameters (Å, room temp.)		Density (g/cm^3)	Melting point (K)	Microhardness, N/mm^2 (M-Mohs Scale)	Specific heat, J/kg·K (300 K)	Debye temp. (K)	Coefficient of thermal linear expansion [10^{-6} K^{-1} (300K)]	Thermal conductivity [mW/cm·K (300K)]
I_2 IV VI_3 Compounds											
Cu_2SiS_3(H.T.)	251.36	41.89	3.684	6.004	3.81	1200					23
Cu_2SiS_3(L.T.)			5.290	10.156	3.63						
Cu_2SiTe_3	537.98	89.66	5.93		5.47						
Cu_2GeS_3(H.T.)	295.88	49.31	5.317		4.45	1210	4550	510	254	7.2	12
Cu_2GeS_3(L.T.)			5.327	5.215	4.46						
Cu_2GeSe_3	436.56	72.76	5.589	5.485	5.57	1030	3840	340	168	8.4	24
Cu_2GeTe_3	582.51	97.09	5.958	5.935	5.92		2890				130
Cu_2SnS_3	341.98	57.00	5.436		5.02	1110	2770	440	214	7.8	28
$CuSnSe_3$	482.66	80.44	5.687		5.94	960	2510	310	148	8.9	35
Cu_2SnTe_3	628.61	104.77	6.048		6.51	680	1970				144
Ag_2GeSe_3	525.21	87.54									
Ag_2SnSe_3	571.31	95.22									
Ag_2GeTe_3	671.13	111.86									
Ag_2SnTe_3	717.23	119.54									
I_3 V VI_4 Compounds											
Cu_3PS_4	349.85	40.73	7.44	6.19							
Cu_3AsS_4	393.79	49.22	6.43	6.14	4.37					3.2	30.2
Cu_3AsSe_4	581.37	72.67	5.570	10.957	5.61				169	9.5	19
Cu_3SbS_4	440.64	55.08	5.38	16.76	4.90						
Cu_3SbSe_4	628.22	78.53	5.654	11.256	6.0				131	12.4	14.6
I IV_2 V_3 Compounds											
$CuSi_2P_3$	212.64	35.44	5.25								
$CuGe_2P_3$	301.65	50.28	5.375		4.318	1113	8500	429	8.21	37.6	
$AgGe_2P_3$	345.97	57.66				1015	6150				

§A6. "Defect Chalcopyrite" Structure Compounds (Strukturbericht symbol E3, Space Group I $\bar{4}$-S_4^2)

Substance	Molecular mass	Average atomic mass	Lattice parameters (Å, room temp.)		Density (g/cm^3)	Melting point (K)
$ZnAl_2Se_4$	435.18	62.17	5.503	10.90	4.37	
$ZnAl_2Te_4$(?)	629.74	84.96	5.904	12.05	4.95	
$ZnGa_2S_4$(?)	333.06	47.58	5.274	10.44	3.80	
$ZnGa_2Se_4$(?)	520.66	74.38	5.496	10.99	5.21	
$ZnGa_2Te_4$(?)	715.22	102.17	5.937	11.87	5.67	
$ZnIn_2Se_4$	610.86	87.27	5.711	11.42	5.44	1250
$ZnIn_2Te_4$	805.42	115.06	6.122	12.24	5.83	1075
$CdAl_2S_4$	294.61	42.09	5.564	10.32	3.06	
$CdAl_2Se_4$	482.21	68.89	5.747	10.68	4.54	
$CdAl_2Te_4$(?)	676.77	97.68	6.011	12.21	5.10	

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Table I
PHYSICO-CHEMICAL PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE) (continued)

Substance	Molecular mass	Average atomic mass	Lattice parameters (Å, room temp.)	Density (g/cm³)	Melting point (K)	Microhardness, N/mm² (M-Mohs Scale)	Specific heat, J/kg·K (300 K)	Debye temp. (K)	Coefficient of thermal linear expansion [10^{-6} K^{-1} (300K)]	Thermal conductivity [mW/cm·K (300K)]
$CdGa_2S_4$	380.09	54.30	5.577 10.08	4.03						
$CdGa_2Se_4$	567.69	81.10	5.743 10.73	5.32						
$CdGa_2Te_4$	762.25	108.89	6.093 11.81	5.77						
$CdIn_2Te_4$	852.45	121.78	6.205 12.41	5.9	1060					
$HgAl_2S_4$	382.79	54.68	5.488 10.26	4.11						
$HgAl_2Se_4$	570.39	82.48	5.708 10.74	5.05						
$HgAl_2Te_4$(?)	764.48	109.28	6.004 12.11	5.81						
$HgGa_2S_4$	468.27	66.90	5.507 10.23	5.00						
$HgGa_2Se_4$	655.87	93.70	5.715 10.78	6.18						
$HgIn_2Se_4$	746.07	106.58	5.764 11.80	6.3	1100					
$HgIn_2Te_4$(?)	940.63	134.38	6.186 12.37	6.3	980					
§A7. Other Adamantine Compounds										
αSiC	40.1	20.1	3.0817 15.1183	3.21	3070					
$Hg_5Ga_2Te_8$	2163.19	144.21	6.235							
$Hg_5In_2Te_8$	2253.39	150.23	6.328							
$CdIn_2Se_4$	657.89	93.98	a = c = 5.823							
PART B. OCTAHEDRAL SEMICONDUCTORS										
§B1. HALITE STRUCTURE SEMICONDUCTORS (Strukturbericht symbol B1, Space Group Fm3m-O_h^5)										
GeTe	200.19	100.1	5.98	6.14						
SnSe	197.65	98.83	6.020		1133					
SnTe	246.29	123.15	6.313	6.45	1080 (max)					91
PbS	239.26	119.63	5.9362	7.61	1390					23
PbSe	286.16	143.08	6.1243	8.15	1340					17
PbTe	334.8	167.4	6.454	8.16	1180					23
Selected other binary halites										
BiSe	287.94	143.97	5.99	7.98	880					
BiTe	336.58	168.29	6.47							
EuSe	230.92	115.46	6.191		2300					2.4
GdSe	236.21	118.11	5.771		2400					
NiD	60.71	30.35	4.1684	6.6	2260					
CdO	128.41	64.21	4.6953		1700					7
SrS	119.68	59.84	6.0199	3.643	3000					
PART C. OTHER SEMICONDUCTORS										
§C1. Antifluorite Structure Compounds (Fm3m - O_h^5)										
Mg_2Si	76.70	25.57	6.338	1.88	1375				11.5	
Mg_2Ge	121.20	40.4	6.380	3.08	1388				15.0	
Mg_2Sn	167.3	55.77	6.765	3.53	1051				9.9	92
Mg_2Pb	225.81	85.27	6.836	5.1	823				10.0	
§C2. Tetradymite Structure Compounds ($\overline{R}3m - D_{3d}^5$)										
Sb_2Te_3	626.3	125.26	4.25 30.3	6.44	895					
Bi_2Se_3	654.84	130.97	4.14 28.7	7.51	979	167				24
Bi_2Te_3	800.76	160.15	4.38 30.45	7.73	858	155	16			30
§C3. Skutterudite Structure Compounds (Im3 - T_h^5)										
CoP_3	151.85	37.96	7.7073		>1270					
$CoAs_3$	286.70	71.65	8.2060	6.73	1230					
$CoSb_3$	424.18	106.05	9.0385		1123			307		50
$NiAs_3$	283.45	70.86	8.330	6.43						
RhP_3	195.83	48.96	7.9951		>1470					
$RhAs_3$	327.67	81.92	8.4427		>1270					
$RhSb_3$	468.16	117.04	9.2322		1170					100
IrP_3	285.14	71.29	8.0151	7.36	>1470					
$IrAs_3$	416.98	104.25	8.4673	9.12	>1470					
$IrSb_3$	557.47	139.37	9.2533	9.35	1170			303		90
§C4. Selected Multinary Compounds										
$AgSbSe_2$	387.54	96.88	5.786	6.60	910					10.5
$AgSbTe_2$ (or $Ag_{19}Sb_{29}Te_{52}$)	484.82	121.2	6.078	7.12	830					86, 0.3
$AgBiS_2$(H.T.)	380.97	95.24	5.648							
$AgBiSe_2$(H.T.)	474.77	118.69	5.82							
$AgBiTe_2$(H.T.)	572.05	143.01	6.155							
Cu_2CdSnS_4	486.43	60.80	5.586	10.83						

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Table I
PHYSICO-CHEMICAL PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE) (continued)

Substance	Molecular mass	Average atomic mass	Lattice parameters (Å, room temp.)		Density (g/cm³)	Melting point (K)	Microhardness, N/mm² (M-Mohs Scale)	Specific heat, J/kg·K (300 K)	Debye temp. (K)	Coefficient of thermal linear expansion [10^{-6} K^{-1} (300K)]	Thermal conductivity [mW/cm·K (300K)]
§C5. Some Elemental Semiconductors											
B		10.81	4.91	12.6	2.34	2348	9.5(M)	1277	1370	8.3	600
Se(gray)		78.96	4.36	4.95	4.81	493	350	292.6		(‖C) 17.89 (⊥C) 74.09	(‖C) 45.2 (⊥C) 13.1
Te		127.6	4.45	5.91	6.23	723		196.5		16.8	(‖C) 33.8 (⊥C) 19.7

Table II
BASIC THERMODYNAMIC, ELECTRICAL, AND MAGNETIC PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE)

PART A. ADAMANTINE SEMICONDUCTORS

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m²/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility (Room temp.) (cm²/V·s) Electrons	Holes	Optical transition	Remarks
§A1. Diamond Structure Elements (Strukturbericht symbol A4, Space Group Fd3m-O_h^7)										
C	714.4	18	5.7	−5.88	2.419 (589 nm)	5.4	1800	1400	i*	
Si	324	0.306	11.8	−3.9	3.49 (589 nm)	1.107	1900	500	i	
Ge	291	0.768	16	−0.12	3.99 (589 nm)	0.67	3800	1820	i	
α-Sn	267.5		24		2.75 (589 nm)	0.0; 0.8	2500	2400		
§A2. Sphalerite (Zinc Blende) Structure Compounds (Strukturbericht symbol B3 Space Group F $\bar{4}$ 3m-T_d^2)										
I VII Compounds										
CuF										
CuCl	481	0.26	7.9		1.93	3.17			d	Nantokite
CuBr	481	0.26	7.9		2.12	2.91			d	
CuI	439	0.27	6.5		2.346	2.95			d	Marshite
AgBr	486		12.4		2.253	2.50	4000		i	Bromirite
AgI	389	0.41	10		2.22	2.22	30		d	Miersite
II VI Compounds										
BeS					4.17				i	
BeSe					3.61				i	
BeTe					1.45		20		d	
BePo										
ZnO										See A3
ZnS	477		8.9	−9.9	2.356	3.54	180	5(400°C)	d	See also A3
ZnSe	422		9.2		2.89	2.58	540	28	d	
ZnTe	376		10.4		3.56	2.26	340	100	d	
ZnPo										
CdS										See A3
CdSe										See A3
CdTe	339		7.2		2.50	1.44	1200	50	d	
CdPo										
HgS					2.85		250		d	Metacinnabarite
HgSe	247					2.10 (α)	20000	≈1.5	s	Tiemannite
HgTe	242					−0.06	25000	350	s	Coloradoite
III V Compounds										
BN	815					4.6				Borazone
BP(L.T.)						≈2.1	500	70		Ignites 470K
BAs						≈1.5				
AlP						2.45	80		i	
AlAs	627		10.9			2.16	1200	420	i	
AlSb	585	0.571	11		3.2	1.60	200—400	550	i	
GaP	635	0.110	11.1	−13.8	3.2	2.24	300	150	i	
GaAs	535	0.771	13.2	−16.2	3.30	1.35	8800	400	d	
GaSb	493	0.457	15.7	−14.2	3.8	0.67	4000	1400	d	
InP	560	0.735	12.4	−22.8	3.1	1.27	4600	150	d	
InAs	477	0.549	14.6	−27.7	3.5	0.36	33000	460	d	
InSb	447	0.442	17.7	−32.9	3.96	0.163	78000	750	d	

* i = indirect, d = direct, s = semimetal.

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Table II
BASIC THERMODYNAMIC, ELECTRICAL, AND MAGNETIC PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE) (continued)

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility (Room temp.) (cm^2/V·s) Electrons	Holes	Optical transition	Remarks
Other sphalerite structure compounds										
MnS										See also §A3
MnSe										See also §A3
β-SiC					2.697	2.3	4000			
Ga_2Te_3	271			−13.5		1.35	50			
In_2Te_3(H.T.)	198			−13.6		1.04	50			
$MgGeP_2$										E1—T^{d12}
$ZnSnP_2$						2.1				Same
$ZnSnAs_2$(H.T.)						≈0.7				Same
$ZnSnSb_2$						0.4				Same

§A3. Wurtzite (Zincite) Structure Compounds (Strukturbericht symbol B4, Space Group P 6_3mc-C^4_{6v})

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility Electrons	Mobility Holes	Optical transition	Remarks
I VII Compounds										
CuCl										
CuBr										
CuI										
AgI						2.63				Iodargirite
II VI Compounds										
BeO										
MgTe										
ZnO	−350					3.2	180			
ZnS	−206					3.67				
ZnTe	−163									
CdS			8.45; 9.12		2.32	2.42	350	40	d	Greenockide
CdSe						1.74	900	50	d	Cadmoselite
CdTe						1.50	650			
III V Compounds										
BP(H.T.)										
AlN						6.02				
GaN						3.34				
InN						2.0				
Other wurtzite structure compounds										
MnS										
MnSe										
SiC					2.654					
MnTe						≈1.0				
Al_2S_3	426					4.1				
Al_2Se_3	367					3.1				

§A4. Chalcopyrite Structure Compounds (Strukturbericht symbol $E1_1$, Space Group I $\bar{4}$ 2d-D^{12}_{2d})

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility Electrons	Mobility Holes	Optical transition	Remarks
I III VI_2 Compounds										
$CuAlS_2$		0.106				2.5				
$CuAlSe_2$						1.1				
$CuAlTe_2$						0.88				
$CuGaS_2$		0.106				2.38				
$CuGaSe_2$		0.141				0.96, 1.63				
$CuGaTe_2$		0.227				0.82, 1.0				
$CuInS_2$		0.141				1.2				
$CuInSe_2$		0.187				0.86, 0.92				
$CuInTe_2$		0.278				0.95				
$CuTlS_2$										
$CuTlSe_2$(L.T.)						1.07				
$CuFeS_2$						0.53				Chalcopyrite
$CuFeSe_2$						0.16				
$CuLaS_2$										
$AgAlS_2$										
$AgAlSe_2$						0.7				
$AgAlTe_2$						0.56				
$AgGaS_2$		0.150				1.66				
$AgGaSe_2$		0.182				1.1				
$AgGaTe_2$		0.280				1.9				
$AgInS_2$(L.T.)		0.185				1.18				
$AgInSe_2$		0.238				0.96, 0.52				
$AgInTe_2$		0.338								
$AgFeS_2$										

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Table II
BASIC THERMODYNAMIC, ELECTRICAL, AND MAGNETIC PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE) (continued)

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility (Room temp.) ($cm^2/V{\cdot}s$) Electrons	Mobility (Room temp.) ($cm^2/V{\cdot}s$) Holes	Optical transition	Remarks
II IV V_2 Compounds										
$ZnSiP_2$	312					2.3	1000			
$ZnGeP_2$	293					2.2				
$ZnSnP_2$	275					1.45				
$CdSiP_2$		0.103				2.2	1000			
$CdGeP_2$	289					1.8				
$CdSnP_2$	270					1.5				
$ZnSiAs_2$	290					1.7		50		
$ZnGeAs_2$	271			−14.4		0.85				
$ZnSnAs_2$	252			−18.4		0.65		300		Disorders at 910K
$CdSiAs_2$		0.143				1.6				
$CdGeAs_2$	266			−23.4		0.53	70	25		Disorders at 903
$CdSnAs_2$	247		13.7	−21.5		0.26	22000	250		

§A5. Other Ternary Semiconductors with Tetrahedral Coordination

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility Electrons	Mobility Holes	Optical transition	Remarks
I_2 IV VI_3 Compounds										
Cu_2SiS_3(H.T.)										Wurtzite
Cu_2SiS_3(L.T.)										Tetragonal
Cu_2SiTe_3										Cubic
Cu_2GeS_3(H.T.)				−18.7						Cubic
Cu_2GeS_3(L.T.)							360			Tetragonal
Cu_2GeSe_3	211.5			−21.3		0.94	238			Same
Cu_2GeTe_3	190.2			−23.4						Same
Cu_2SnS_3				−18.2		0.91	405			Cubic
$CuSnSe_3$				−21.0		0.66	870			Cubic
Cu_2SnTe_3				−28.4						Cubic
Ag_2GeSe_3				−29.6		0.91 (77K)				
Ag_2SnSe_3				−29.5		0.81				
Ag_2GeTe_3				−31.4		0.25				
Ag_2SnTe_3				−31.0		0.08				
I_3 V VI_4 Compounds										
Cu_3PS_4										Enargite
Cu_3AsS_4	269.6			−15.8		1.24				
Cu_3AsSe_4	161.3			−13.1		0.88				Famatinite
Cu_3SbS_4				−8.3		0.74				Famatinite
Cu_3SbSe_4	127.1			−20.5		0.31				
I IV_2 V_3 Compounds										
$CuSi_2P_3$										E1
$CuGe_2P_3$		0.12				0.9				E1
$AgGe_2P_3$										

§A6. "Defect Chalcopyrite" Structure Compounds (Strukturbericht symbol E3, Space Group I $\bar{4}$-S_4^2)

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility Electrons	Mobility Holes	Optical transition	Remarks
$ZnAl_2Se_4$										
$ZnAl_2Te_4$(?)										
$ZnGa_2S_4$(?)						≈3.4				
$ZnGa_2Se_4$(?)						≈2.2				
$ZnGa_2Te_4$(?)						1.35				
$ZnIn_2Se_4$	206					1.82	35			
$ZnIn_2Te_4$	198					1.2				
$CdAl_2S_4$										
$CdAl_2Se_4$										
$CdAl_2Te_4$(?)										
$CdGa_2S_4$	256					3.44	60			
$CdGa_2Se_4$	216					2.43	33			
$CdGa_2Te_4$										
$CdIn_2Te_4$	195					(1.26 or 0.9)	4000			
$HgAl_2S_4$										
$HgAl_2Se_4$										
$HgAl_2Te_4$(?)										
$HgGa_2S_4$	249					2.84				
$HgGa_2Se_4$	204					1.95	400			
$HgIn_2Se_4$	196					0.6	290			
$HgIn_2Te_4$(?)	188					0.86	200			

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Table II
BASIC THERMODYNAMIC, ELECTRICAL, AND MAGNETIC PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE) (continued)

§A7. Other Adamantine Compounds

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility (Room temp.) ($cm^2/V{\cdot}s$) Electrons	Holes	Optical transition	Remarks
αSiC			10.2	–6.4	2.67	2.86	400			6H structure
$Hg_5Ga_2Te_8$										B3 with superlattice
$Hg_5In_2Te_8$						0.7	2000			B3 with superlattice
$CdIn_2Se_4$						1.55				

PART B. OCTAHEDRAL SEMICONDUCTORS

§B1. HALITE STRUCTURE SEMICONDUCTORS (Strukturbericht symbol B1, Space Group Fm3m-O_h^5)

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility Electrons	Holes	Optical transition	Remarks
GeTe										
SnSe										
SnTe										
PbS	435					0.5	600	600		
PbSe	393		161			0.37	1000	900		
PbTe	393		280			0.26	1600	600		Altaite
			360			0.25				
Selected other binary halites										
BiSe										
BiTe						0.4				
EuSe										
GdSe						1.8	4			
NiD						2.0 or 3.7	100			
CdO	531					2.5				
SrSW						4.1				

PART C. OTHER SEMICONDUCTORS

§C1. Antifluorite Structure Compounds (Fm3m - O_h^5)

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility Electrons	Holes	Optical transition	Remarks
Mg_2Si	79.08					0.77	405	70		
Mg_2Ge						0.74	520	110		
Mg_2Sn	76.57					0.36	320	260		
Mg_2Pb	52.72					0.1				

§C2. Tetradymite Structure Compounds (R$\bar{3}$m – D_{3d}^5)

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility Electrons	Holes	Optical transition	Remarks
Sb_2Te_3						0.3		360		
Bi_2Se_3						0.35	600			
Bi_2Te_3						0.21	1140	680		R3m (166)

§C3. Skutterudite Structure Compounds (Im3-T_h^5)

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility Electrons	Holes	Optical transition	Remarks
CoP_3						0.43				
$CoAs_3$						0.69		~4000		
$CoSb_3$						0.63	70	~3000		
RhP_3								700		
$RhAs_3$						0.85		~3000		
$RhSb_3$						0.80		~7000		
$IrSb_3$						1.18		1500		

§C4. Selected Multinary Compounds

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility Electrons	Holes	Optical transition	Remarks
$AgSbSe_2$						0.58				
$AgSbTe_2$ (or $Ag_{19}Sb_{29}Te_{52}$)						0.7, 0.27				
$AgBiS_2$(H.T.)										
$AgBiSe_2$(H.T.)										
$AgBiTe_2$(H.T.)										
Cu_2CdSnS_4						1.16	<2			

§C5. Some Elemental Semiconductors

Substance	Heat of formation [kJ/mole (300K)]	Volume compressibility (10^{-10} m^2/N)	Static dielectric constant	Atomic magnetic susceptibility (10^{-6} CGS)	Index of refraction	Minimum room temperature energy gap (eV)	Mobility Electrons	Holes	Optical transition	Remarks
B	397.1			–6.7	3.4	1.55	10			
Se(gray)			6.6 (0.1 GHz)	– 22.1	2.5	1.5		5		$P3_121$(152)
Te				–39.5	3.3	0.33	1700	1200		Same

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Table III
SEMICONDUCTING PROPERTIES OF SELECTED MATERIALS

Substance	Minimum Energy Gap (eV) R.T.	Minimum Energy Gap (eV) 0 K	$\frac{dE_g}{dT}$ x 10^4 eV/°C	$\frac{dE_g}{dP}$ x 10^6 eV·cm²/kg	Density of States Electron Effective Mass m_{d_n} (m_o)	Electron Mobility and Temperature Dependence μ_n cm²/V·s	$-x$	Density of States Hole Effective Mass m_{d_p} (m_o)	Hole Mobility and Temperature Dependence μ_p cm²/V·s	$-x$
Si	1.107	1.153	−2.3	−2.0	1.1	1,900	2.6	0.56	500	2.3
Ge	0.67	0.744	−3.7	+7.3	0.55	3,800	1.66	0.3	1,820	2.33
αSn	0.08	0.094	−0.5		0.02	2,500	1.65	0.3	2,400	2.0
Te	0.33				0.68	1,100		0.19	560	
III–V Compounds										
AlAs	2.2	2.3				1,200			420	
AlSb	1.6	1.7	−3.5	−1.6	0.09	200	1.5	0.4	500	1.8
GaP	2.24	2.40	−5.4	−1.7	0.35	300	1.5	0.5	150	1.5
GaAs	1.35	1.53	−5.0	+9.4	0.068	9,000	1.0	0.5	500	2.1
GaSb	0.67	0.78	−3.5	+12	0.050	5,000	2.0	0.23	1,400	0.9
InP	1.27	1.41	−4.6	+4.6	0.067	5,000	2.0		200	2.4
InAs	0.36	0.43	−2.8	+8	0.022	33,000	1.2	0.41	460	2.3
InSb	0.165	0.23	−2.8	+15	0.014	78,000	1.6	0.4	750	2.1
II–VI Compounds										
ZnO	3.2		−9.5	+0.6	0.38	180	1.5			
ZnS	3.54		−5.3	+5.7		180			5(400°C)	
ZnSe	2.58	2.80	−7.2	+6		540			28	
ZnTe	2.26			+6		340			100	
CdO	2.5 ± .1		−6		0.1	120				
CdS	2.42		−5	+3.3	0.165	400		0.8		
CdSe	1.74	1.85	−4.6		0.13	650	1.0	0.6		
CdTe	1.44	1.56	−4.1	+8	0.14	1,200		0.35	50	
HgSe	0.30				0.030	20,000	2.0			
HgTe	0.15		−1		0.017	25,000		0.5	350	
Halite Structure Compounds										
PbS	0.37	0.28	+4		0.16	800		0.1	1,000	2.2
PbSe	0.26	0.16	+4		0.3	1,500		0.34	1,500	2.2
PbTe	0.25	0.19	+4	−7	0.21	1,600		0.14	750	2.2
Others										
ZnSb	0.50	0.56			0.15	10				1.5
CdSb	0.45	0.57	−5.4		0.15	300			2,000	1.5
Bi_2S_3	1.3					200			1,100	
Bi_2Se_3	0.27					600			675	
Bi_2Te_3	0.13		−0.95		0.58	1,200	1.68	1.07	510	1.95
Mg_2Si		0.77	−6.4		0.46	400	2.5		70	
Mg_2Ge		0.74	−9			280	2		110	
Mg_2Sn	0.21	0.33	−3.5		0.37	320			260	
Mg_3Sb_2		0.32				20			82	
Zn_3As_2	0.93					10	1.1		10	
Cd_3As_2	0.55				0.046	100,000	0.88			
GaSe	2.05		3.8						20	
GaTe	1.66	1.80	−3.6			14	−5			
InSe	1.8					900				
TlSe	0.57		−3.9		0.3	30		0.6	20	1.5
$CdSnAs_2$	0.23				0.05	25,000	1.7			
Ga_2Te_3	1.1	1.55	−4.8							
α-In_2Te_3	1.1	1.2			0.7				50	1.1
β-In_2Te_3	1.0								5	
$Hg_5In_2Te_8$	0.5								11,000	
SnO_2									78	

Table IV
BAND PROPERTIES OF SEMICONDUCTORS

PART A. DATA ON VALENCE BANDS OF SEMICONDUCTORS (ROOM TEMPERATURES)

Substance	Band Curvature Effective Mass: Heavy Holes	Light Holes	"Split-off" Band Holes	Energy Separation of "Split-off" Band (eV)	Measured (Light) Hole Mobility cm²/V·s
	(Expressed as fraction of free electron mass)				
Semiconductors with Valence Band Maximum at the Center of the Brillouin Zone ('Γ')					
Si	0.52	0.16	0.25	0.044	500
Ge	0.34	0.043	0.08	0.3	1,820
Sn	0.3				2,400
AlAs					
AlSb	0.4			0.7	550
GaP				0.13	100
GaAs	0.8	0.12	0.20	0.34	400
GaSb	0.23	0.06		0.7	1,400
InP				0.21	150
InAs	0.41	0.025	0.083	0.43	460
InSb	0.4	0.015		0.85	750
CdTe	0.35				50
HgTe	0.5				350

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Table IV
BAND PROPERTIES OF SEMICONDUCTORS (continued)

Semiconductors with Multiple Valence Band Maxima

Substance	Number of Equivalent Valleys and Direction	Band Curvature Effective Masses Longitudinal m_L	Transverse m_T	Anisotropy $K = m_L/m_T$	Measured (Light) Hole Mobility cm²/V·s
PbSe	4 "L" [111]	0.095	0.047	2.0	1,500
PbTe	4 "L" [111]	0.27	0.02	10	750
Bi_2Te_3	6	0.207	~0.045	4.5	515

PART B. DATA ON CONDUCTION BANDS OF SEMICONDUCTORS (Room Temperature Data)

Single Valley Semiconductors

Substance	Energy Gap (eV)	Effective Mass (m_o)	Mobility (cm²/V.s)	Comments
GaAs	1.35	0.067	8,500	3(or 6?) equivalent [100] valleys 0.36 eV above this maximum with a mobility of ~50
InP	1.27	0.067	5,000	3(or 6?) equivalent [100] valleys 0.4 eV above this minimum.
InAs	0.36	0.022	33,000	equivalent valleys ~1.0 eV above this minimum.
InSb	0.165	0.014	78,000	
CdTe	1.44	0.11	1,000	4(or 8?) equivalent [111] valleys 0.51 eV above this minimum.

Multivalley Semiconductors

Substance	Energy Gap	Number of Equivalent Valleys and Direction	Band Curvature Effective Mass Longitudinal m_L	Transverse m_T	Anisotropy $K = m_L/m_T$	Comments
Si	1.107	6 in [100] "Δ"	0.90	0.192	4.7	
Ge	0.67	4 in [111] at "L"	1.588	0.0815	19.5	
GaSb	0.67	as Ge (?)	~1.0	~0.2	~5	
PbSe	0.26	4 in [111] at "L"	0.085	0.05	1.7	
PbTe	0.25	4 in [111] at "L"	0.21	0.029	5.5	
Bi_2Te_3	0.13	6			~0.05	

Table V
RESISTIVITY OF SEMICONDUCTING MINERALS

Mineral	ρ (ohm · m)
Diamond (C)	2.7
Sulfides	
Argentite, Ag_2S	1.5 to 2.0 × 10^{-3}
Bismuthinite, Bi_2S_3	3 to 570
Bornite, $Fe_2S_3 \cdot nCu_2S$	1.6 to 6000 × 10^{-6}
Chalcocite, Cu_2S	80 to 100 × 10^{-6}
Chalcopyrite, $Fe_2S_3 \cdot Cu_2S$	150 to 9000 × 10^{-6}
Covellite, CuS	0.30 to 83 × 10^{-6}
Galena, PbS	6.8 × 10^{-6} to 9.0 × 10^{-2}
Haverite, MnS_2	10 to 20
Marcasite, FeS_2	1 to 150 × 10^{-3}
Metacinnabarite, 4HgS	2 × 10^{-6} to 1 × 10^{-3}
Millerite, NiS	2 to 4 × 10^{-7}
Molybdenite, MoS_2	0.12 to 7.5
Pentlandite, $(Fe, Ni)_9S_8$	1 to 11 × 10^{-6}
Pyrrhotite, Fe_7S_8	2 to 160 × 10^{-6}
Pyrite, FeS_2	1.2 to 600 × 10^{-3}
Sphalerite, ZnS	2.7 × 10^{-3} to 1.2 × 10^{4}
Antimony-sulfur compounds	
Berthierite, $FeSb_2S_4$	0.0083 to 2.0
Boulangerite, $Pb_5Sb_4S_{11}$	2 × 10^{3} to 4 × 10^{4}
Cylindrite, $Pb_3Sn_4Sb_2S_{14}$	2.5 to 60
Franckeite, $Pb_5Sn_3Sb_2S_{14}$	1.2 to 4
Hauchecornite, $Ni_9(Bi, Sb)_2S_8$	1 to 83 × 10^{-6}
Jamesonite, $Pb_4FeSb_6S_{14}$	0.020 to 0.15
Tetrahedrite, Cu_3SbS_3	0.30 to 30,000
Arsenic-sulfur compounds	
Arsenopyrite, FeAsS	20 to 300 × 10^{-6}
Cobaltite, CoAsS	6.5 to 130 × 10^{-3}
Enargite, Cu_3AsS_4	0.2 to 40 × 10^{-3}
Gersdorffite, NiAsS	1 to 160 × 10^{-6}
Glaucodote, (Co, Fe)AsS	5 to 100 × 10^{-6}
Antimonide	
Dyscrasite, Ag_3Sb	0.12 to 1.2 × 10^{-6}
Arsenides	
Allemonite, $SbAs_3$	70 to 60,000
Lollingite, $FeAs_2$	2 to 270 × 10^{-6}
Nicollite, NiAs	0.1 to 2 × 10^{-6}
Skutterudite, $CoAs_3$	1 to 400 × 10^{-6}
Smaltite, $CoAs_2$	1 to 12 × 10^{-6}
Tellurides	
Altaite, PbTe	20 to 200 × 10^{-6}
Calavarite, $AuTe_2$	6 to 12 × 10^{-6}
Coloradoite, HgTe	4 to 100 × 10^{-6}
Hessite, Ag_2Te	4 to 100 × 10^{-6}
Nagyagite, $Pb_6Au(S, Te)_{14}$	20 to 80 × 10^{-6}
Sylvanite, $AgAuTe_4$	4 to 20 × 10^{-6}
Oxides	
Braunite, Mn_2O_3	0.16 to 1.0
Cassiterite, SnO_2	4.5 × 10^{-4} to 10,000
Cuprite, Cu_2O	10 to 50
Hollandite, $(Ba, Na, K)Mn_8O_{16}$	2 to 100 × 10^{-3}
Ilmenite, $FeTiO_3$	0.001 to 4
Magnetite, Fe_3O_4	52 × 10^{-6}
Manganite, MnO · OH	0.018 to 0.5
Melaconite, CuO	6000
Psilomelane, $KMnO \cdot MnO_2 \cdot nH_2O$	0.04 to 6000
Pyrolusite, MnO_2	0.007 to 30
Rutile, TiO_2	29 to 910
Uraninite, UO	1.5 to 200

From Carmichael, R. S., ed., *Handbook of Physical Properties of Rocks,* Vol. I, CRC Press, 1982.

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REFERENCES

1. Beer, A. C., *Galvanomagnetic Effects in Semiconductors*, Academic Press, 1963.
2. Goryunova, N. A., *The Chemistry of Diamond-Like Semiconductors*, The MIT Press, 1965.
3. Abrikosov, N. Kh., Bankina, V. F., Poretskaya, L. E., Shelimova, L. E., and Skudnova, E. V., *Semiconducting II-VI, IV-VI, and V-VI Compounds*, Plenum Press, 1969.
4. Berger, L. I. and Prochukhan, V. D., *Ternary Diamond-Like Semiconductors*, Cons. Bureau/Plenum Press, 1969.
5. Shay, J. L. and Wernick, J. H., *Ternary Chalcopyrite Semiconductors: Growth, Electronic Properties, and Applications*, Pergamon Press, 1975.
6. Bergman, R., *Thermal Conductivity in Solids*, Clarendon, Oxford, 1976.
7. Handbook of Semiconductors, Vol. 1, Moss, T. S. and Paul, W., Eds., *Band Theory and Transport Properties*; Vol. 2, Moss, T. S. and Balkanski, M., Eds., *Optical Properties of Solids*; Vol. 3, Moss, T. S. and Keller, S. P., Eds., *Materials Properties and Preparation*, North Holland Publ. Co., 1980.
8. Böer, K. W., *Survey of Semiconductor Physics*, Van Nostrand Reinhold, 1990.
9. Rowe, D. M., Ed., *CRC Handbook of Thermoelectrics*, CRC Press, Boca Raton, FL, 1995.
10. Berger, L. I., *Semiconductor Materials*, CRC Press, Boca Raton, FL, 1997.
11. Glazov, V. M., Chizhevskaya, S. N., and Glagoleva, N. N., *Liquid Semiconductors*, Plenum Press, New York, 1969.
12. Phillips, J. C., *Bonds and Bands in Semiconductors*, Academic Press, New York, 1973.
13. Harrison, W. A., *Electronic Structure and the Properties of Solids*, Freeman Publ. House, San Francisco, 1980.
14. Balkanski, M., Ed., *Optical Properties of Solids*, North-Holland, Amsterdam, 1980.
15. *Landolt-Börnstein. Numerical Data and Functional Relationships in Science and Technology, New Series, Group III: Crystal and Solid State Physics*, Hellwege, K.-H., and Madelung, O., Eds., Volumes 17 and 22, Springer Verlag, Berlin, 1984 (and further).
16. Shklovskii, B. L., and Efros, A. L., *Electronic Processes in Doped Semiconductors*, Springer Verlag, Berlin, 1984.
17. Cohen, M. L., and Chelikowsky, J. R., *Electronic Structure and Optical Properties of Semiconductors*, Springer Verlag, New York, 1988.
18. Glass, J. T., Messier, R. F., and Fujimori, N., Eds., *Diamond, Silicon Carbide, and Related Wide Bandgap Semiconductors*, MRS Symposia Proc. 1652, Mater. Res. Soc., Pittsburgh, 1990.
19. Palik, E., Ed., *Handbook of Optical Constants of Solids II*, Academic Press, New York, 1991.
20. Reed, M., Ed., *Semiconductors and Semimetals*, Volume 35, Academic Press, Boston, 1992.
21. Haug, H., and Koch, S. W., *Quantum Theory of the Optical and Electronic Properties of Semiconductors*, 2nd Edition, World Scientific, Singapore, 1993.
22. Lockwood, D. J., Ed., *Proc. 22nd Intl. Conf. on the Physics of Semiconductors, Vancouver, 1994*, World Scientific, Singapore, 1994.
23. Morelli, D. T., Caillat, T., Fleurial, J.-P., Borschchevsky, A., Vandersande, J., Chen, B., and Uher, C., *Phys. Rev.*, B51, 9622, 1995.
24. Caillat, T., Borshchevsky, A., and Fleurial, J.-P., *J. Appl. Phys.*, 80, 4442, 1996.
25. Fleurial, J.-P., Caillat, T., and Borshchevsky, A., *Proc. XVI Intl. Conf. Thermoelectrics*, Dresden, Germany, August 26–29, 1997 (in print).
26. Borshchevsky A. et al., U.S. Patents 5,610,366 (March 1997) and 5,831,286 (March 1998).

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DIFFUSION DATA FOR SEMICONDUCTORS

B. L. Sharma

The diffusion coefficient D in many semiconductors may be expressed by an Arrhenius-type relation

$$D = D_o \exp(-Q/kT)$$

where D_o is a frequency factor, Q is the activation energy for diffusion, k is the Boltzmann constant, and T is the absolute temperature. This table lists D_o and Q for various diffusants in common semiconductors.

Abbreviations used in the table are

AES — Auger Electron Spectroscopy
DLTS — Deep Level Transient Spectroscopy
SEM — Scanning Electron Microscopy
SIMS — Secondary Ion Mass Spectrometry
D(c) — Concentration Dependent Diffusion Coefficient
D_{max} — Maximum Diffusion Coefficient

(f) — Fast Diffusion Component
(i) — Interstitial Diffusion Component
(s) — Slow Diffusion Component
(‖) — Parallel to *c* Direction
(⊥) — Perpendicular to *c* Direction

Semiconductor	Diffusant	Frequency factor, D_o (cm²/s)	Activation energy, Q (eV)	Temperature range (°C)	Method of measurement	Ref.
Si	H	6×10^{-1}	1.03	120—1207	Electrical and SIMS	1
	Li	2.5×10^{-3}	0.65	25—1350	Electrical	2
	Na	1.65×10^{-3}	0.72	530—800	Electrical and flame photometry	3
	K	1.1×10^{-3}	0.76	740—800	Electrical and flame photometry	3
	Cu	4×10^{-2}	1.0	800—1100	Radioactive	4
		4.7×10^{-3}	0.43 (i)	300—700	Radioactive	5
	Ag	2×10^{-3}	1.6	1100—1350	Radioactive	6
	Au	2.4×10^{-4}	0.39 (i)	700—1300	Radioactive	7
		2.75×10^{-3}	2.05 (s)			
	Be	($D \sim 10^{-7}$)	—	1050	Electrical	8
	Ca	($D \sim 6 \times 10^{-14}$)	—	1100	Electrical and SIMS	1
	Zn	1×10^{-1}	1.4	980—1270	Electrical	9
	B	2.46	3.59	1100—1250	Electrical	10
		2.4×10^{1}	3.87	840—1250	Electrical	11
	Al	1.38	3.41	1119—1390	Electrical	12
		1.8	3.2	1025—1175	Electrical	13
	Ga	3.74×10^{-1}	3.39	1143—1393	Electrical	12
		6×10^{1}	3.89	900—1050	Radioactive	14
	In	7.85×10^{-1}	3.63	1180—1389	Electrical	12
		1.94×10^{1}	3.86	1150—1242	Radioactive	15
	Tl	1.37	3.7	1244—1338	Electrical	12
		1.65×10^{1}	3.9	1105—1360	Electrical	16
	Sc	8×10^{-2}	3.2	1100—1250	Radioactive	1
	Ce	($D \sim 3.9 \times 10^{-13}$)	—	1050	SIMS	1
	Pr	2.5×10^{-7}	1.74	1100—1280	Electrical	1
	Pm	7.5×10^{-9}	1.2 (s)	730—1270	Radioactive	1
		4.2×10^{-12}	0.13 (f)			
	Er	2×10^{-3}	2.9	1100—1250	Radioactive	1
	Tm	8×10^{-3}	3.0	1100—1280	Radioactive	1
	Yb	2.8×10^{-5}	0.95	947—1097	Neutron activation	1
	Ti	1.45×10^{-2}	1.79	950—1200	DLTS	17
	C	3.3×10^{-1}	2.92	1070—1400	Radioactive	18
	Si (self)	1.54×10^{2}	4.65	855—1175	SIMS	19
		1.6×10^{3}	4.77	1200—1400	Radioactive	20
	Ge	3.5×10^{-1}	3.92	855—1000	Radioactive	21
		2.5×10^{3}	4.97	1030—1302	Radioactive	21
		7.55×10^{3}	5.08	1100—1300	SIMS	22
	Sn	3.2×10^{1}	4.25	1050—1294	Neutron activation	23

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DIFFUSION DATA FOR SEMICONDUCTORS (continued)

Semiconductor	Diffusant	Frequency factor, D_o (cm^2/s)	Activation energy, Q (eV)	Temperature range (°C)	Method of measurement	Ref.
	N	2.7×10^{-3}	2.8	800—1200	Out Diffusion; SIMS	1
	P	2.02×10^{1}	3.87	1100—1250	Electrical	10
		1.1	3.4	900—1200	Radioactive	24
		7.4×10^{-2}	3.3	1130—1405	Electrical	25
	As	6.0×10^{1}	4.2	950—1350	Radioactive	26
		6.55×10^{-2}	3.44	1167—1394	Electrical	27
		2.29×10^{1}	4.1	900—1250	Electrical	28
	Sb	1.29×10^{1}	3.98	1190—1398	Radioactive	29
		2.14×10^{-1}	3.65	1190—1405	Electrical	27
	Bi	1.03×10^{3}	4.64	1220—1380	Electrical	16
		1.08	3.85	1190—1394	Electrical	27
	Cr	1×10^{-2}	1	1100—1250	Radioactive	30
	Mo	($D \sim 2 \times 10^{-10}$)	—	1000	DLTS	1
	W	($D \sim 10^{-12}$)	—	1100	DLTS	1
	O	7×10^{-2}	2.44	700—1250	SIMS	31
		1.4×10^{-1}	2.53	700—1160	SIMS	32
	S	5.95×10^{-3}	1.83	975—1200	Radioactive	33
	Se	9.5×10^{-1}	2.6	1050—1250	Electrical	34
	Te	5×10^{-1}	3.34	900—1250	SIMS	1
	Mn	6.9×10^{-4}	0.63	900—1200	Radioactive	35
	Fe	1.3×10^{-3}	0.68	30—1250	Radioactive	36
	Co	2×10^{-3}	0.69	700—1300	Radioactive	37
	Ni	2×10^{-3}	0.47	800—1300	Radioactive	38
	Ru	($D \sim 5 \times 10^{-7}$ — 5×10^{-6})	—	1000—1280	Electrical	1
	Rh	($D \sim 10^{-6}$—10^{-4})	—	1000—1200	Electrical	39
	Pd	2.95×10^{-4}	0.22 (i)	702—1320	Nuclear Activation	1
	Pt	1.5×10^{2}	2.22	800—1000	Electrical	1
	Os	($D \sim 2 \times 10^{-6}$)	—	1280	Electrical	40
	Ir	4.2×10^{-2}	1.3	950—1250	Electrical	41
Ge	Li	1.3×10^{-3}	0.46	350—800	Electrical	42
		9.1×10^{-3}	0.57	800—500	Electrical	43
	Na	3.95×10^{-1}	2.03	700—850	Radioactive	44
	Cu	1.9×10^{-4}	0.18 (i)	750—900	Radioactive	45
		4×10^{-2}	0.99 (s)	600—700		
		4×10^{-3}	0.33 (i)	350—750	Radioactive	5
	Ag	4.4×10^{-2}	1.0 (i)	700—900	Radioactive	46, 47
		4×10^{-2}	2.23 (s)	800—900	Radioactive	48
	Au	2.25×10^{2}	2.5	600—900	Radioactive	49
	Be	5×10^{-1}	2.5	720—900	Electrical	50
	Mg	($D \sim 8 \times 10^{-9}$)	—	900	Electrical	1
	Zn	5	2.7	600—900	Radioactive and electrical	51
	Cd	1.75×10^{9}	4.4	760—915	Radioactive	52
	B	1.8×10^{9}	4.55	600—900	Electrical	51
	Al	1.0×10^{3}	3.45	554—905	SIMS	53
		$\sim 1.6 \times 10^{2}$	~3.24	750—850	Electrical	54
	Ga	1.4×10^{2}	3.35	554—916	SIMS	55
		3.4×10^{1}	3.1	600—900	Electrical	51
	In	1.8×10^{4}	3.67	554—919	SIMS	56
		3.3×10^{1}	3.02	700—855	Radioactive	57
	Tl	1.7×10^{3}	3.4	800—930	Radioactive	58
	Si	2.4×10^{-1}	2.9	650—900	(γ) resonance	59
	Ge (self)	2.48×10^{1}	3.14	549—891	Radioactive	60
		7.8	2.95	766—928	Radioactive	61
	Sn	1.7×10^{-2}	1.9	—	Radioactive	45
	P	3.3	2.5	600—900	Electrical	51

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Semiconductor	Diffusant	Frequency factor, D_o (cm^2/s)	Activation energy, Q (eV)	Temperature range (°C)	Method of measurement	Ref.
	As	2.1	2.39	700—900	Electrical	62
	Sb	3.2	2.41	700—855	Radioactive	57
		1.0×10^{1}	2.5	600—900	Radioactive and electrical	51
	Bi	3.3	2.57	650—850	—	63
	O	4×10^{-1}	2.08	—	Optical	64
	S	($D \sim 10^{-9}$)	—	920	—	65
	Se	($D \sim 10^{-10}$)	—	920	—	65
	Te	5.6	2.43	750—900	Radioactive	66
	Fe	1.3×10^{-1}	1.08	750—900	Radioactive	67
	Co	1.6×10^{-1}	1.12	750—850	Radioactive	47
	Ni	8×10^{-1}	0.9	670—900	Electrical	68
GaAs	Li	5.3×10^{-1}	1.0	250—500	Electrical and chemical	69
	Cu	3×10^{-2}	0.53	100—500	Radioactive	69
		6×10^{-2}	0.98	450—750	Ultrasonic	69
		1.5×10^{-3}	0.6	800—1000	Radioactive	69
	Ag	4×10^{-4}	0.8	500—1150	Radioactive	69
	Au	1×10^{-3}	1.0	740—1025	Radioactive	69
	Be	7.3×10^{-6}	1.2	800—990	Electrical	69
	Mg	4×10^{-5}	1.22	800—1200	Electrical	69
	Zn	1.5×10^{1}	2.49	600—980	Radioactive	69
		2.5×10^{-1}	3.0	750—1000	Radioactive	69
	Cd	1.3×10^{-3}	2.2	800—1100	Radioactive	69
		5×10^{-2}	2.43	868—1149	Radioactive	69
	Hg	($D \sim 5 \times 10^{-14}$)	—	1100	Radioactive	69
	Al	($D \sim 4 \times 10^{-18}$—10^{-14})	4.3	850—1100	AES	70
	Ga (self)	4×10^{-5}	2.6	1025—1100	Radioactive	69
		1×10^{7}	5.6	1125—1230	Radioactive	69
	In	($D \sim 7 \times 10^{-11}$)	—	1000	Radioactive	69
	C	($D \sim 1.04 \times 10^{-16}$)	—	825	SIMS	69
	Si	1.1×10^{-1}	2.5	850—1050	SIMS	69
	Ge	1.6×10^{-5}	2.06	650—850	SIMS	69
	Sn	6×10^{-4}	2.5	1060—1200	Radioactive	69
		1×10^{-5}	2	800—1000	Radioactive	69
	P	($D \sim 10^{-12}$—10^{-10})	2.9	800—1150	Reflectance measurements	69
	As (self)	7×10^{-1}	3.2	—	Radioactive	69
	Cr	2.04×10^{-6}	0.83 (f)	750—1000	SIMS	69
			1.7 (s)	700—900		
		7.9×10^{-3}	2.2	800—1100	Chemical analysis	69
	O	2×10^{-3}	1.1	700—900	Mass spectroscopy	69
	S	1.85×10^{-2}	2.6	1000—1300	Radioactive	69
		1.1×10^{1}	2.95	750—900	Electrical	69
	Se	3×10^{3}	4.16	1025—1200	Radioactive	69
	Te	1.5×10^{-1}	3.5	1000—1150	Radioactive	69
	Mn	6.5×10^{-1}	2.49	850—1100	Radioactive	69
	Fe	4.2×10^{-2}	1.8	850—1150	Radioactive	69
		2.2×10^{-3}	2.32	750—1050	Radioactive	69
	Co	5×10^{2}	2.5	800—1000	Radioactive	69
		1.2×10^{-1}	2.64	750—1050	Radioactive	69
	Tm	2.3×10^{-16}	1.0	800—1000	Radioactive	69
GaSb	Li	2.3×10^{-4}	1.9 (s)	527—657	Electrical and flame photometry	69
		1.2×10^{-1}	0.7 (f)	277—657		
	Cu	4.7×10^{-3}	0.9	470—650	Radioactive	69

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Semiconductor	Diffusant	Frequency factor, D_o (cm^2/s)	Activation energy, Q (eV)	Temperature range (°C)	Method of measurement	Ref.
	Zn	($D \sim 2 \times 10^{-13}$— 1×10^{-11})	2	510—600	Radioactive	69
	Cd	1.5×10^{-6}	0.72	640—800	Electrical	69
	Ga (self)	3.2×10^{3}	3.15	658—700	Radioactive	69
	In	1.2×10^{-7}	0.53	320—650	Radioactive	69
	Sn	2.4×10^{-5}	0.8	320—650	Radioactive	69
		1.3×10^{-5}	1.1	500—650	Radioactive	69
	Sb (self)	3.4×10^{4}	3.45	658—700	Radioactive	69
	Se	($D \sim 2.4 \times 10^{-13}$— 1.37×10^{-11})	—	400—500	Radioactive	69
	Te	3.8×10^{-4}	1.20	320—650	Radioactive	69
	Fe	5×10^{-2}	1.9 (I)	500—650	Radioactive	69
		5×10^{2}	2.3 (II)	500—650		
GaP	Ag	—	—	1000—1300	Radioactive	69
	Au	8	2.5 (I)	1050—1250	Radioactive	69
		20	2.4 (II)	1100—1250	Diffusion (I) A face and (II) B face	
	Be	($D_{max} \sim 2.4 \times 10^{-9}$— 8.5×10^{-8})	—	900—1000	Atomic absorption analysis	69
	Mg	5×10^{-5}	1.4	700—1050	Electrical	69
	Zn	1.0	2.1	700—1300	Radioactive	69
	Ge	—	—	900—1000	Radioactive	69
	Cr	6.2×10^{-4}	1.2	900—1130	Radioactive; ESR	69
	S	3.2×10^{3}	4.7	1120—1305	Radioactive	69
	Mn	2.1×10^{9}	4.7	$T < 950$	Radioactive; ESR	69
		1.1×10^{-6}	0.9	950—1130		
	Fe	1.6×10^{-1}	2.3	980—1180	Radioactive	69
	Co	2.8×10^{-3}	2.9	850—1100	Radioactive	69
InP	Cu	3.8×10^{-3}	0.69	600—900	Radioactive	69
	Ag	3.6×10^{-4}	0.59	500—900	Radioactive	69
	Au	1.32×10^{-5}	0.48	600—820	Radioactive	69
		1.37×10^{-4}	0.73	600—900	Radioactive	69
	Zn	1.6×10^{-8}	0.3	750—900	Electrical	69
		($D \sim 2 \times 10^{-9}$— 4×10^{-8})	—	700—900	Radioactive	69
	Cd	1.8	1.9	700—900	Radioactive	69
		1.1×10^{-7}	0.72	700—900	Electrical	69
		($D \sim 7 \times 10^{-13}$— 2×10^{-10})	—	450—650	Electrical	69
	In (self)	1×10^{5}	3.85	830—990	Radioactive	69
	Sn	($D \sim 3 \times 10^{-8}$)	—	550	Etching and cathodo-luminescence	69
	P (self)	7×10^{10}	5.65	900—1000	Radioactive	69
	Cr	—	—	600—900	Radioactive	69
	S	3.6×10^{-4}	1.94	585—708	Electrical	69
	Se	($D \sim 2 \times 10^{-8}$)	—	550	Cathodoluminescence	69
	Mn	—	2.9	650—750	SIMS	69
	Fe	3	2	600—950	Radioactive	69
		6.8×10^{5}	3.4	600—700	SIMS	69
	Co	9×10^{-1}	1.8	600—950	Radioactive	69
InAs	Cu	3.6×10^{-3}	0.52	342—875	Radioactive	69
		2.2×10^{-2}	0.54	525—890	Radioactive	69
	Ag	7.3×10^{-4}	0.26	450—900	Radioactive	69
	Au	5.8×10^{-3}	0.65	600—900	Radioactive	69
	Mg	1.98×10^{-6}	1.17	600—900	Electrical	69
	Zn	4.2×10^{-3}	0.96	600—900	Radioactive	69
		3.11×10^{-3}	1.17	600—900	Electrical	69

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Semiconductor	Diffusant	Frequency factor, D_o (cm^2/s)	Activation energy, Q (eV)	Temperature range (°C)	Method of measurement	Ref.
	Cd	7.4×10^{-4}	1.15	650—900	Radioactive	69
	Hg	1.45×10^{-5}	1.32	650—850	Radioactive	69
	In (self)	6×10^{5}	4.0	740—900	Radioactive	69
	Ge	3.74×10^{-6}	1.17	600—900	Electrical	69
	Sn	1.49×10^{-6}	1.17	600—900	Electrical	69
	As (self)	3×10^{7}	4.45	740—900	Radioactive	69
	S	6.78	2.2	600—900	Electrical	69
	Se	12.6	2.2	600—900	Electrical	69
	Te	3.43×10^{-5}	1.28	600—900	Electrical	69
InSb	Li	7×10^{-4}	0.28	0—210	Electrical	69
	Cu	9×10^{-4}	1.08	200—500	Radioactive	69
		3×10^{-5}	0.37	230—490	Radioactive	69
	Ag	1×10^{-7}	0.25	440—510	Radioactive	69
	Au	7×10^{-4}	0.32	140—510	Radioactive	69
	Zn	5×10^{-1}	1.35	362—508	Radioactive	69
		—	1.5	355—455	SIMS	69
	Cd	1×10^{-5}	1.1	250—500	Radioactive	69
		1.3×10^{-4}	1.2	360—500	Electrical	69
	Hg	4×10^{-6}	1.17	425—500	Radioactive	69
	In (self)	6×10^{-7}	1.45	400—500	Radioactive	69
		1.8×10^{13}	4.3	475—517	Radioactive	69
	Sn	5.5×10^{-8}	0.75	390—512	Radioactive	69
	Pb	($D \sim 2.7 \times 10^{-15}$)	—	500	Radioactive	71
	Sb (self)	5.35×10^{-4}	1.91	400—500	Radioactive	69
		3.1×10^{13}	4.3	475—517	Radioactive	69
	S	9×10^{-2}	1.4	360—500	Electrical	69
	Se	1.6	1.87	380—500	Electrical	69
	Te	1.7×10^{-7}	0.57	300—500	Radioactive	69
	Fe	1×10^{-7}	0.25	440—510	Radioactive	69
	Co	2.7×10^{-11}	0.39	420—500	Radioactive	69
AlAs	Ga	($D \sim 2 \times 10^{-18}$— 10^{-15})	3.6	850—1100	AES	70
	Zn	($D \sim 9 \times 10^{-11}$)	—	557	SEM	69
AlSb	Cu	3.5×10^{-3}	0.36	150—500	Radioactive	69
	Zn	3.3×10^{-1}	1.93	660—860	Radioactive	69
	Cd	D(c) $\sim 4 \times 10^{-12}$— 3×10^{-10}	—	900	Radioactive	69
	Al (self)	2	1.88	570—620	X-ray	69
	Sb (self)	1	1.7	570—620	X-ray	69
ZnS	Cu	2.6×10^{-3}	0.79	470—750	Radioactive	69
		4.3×10^{-4}	0.64	250—1200	Electroluminescence	69
		9.75×10^{-3}	1.04	400—800	Luminescence	69
	Au	1.75×10^{-4}	1.16	500—800	Radioactive	69
	Zn (self)	3×10^{-4}	1.5	925<T<940	Radioactive	69
		1.5×10^{4}	3.26	940<T<1030		
		1×10^{16}	6.5	1030<T<1075		
	Cd	($D \sim 10^{-10}$)	—	1100	Luminescence	72
	Al	5.69×10^{-4}	1.28	800—1000	Luminescence	69
	In	3×10^{1}	2.2	750—1000	Radioactive	69
	S (self)	2.16×10^{4}	3.15	600—800	Radioactive	69
		8×10^{-5}	2.2	740—1100	Radioactive	69
	Se	($D \sim 5 \times 10^{-13}$)	—	1070	X-ray microprobe	69
	Mn	2.3×10^{3}	2.46	500—800	Radioactive	69
ZnSe	Li	2.66×10^{-6}	0.49	950—980	Electrical	69
	Cu	1×10^{-4}	0.66	400—800	Luminescence	69
		1.7×10^{-5}	0.56	200—570	Radioactive	69
	Ag	2.2×10^{-2}	1.18	400—800	Luminescence	69

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DIFFUSION DATA FOR SEMICONDUCTORS (continued)

Semiconductor	Diffusant	Frequency factor, D_o (cm^2/s)	Activation energy, Q (eV)	Temperature range (°C)	Method of measurement	Ref.
	Zn (self)	9.8	3.0	760—1150	Radioactive	69
	Cd	6.39×10^{-4}	1.87	700—950	Photoluminescence	69
	Al	2.3×10^{-2}	1.8	800—1100	Luminescence	69
	Ga	1.81×10^{2}	3.0	900—1100	Luminescence	69
		—	1.3	700—850	Electron probe	69
	In	($D \sim 2 \times 10^{-12}$)	—	940	—	69
	S	($D \sim 8 \times 10^{-12}$)	—	1060	X-ray microprobe	69
	Se (self)	1.3×10^{1}	2.5	860—1020	Radioactive	69
		2.3×10^{-1}	2.7	1000—1050	Radioactive	69
	Ni	($D \sim 1.5 \times 10^{-8}$— 1.7×10^{-7})	—	740—910	Luminescence	69
ZnTe	Li	2.9×10^{-2}	1.22 (s)	400—700	Nuclear and chemical analysis	69
		1.7×10^{-4}	0.78 (f)			
	Zn (self)	2.34	2.56	760—860	Radioactive	69
		1.4×10^{1}	2.69	667—1077	Radioactive	69
	Al	—	2.0	700—1000	Electrical and optical	69
	In	4	1.96	1100—1300	Radioactive	69
	Te (self)	2×10^{4}	3.8	727—977	Radioactive	69
CdS	Li	3×10^{-6}	0.68	610—960	Microhardness	69
	Na	($D \sim 3 \times 10^{-7}$)	—	800	Radioactive	69
	Cu	1.5×10^{-3}	0.76	400—700	Radioactive	69
		1.2×10^{-2}	1.05	300—700	Ultrasonic	69
		8×10^{-5}	0.72	20—200	Electrical	69
	Ag	2.5×10^{1}	1.2 (s)	300—500	Radioactive	69
		2.4×10^{-1}	0.8 (f)			
	Au	2×10^{2}	1.8	500—800	Radioactive	69
	Zn	1.27×10^{-9}	0.86 (s)	720—1000	Radioactive	69
		1.22×10^{-8}	0.66 (f)			
	Cd (self)	3.4	2.0	700—1100	Radioactive	69
	Ga	—	—	667—967	Optical and microprobe	69
	In	6×10^{1}	2.3 (‖)	650—930	Radioactive, optical and microprobe	69
		1×10^{1}	2.03 (⊥)			
	P	6.5×10^{-4}	1.6	800—1100	Radioactive	69
	S (self)	1.6×10^{-2}	2.05	800—900	Radioactive	69
		—	2.4	750—1050	Radioactive	69
	Se	($D \sim 1.2 \times 10^{-9}$)	—	900	Radioactive	69
	Te	1.3×10^{-7}	10.4	700—1000	Radioactive	69
	Cl	($D \sim 3 \times 10^{-10}$)	—	800	Electrical	69
	I	($D \sim 5 \times 10^{-12}$)	—	1000	Radioactive	69
	Ni	6.75×10^{-3}	10.9	570—900	Luminescence	69
	Yb	($D \sim 1.3 \times 10^{-9}$)	—	960	Photoluminescence	69
CdSe	Ag	2×10^{-4}	0.53	22—400	Ultrasonic	69
	Cd (self)	1.6×10^{-3}	1.5	700—1000	Radioactive	69
		6.3×10^{-2}	1.25 (I)	600—900	Radioactive;	69
		4.12×10^{-2}	2.18 (II)	600—900	(I) saturated Cd and (II) saturated Se pressure	
	P	($D \sim 5.3 \times 10^{-12}$— 6×10^{-11})	—	900—1000	Radioactive	69
	Se (self)	2.6×10^{3}	1.55	700—1000	Radioactive; saturated Se pressure	69
CdTe	Li	($D \sim 1.5 \times 10^{-10}$)	—	300	Ion microprobe	69
	Cu	3.7×10^{-4}	0.67	97—300	Radioactive	69
		8.2×10^{-8}	0.64	290—350	Ion backscattering	69
	Ag	—	—	700—800	Electrical and photo-	

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DIFFUSION DATA FOR SEMICONDUCTORS (continued)

Semiconductor	Diffusant	Frequency factor, D_o (cm^2/s)	Activation energy, Q (eV)	Temperature range (°C)	Method of measurement	Ref.
					luminescence	69
	Au	6.7×10^{1}	2.0	600—1000	Radioactive	69
	Cd (self)	1.26	2.07	700—1000	Radioactive	69
		3.26×10^{2}	2.67 (I)	650—900	Radioactive;	69
		1.58×10^{1}	2.44 (II)		(I) saturated Cd and (II) saturated Te pressure	
	In	8×10^{-2}	1.61	650—1000	Radioactive	69
		$1.17 \times {}^{2}$	2.21 (I)	500—850	Radioactive; (I) saturated	
		6.48×10^{-4}	1.15 (II)		Cd and (II) saturated Te pressure	69
	Sn	8.3×10^{-2}	2.2	700—925	Radioactive	69
	P	($D \sim 1.2 \times 10^{-10}$)	—	900	Radioactive	69
	As	—	—	850	—	69
	O	5.6×10^{-9}	1.22	200—650	Mass spectrometry	69
		6.0×10^{-10}	0.29	650—900		
	Se	1.7×10^{-4}	1.35	700—1000	Radioactive	69
	Te (self)	8.54×10^{-7}	1.42 (I)	600—900	Radioactive; (I) saturated Cd and (II) saturated Te pressure	69
		1.66×10^{-4}	1.38 (II)	500—800		
	Cl	7.1×10^{-2}	1.6	520—800	Radioactive	69
	Fe	($D \sim 4 \times 10^{-8}$)	0.77	900	Radioactive	69
HgSe	Sb	6.3×10^{-5}	0.85	540—630	Radioactive	69
	Se (self)	—	—	200—400	Radioactive	69
HgTe	Ag	6×10^{-4}	0.8	250—350	Radioactive	69
	Zn	5×10^{-8}	0.6	250—350	Radioactive	69
	Cd	3.1×10^{-4}	0.66	250—350	Radioactive	69
	Hg (self)	2×10^{-8}	0.6	200—350	Radioactive	69
	In	6×10^{-6}	0.9	200—300	Radioactive	69
	Sn	1.72×10^{-6}	0.66 (s)	200—300	Radioactive	69
		1.8×10^{-3}	0.80 (f)			
	Te (self)	10^{-6}	1.4	200—400	Radioactive	69
	Mn	1.5×10^{-4}	1.3	250—350	Radioactive	69
PbS	Cu	4.6×10^{-4}	0.36	150—450	Electrical	69
		5×10^{-3}	0.31	100—400	Electrical	69
	Pb (self)	8.6×10^{-5}	1.52	500—800	Radioactive	69
	S (self)	6.8×10^{-5}	1.38	500—750	Radioactive	69
	Ni	1.78×10^{1}	0.95	200—500	Electrical	69
PbSe	Na	1.5×10^{1}	1.74 (s)	400—850	Radioactive	69
		5.6×10^{-6}	0.4 (f)			
	Cu	2×10^{-5}	0.31	93—520	Radioactive	69
	Ag	7.4×10^{-4}	0.35	400—850	Radioactive	69
	Pb (self)	4.98×10^{-6}	0.83	400—800	Radioactive	69
	Sb	3.4×10^{-1}	2.0	650—850	Radioactive	69
	Se (self)	2.1×10^{-5}	1.2	650—850	Radioactive	69
	Cl	1.6×10^{-8}	0.45	400—850	Radioactive	69
	Ni	($D \sim 1 \times 10^{-10}$)	—	700	Radioactive	69
PbTe	Na	1.7×10^{-1}	1.91	600—850	Radioactive	69
	Sn	3.1×10^{-2}	1.56	500—800	Radioactive	69
	Pb (self)	2.9×10^{-5}	0.6	250—500	Radioactive	69
	Sb	4.9×10^{-2}	1.54	500—800	Radioactive	69
	Te	2.7×10^{-6}	0.75	500—800	Radioactive	69
	Cl	($D > 2.3 \times 10^{-10}$)	—	700	Radioactive	69
	Ni	($D > 1 \times 10^{-6}$)	—	700	Radioactive	69

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DIFFUSION DATA FOR SEMICONDUCTORS (continued)

REFERENCES

1. N. A. Stolwijk and H. Bracht, in *Diffusion in Semiconductors and Non-Metallic Solids*, D. L. Beke, Ed., Springer-Verlag, Berlin, 1998, 2-1.
2. E. M. Pell, *Phys. Rev.*, 119, 1960; 119, 1014, 1960.
3. L. Svob, *Solid State Electron*, 10, 991, 1967.
4. B. I. Boltaks and I. I. Sosinov, *Zh. Tekh. Fiz.*, 28, 3, 1958.
5. R. N. Hall and J. N. Racette, *J. Appl. Phys.*, 35, 379, 1964.
6. B. I. Boltaks and Hsueh Shih-Yin, *Sov. Phys. Solid State*, 2, 2383, 1961.
7. W. R. Wilcox and T. J. LaChapelle, *J. Appl. Phys.*, 35, 240, 1964.
8. E. A. Taft and R. O. Carlson, *J. Electrochem. Soc.*, 117, 711, 1970.
9. R. Sh. Malkovich and N. A. Alimbarashvili, *Sov. Phys. Solid State*, 4, 1725, 1963.
10. R. N. Ghoshtagore, *Solid State Electron*, 15, 1113, 1972.
11. C. Hill, *Semiconductor Silicon 1981*, H. R. Huff, R. J. Kreiger, and Y. Takeishi, Eds., p. 988, *Electrochem. Soc.*, 1981.
12. R. N. Ghoshtagore, *Phys. Rev. B*, 3, 2507, 1971.
13. W. Rosnowski, *J. Electrochem. Soc.*, 125, 957, 1978.
14. J. S. Makris and B. J. Masters, *J. Appl. Phys.*, 42, 3750, 1971.
15. M. F. Millea, *J. Phys. Chem. Solids*, 27, 315, 1965 (refer Reference 2).
16. C. S. Fuller and J. A. Ditzenberger, *J. Appl. Phys.*, 27, 544, 1956.
17. S. Hocine and D. Mathiot, *Appl. Phys. Lett.*, 53, 1269, 1988.
18. R. C. Newman and J. Wakefield, *J. Phys. Chem. Solids*, 19, 230, 1961.
19. L. Kalinowski and R. Seguin, *Appl. Phys. Lett.*, 35, 211, 1979; *Appl. Phys. Lett.*, 36, 171, 1980.
20. R. F. Peart, *Phys. Stat. Sol.*, 15, K 119, 1966.
21. G. Hettich, H. Mehrer and K. Maler, *Inst. Phys. Conf. Ser.*, 46, 500, 1979.
22. M. Ogina, Y. Oana and M. Watanabe, *Phys. Stat. Sol. (a)*, 72, 535, 1982.
23. T. H. Yeh, S. M. Hu, and R. H. Kastl, *Appl. Phys.*, 39, 4266, 1968.
24. I. Franz and W. Langheinrich, *Solid State Electron*, 14, 835, 1971.
25. R. N. Ghoshtagore, *Hys. Rev. B*, 3, 389, 1971.
26. B. J. Masters and J. M. Fairfield, *J. Appl. Phys.*, 40, 2390, 1969.
27. R. N. Goshtagore, *Phys. Rev. B*, 3, 397, 1971.
28. R. S. Fair and J. C. C. Tsai, *J. Electrochem. Soc.*, 122, 1689, 1975.
29. J. J. Rohan, N. E. Pickering and J. Kennedy, *J. Electrochem. Soc.*, 106, 705, 1969.
30. W. Wuerker, K. Roy, and J. Hesse, *Matsr. Res. Bull.*, 9, 971, 1974.
31. J. C. Mikkelsen, Jr., *Appl. Phys. Lett.*, 40, 336, 1982.
32. S. Tang Lee and D. Nicols, *Appl. Phys. Lett.*, 47, 1001, 1985.
33. P. L. Gruzin, S. V. Zemskii, A. D. Bullkin, and N. M. Makarov, *Sov. Phys. Sem.*, 7, 1241, 1974.
34. N. S. Zhdanovich and Yu. I. Kozlov, *Svoistva Legir, Poluprovodn.*, V. S. Zemskov, Ed., Nauka, Moscow, 1977, 115-120; *Fiz Tekh. Poluprovod.*, 9, 1594, 1975.
35. D. Gilles, W. Bergholze, and W. Schroeter, *J. Appl. Phys.*, 59, 3590, 1986.
36. E. R. Weber, *Appl. Phys. A*, 30, 1, 1983.
37. E. R. Weber, Properties of Silicon, EMIS Datareviews Ser. No. 4, INSPEC Publications, 1988, 409-451.
38. M. K. Bakhadyrkhanov, S. Zainabidinov, and A. Khamidov, *Sov. Phys. Sem.*, 14, 243, 1980.
39. S. A. Azimov, M. S. Yunosov, F. K. Khatamkulov, and G. Nasyrov, *Poluprovod.*, N. Kh. Abrikosov and V. S. Zemskov, Eds., Nauka, Moscow, 1975, 21-23.
40. S. A. Azimov, M. S. Yunosov, G. Nurkuziev, and F. R. Karimov, *Sov. Phys. Sem.*, 12, 981, 1978.
41. S. A. Azimov, B. V. Umarov, and M. S. Yunusov, *Sov. Phys. Sem.*, 10, 842, 1976.
42. C. S. Fuller and J. A. Ditzenberger, *Phys. Rev.*, 91, 193, 1953.
43. B. Pratt and F. Friedman, *J. Appl. Phys.*, 37, 1893, 1966.
44. M. Stojic, V. Spiric, and D. Kostoski, *Inst. Phys. Conf. Ser.*, 31, 304, 1976.
45. B. I. Boltaks, *Diffusion in Semiconductors*, Inforsearch, London, 1963, 162.
46. A. A. Bugai, V. E. Kosenko, and E. G. Miselyuk, *Zh. Tekh. Fiz.*, 27, 67, 1957.
47. L. Y. Wei, *J. Phys. Chem. Solids*, 18, 162, 1961.
48. V. E. Kosenko, *Sov. Phys. Solid State*, 4, 42, 1962.
49. W. C. Dunlap, Jr., *Phys. Rev.*, 97, 614, 1955
50. Yu. I. Belyaev and V. A. Zhidkov, *Sov. Phys. Solid State*, 3, 133, 1961.
51. W. C. Dunlap, Jr. *Phys. Rev.*, 94, 1531, 1954.
52. V. E. Kosenko, *Sov. Phys. Solid State*, 1, 1481, 1960.
53. P. Dorner, W. Gust, A. Lodding, H. Odelius, B. Predel, and U. Roll, *Acta Metall.*, 30, 941, 1982.
54. W. Meer and D. Pommerrening, *Z. Agnew. Phys.*, 23, 369, 1967.
55. U. Sodervall, H. Odelius, A. Lodding, U. Roll, B. Predel, W. Gust, and P. Dorner, *Phil. Mag. A*, 54, 539, 1986.
56. P. Dorner, W. Gust, A. Lodding, H. Odelius, B. Predel, and U. Roll, *Z. Metalkd.*, 73, 325, 1982.

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57. P. V. Pavlov, *Sov. Phys. Solid State*, 8, 2377, 1967.
58. V. I. Tagirov and A. A. Kuliev, *Sov. Phys. Solid State*, 4, 196, 1962.
59. J. Raisanen, J. Hirvonen, and A. Anttila, *Solid State Electron.*, 24, 333, 1981.
60. C. Vogel, G. Hettich, and H. Mehrer, *J. Phys. C.*, 16, 6197, 1983.
61. H. Letaw, Jr., W. M. Portnoy, and L. Slifkin, *Phys. Rev.*, 102, 363, 1956.
62. W. Bosenberg, *Z. Naturforsch.*, 10a, 285, 1955.
63. V. M. Glazov and V. S. Zemskov, Physicochemical Principles of Semiconductor Doping, Israel Program for Scientific Translation, Jerusalem, 1968.
64. J. W. Corbett, R. S. McDonald, and G. D. Watkins, *J. Phys. Chem. Solids*, 25, 873, 1964.
65. W. W. Tyler, *J. Phys. Chem. Solids*, 8, 59, 1959.
66. V. D. Ignatkov and V. E. Kosenko, *Sov. Phys. Solid State*, 4, 1193, 1962.
67. A. A. Bugal, V. E. Kosenko, and E. G. Miseluk, *Zh. Tekh. Fiz.*, 27, 210, 1957.
68. F. van der Maesen and J. A. Brenkman, *Phillips Res. Rep.*, 9, 255, 1954.
69. M. B. Dutt and B. L. Sharma, in *Diffusion in Semiconductors and Non-Metallic Solids*, D. L. Beke, Ed., Springer-Verlag, Berlin, 1998, 3-1.
70. L. L. Chang and A. Koma, *Appl. Physics Lett.*, 29, 138, 1976.
71. D. L. Kendall, *Semiconductors and Semimetals*, Vol. 4, R. K. Willardson and A. C. Beer, Eds., Academic, 1968, 255.
72. H. J. Biter and F. Williams, *J. Luminescence*, 3, 395, 1971.

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CRYSTAL STRUCTURES AND LATTICE PARAMETERS OF ALLOTROPES OF THE ELEMENTS

H. W. King

The crystal structures of the allotropic forms of the elements are presented in terms of the Pearson symbol, the Strukturbericht designation, and the prototype of the structure. The temperatures of the phase transformations are listed in degrees Celsius and the pressures are in GPa. A consistent nomenclature is used, whereby all allotropes are labeled by Greek letters. The lattice parameters of the unit cells are given in nanometers (nm) and are considered to be accurate to ±2 in the last reported digit.

This compilation is restricted to changes in crystal structure that occur as a result of a change in temperature or pressure. Low-temperature structures are included for the diatomic and rare gases, which show many similarities with respect to the metallic elements. The elements identified with an asterisk (*) have polymorphic structures based on different molecular configurations. The crystal data given for these elements refer to the most stable structure at room temperature.

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Element	Temperature, °C	Pressure, GPa	Pearson symbol	Space group	Strukturbericht designation	Prototype	Lattice parameters, nm a	b	c	Comment, c/a or α or β
Ac	25	atm	cF4	Fm3m	A1	Cu	0.5311	···	···	···
Ag	25	atm	cF4	Fm3m	A1	Cu	0.40857	···	···	···
αAl	25	atm	cF4	Fm3m	A1	Cu	0.40496	···	···	···
βAl	25	>20.5	hP2	$P6_3/mmc$	A3	Mg	0.2693	···	0.4398	1.6331
α'Am	25	atm	hP4	$P6_3/mmc$	A3'	αLa	0.34681	···	1.1241	2*1.621
αAm	>769	atm	cF4	Fm3m	A1	Cu	0.4894	···	···	···
βAm	>1074	atm	cI2	Im3m	A2	W	?	···	···	···
γAm	25	>15	oC4	Cmcm	A20	αU	0.3063	0.5968	0.5169	···
αAr	<−189.35	atm	cF4	Fm3m	A1	Cu	0.5316	···	···	···
(βAr)	<−189.40	atm	hP2	$P6_3/mmc$	A3	Mg	0.3760	···	0.6141	1.633
αAs	25	atm	hR2	$R\bar{3}m$	A7	αAs	0.41319	···	···	α = 54.12°
εAs	>448	atm	oC8	Cmca	···	P (black)	0.362	1.085	0.448	···
Au	25	atm	cF4	Fm3m	A1	Cu	0.40782	···	···	···
βB	25	atm	hR105	R3m	···	βB	1.017	···	···	α = 65.12°
αBa	25	atm	cI2	$Im\bar{3}m$	A2	W	0.50227	···	···	···
βBa	25	>5.33	hP2	$P6_3/mmc$	A3	Mg	0.3901	···	0.6154	1.5775
γBa	25	>23	?	?	···	···	···	···	···	···
αBe	25	atm	hP2	$P6_3/mmc$	A3	Mg	0.22859	···	0.35845	1.5681
βBe	>1270	atm	cI2	Im3m	A2	W	0.25515	···	···	···
γBe	25	>9.3	?	···	···	···	···	···	···	···
αBi	25	atm	hR2	$R\bar{3}m$	A7	αAs	0.47460	···	···	α = 57.23°
βBi	25	>2.6	mC4	C2/m	···	βBi	0.6674	0.6117	0.3304	β = 110.33°
γBi	25	>3.0	mP3	?	···	···	0.605	0.42	0.465	β = 85.33°
σBi	25	>4.3	?	?	···	···	···	···	···	···
εBi	25	>6.5	?	?	···	···	···	···	···	···
ζBi	25	>9.0	cI2	Im3m	A2	W	0.3800	···	···	···
αBk	25	atm	hP4	$P6_3/mmc$	A3'	αLa	0.3416	···	1.1069	2*1.620
βBk	>977	atm	cF4	Fm3m	A1	Cu	0.4997	···	···	···
Br	<7.25	atm	oC8	Cmca	···	Cl	0.668	0.449	0.874	···
C (graphite)	25	atm	hP4	$P6_3/mmc$	A9	C (graphite)	0.24612	···	0.6709	2.7258
C (diamond)	25	>60	cF8	Fd3m	A4	C (diamond)	0.35669	···	···	···
C (hd)	25	HP	hP4	$P6_3/mmc$	···	C (hd)	0.2522	···	0.4119	1.633
αCa	25	atm	cF4	Fm3m	A1	Cu	0.55884	···	···	···
βCa	>443	atm	cI2	Im3m	A2	W	0.4480	···	···	···
γCa	25	>1.5	?	···	···	···	···	···	···	···
Cd	25	atm	hP2	$P6_3/mmc$	A3	Mg	0.29793	···	0.56196	1.8862
αCe	<−177	atm	cF4	Fm3m	A1	Cu	0.485	···	···	···
βCe	25	atm	hP4	$P6_3/mmc$	A3'	αLa	0.36810	···	1.1857	2*1.611
γCe	25	atm	cF4	Fm3m	A1	Cu	0.51610	···	···	···
δ-Ce	>726	atm	cI2	Im3m	A2	W	0.412	···	···	···
α'Ce	25	>5.4	oC4	Cmcm	A20	αU	0.3049	0.5998	0.5215	···
αCf	25	atm	hP4	$P6_3/mmc$	A3'	αLa	0.339	···	1.1015	2*1.625
βCf	>590	atm	cF4	Fm3m	A1	Cu	?	···	···	···
Cl	25	atm	oC8	Cmca	···	Cl	0.624	0.448	0.826	···
αCm	25	atm	hP4	$P6_3/mmc$	A3'	αLa	0.3496	···	1.1331	2*1.621
βCm	>1277	atm	cF4	Fm3m	A1	Cu	0.4382	···	···	···
εCo	25	atm	hP2	$P6_3/mmc$	A3	Mg	0.25071	···	0.40686	1.6228
αCo	>422	atm	cF4	Fm3m	A1	Cu	0.35447	···	···	···
αCr	25	atm	cI2	Im3m	A2	W	0.28848	···	···	···
α'Cr	25	HP	tI2	I4/mmm	···	α'Cr	0.2882	···	0.2887	1.002
αCs	25	atm	cI2	Im3m	A2	W	0.6141	···	···	···
βCs	25	>2.37	cF4	Fm3m	A1	Cu	0.6465	···	···	···
β'Cs	25	>4.22	cF4	Fm3m	A1	Cu	0.5800	···	···	···
γCs	25	>4.27	?	···	···	···	···	···	···	···
Cu	25	atm	cF4	Fm3m	A1	Cu	0.36146	···	···	···
α'Dy	<−187	atm	oC4	Cmcm	···	α'Dy	0.3595	0.6184	0.5678	···
αDy	25	atm	hP2	$P6_3/mmc$	A3	Mg	0.35915	···	0.56501	1.5732

PROPERTIES OF MAGNETIC MATERIALS

H. P. R. Frederikse

Glossary of Symbols

Quantity	Symbol	Units SI	Units emu
Magnetic field	H	A m^{-1}	Oe (oersted)
Magnetic induction	B	T (tesla)	G (gauss)
Magnetization	M	A m^{-1}	emu cm^{-3}
Spontaneous magnetization	M_s	A m^{-1}	emu cm^{-3}
Saturation magnetization	M_0	A m^{-1}	emu cm^{-3}
Magnetic flux	Φ	Wb (weber)	maxwell
Magnetic moment	m, μ	A m^2	erg/G
Coercive field	H_c	A m^{-1}	Oe
Remanence	B_r	T	G
Saturation magnetic polarization	J_s	T	G
Magnetic susceptibility	χ		
Magnetic permeability	μ	H m^{-1} (henry/meter)	
Magnetic permeability of free space	μ_0	H m^{-1}	
Saturation magnetostriction	λ ($\Delta l/l$)		
Curie temperature	T_C	K	K
Néel temperature	T_N	K	K

Magnetic moment $\mu = \gamma\hbar J = g\,\mu_B\,J$
where

γ = gyromagnetic ratio; J = angular momentum; g = spectroscopic splitting factor (~2)

μ_B = bohr magneton = $9.2741 \cdot 10^{-24}$ J/T = $9.2741 \cdot 10^{-21}$ erg/G

Earth's magnetic field H = 56 A m^{-1} = 0.7 Oe
For iron: $M_0 = 1.7 \cdot 10^6$ A m^{-1}; $B_r = 0.8 \cdot 10^6$ A m^{-1}
1 Oe = $(1000/4\pi)$ A m^{-1}; 1 G = 10^{-4} T; 1 emu cm^{-3} = 10^3 A m^{-1}
1 maxwell = 10^{-8} Wb
$\mu_0 = 4\pi \cdot 10^{-7}$ H m^{-1}

Relation Between Magnetic Induction and Magnetic Field

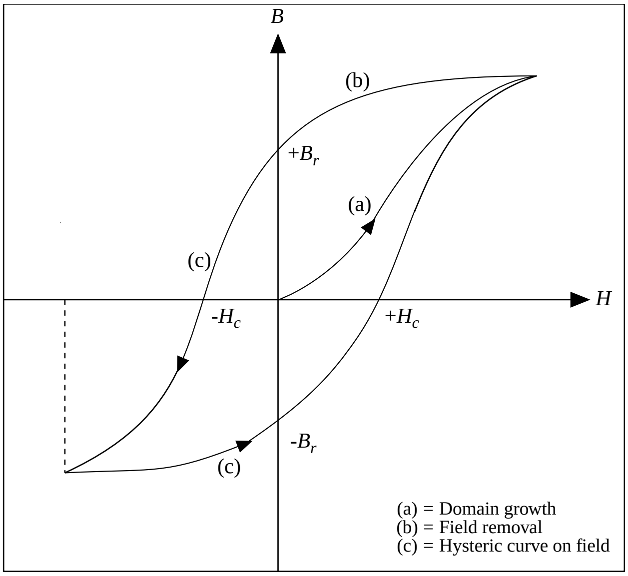

Figure 1. Typical curve representing the dependence of magnetic induction B on magnetic field H for a ferromagnetic material. When H is first applied, B follows curve a as the favorably oriented magnetic domains grow. This curve flattens as saturation is approached. When H is then reduced, B follows curve **b**, but retains a finite value (the remanence B_r) at $H = 0$. In order to demagnetize the material, a negative field $-H_c$ (where H_c is called the coercive field or coercivity) must be applied. As H is further decreased and then increased to complete the cycle (curve c), a hysteresis loop is obtained. The area within this loop is a measure of the energy loss per cycle for a unit volume of the material.

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Relation Between Magnetic Induction and Magnetic Field (continued)

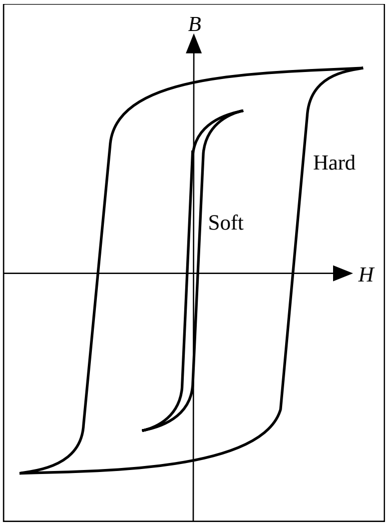

Figure 2. Schematic curve illustrating the *B* vs. *H* dependence for hard and soft magnetic materials. Hard materials have a larger remanence and coercive field, and a correspondingly large hysteresis loss.

REFERENCE

Ralls, K.M., Courtney, T.H., and Wulff, J., *Introduction to Materials Science and Engineering,* J. Wiley & Sons, New York, 1976, p. 577, 582. With permission.

Magnetic Susceptibility of the Elements

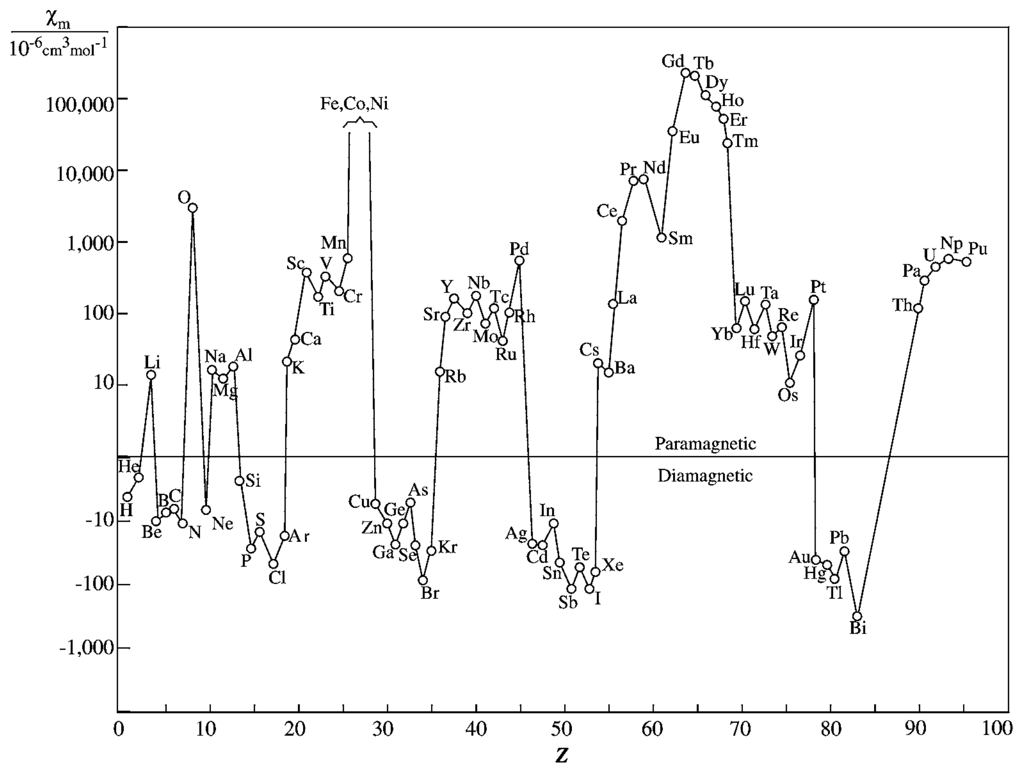

Figure 3. Molar susceptibility of the elements at room temperature (cgs units of 10^{-6} cm^3/mol). Values are not available for *Z*=9, 61, and 84–89; Fe, Co, and Ni (*Z* = 26–28) are ferromagnetic. Data taken from the table "Magnetic Susceptibility of the Elements and Inorganic Compounds" in Section 4.

REFERENCE

Gray, D.E., Ed., *American Institute of Physics Handbook, Third Edition,* McGraw Hill, New York, 1972, p. 5-224. With permission.

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PROPERTIES OF MAGNETIC MATERIALS (continued)

Ground State of Ions with Partly Filled *d* or *f* Shells

Z	Element	n	S	L	J	Gr. state	p_{calc}[a]	p_{calc}[b]	p_{meas}
22	Ti^{3+}	1	1/2	2	3/2	$^2D_{3/2}$	1.73	1.55	1.8
23	V^{4+}	1	1/2	2	3/2	$^2D_{3/2}$	1.73	1.55	1.8
23	V^{3+}	2	1	3	2	$^3F_2$	2.83	1.63	2.8
23	V^{2+}	3	3/2	3	3/2	$^4F_{3/2}$	3.87	0.77	3.8
24	Cr^{3+}	3	3/2	3	3/2	$^4F_{3/2}$	3.87	0.77	3.7
25	Mn^{4+}	3	3/2	3	3/2	$^4F_{3/2}$	3.87	0.77	4.0
24	Cr^{2+}	4	2	2	0	$^5D_0$	4.90	0	4.9
25	Mn^{3+}	4	2	2	0	$^5D_0$	4.90	0	5.0
25	Mn^{2+}	5	5/2	0	5/2	$^6S_{5/2}$	5.92	5.92	5.9
26	Fe^{3+}	5	5/2	0	5/2	$^6S_{5/2}$	5.92	5.92	5.9
26	Fe^{2+}	6	2	2	4	$^5D_4$	4.90	6.70	5.4
27	Co^{2+}	7	3/2	3	9/2	$^4F_{9/2}$	3.87	6.54	4.8
28	Ni^{2+}	8	1	3	4	$^3F_4$	2.83	5.59	3.2
29	Cu^{2+}	9	1/2	2	5/2	$^2D_{5/2}$	1.73	3.55	1.9
							p_{calc}[c]		
58	Ce^{3+}	1	1/2	3	5/2	$^2F_{5/2}$	2.54		2.4
59	Pr^{3+}	2	1	5	4	$^3H_4$	3.58		3.5
60	Nd^{3+}	3	3/2	6	9/2	$^4I_{9/2}$	3.62		3.5
61	Pm^{3+}	4	2	6	4	$^5I_4$	2.68		
62	Sm^{3+}	5	5/2	5	5/2	$^6H_{5/2}$	0.84		1.5
63	Eu^{3+}	6	3	3	0	$^7F_0$	0.0		3.4
64	Gd^{3+}	7	7/2	0	7/2	$^8S_{7/2}$	7.94		8.0
65	Tb^{3+}	8	3	3	6	$^7F_6$	9.72		9.5
66	Dy^{3+}	9	5/2	5	15/2	$^6H_{15/2}$	10.63		10.6
67	Ho^{3+}	10	2	6	8	$^5I_8$	10.60		10.4
68	Er^{3+}	11	3/2	6	15/2	$^4I_{15/2}$	9.59		9.5
69	Tm^{3+}	12	1	5	6	$^3H_6$	7.57		7.3
70	Yb^{3+}	13	1/2	3	7/2	$^2F_{7/2}$	4.54		4.5

[a] $p_{calc} = 2[S(S+1)]^{1/2}$
[b] $p_{calc} = 2[J(J+1)]^{1/2}$
[c] $p_{calc} = g[J(J+1)]^{1/2}$

REFERENCES

1. Jiles, D., *Magnetism and Magnetic Materials*, Chapman & Hall, London, 1991, p. 243.
2. Kittel, C., *Introduction to Solid State Physics, 6th Edition*, J. Wiley & Sons, New York, 1986, pp. 405—406.
3. Ashcroft, N.W. and Mermin, N.D., *Solid State Physics,* Holt, Rinehart, and Winston, New York, 1976, p. 652.

Ferro- and Antiferromagnetic Elements

M_0 is the saturation magnetization at $T = 0$ K
n_B is the number of Bohr magnetons per atom
T_C is the Curie temperature
T_N is the Néel temperature

	M_0/gauss	n_B	T_C/K	T_N/K	Comments
Fe	1752	2.22	1043		
Co	1446	1.72	1388		
Ni	510	0.62	627		
Cr				311	
Mn				100	
Ce				12.5	c-Axis antiferromagnetic
Nd				19.2	Basal plane modulation on hexagonal sites

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Ferro- and Antiferromagnetic Elements (continued)

	M_0/gauss	n_B	T_C/K	T_N/K	Comments
				7.8	Cubic sites order (periodicity different from high-T phase)
Sm				106	Ordering on hexagonal sites
				13.8	Cubic site order
Eu				90.5	Spiral along cube axis
Gd	1980	7	293		
Tb		9	220		Basal plane ferromagnet
				230.2	Basal plane spiral
Dy		10	87		Basal plane ferromagnet
				176	Basal plane spiral
Ho		10	20		Bunched cone structure
				133	Basal plane spiral
Er		9	32		c-Axis ferrimagnetic cone structure
				80	c-Axis modulated structure
Tm		7	32		c-Axis ferrimagnetic cone structure
				56	c-Axis modulated structure

REFERENCES

1. Ashcroft, N.W., and Mermin, N.D., *Solid State Physics*, Holt, Rinehart, and Winston, New York, 1976, p.652.
2. Gschneidner, K.A., and Eyring, L., *Handbook on the Physics and Chemistry of Rare Earths*, North Holland Publishing Co., Amsterdam, 1978.

Selected Ferromagnetic Compounds

M_0 is the saturation magnetization at T = 293 K
T_C is the Curie temperature

Compound	M_0/gauss	T_C/K	Crystal system
MnB	152	578	orthorh(FeB)
MnAs	670	318	hex(FeB)
MnBi	620	630	hex(FeB)
MnSb	710	587	hex(FeB)
M_4N	183	743	
MnSi		34	cub(FeSi)
CrTe	247	339	hex(NiAs)
$CrBr_3$	270	37	hex(BiI_3)
CrI_3		68	hex(BiI_3)
CrO_2	515	386	tetr(TiO_2)
EuO	1910*	77	cub
EuS	1184*	16.5	cub
$GdCl_3$	550*	2.2	orthorh
FeB		598	orthorh
Fe_2B		1043	tetr ($CuAl_2$)
$FeBe_5$		75	cub($MgCu_2$)
Fe_3C		483	orthorh
FeP		215	orthorh (MnP)

* At T = 0 K

REFERENCES

1. Kittel, C., *Introduction to Solid State Physics, 6th Edition*, J. Wiley & Sons, New York, 1986.
2. Ashcroft, N.W., and Mermin, N.D., *Solid State Physics*, Holt, Rinehart, and Winston, New York, 1976.

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PROPERTIES OF MAGNETIC MATERIALS (continued)

Magnetic Properties of High-Permeability Metals and Alloys (Soft)

μ_i is the initial permeability
μ_m is the maximum permeability
H_c is the coercive force
J_s is the saturation polarization
W_H is the hysteresis loss per cycle
T_C is the Curie temperature

Material	Composition (mass %)	μ_i/μ_0	μ_m/μ_0	H_c/A m^{-1}	J_s/T	W_H/J m^{-3}	T_C/K
Iron	Commercial 99Fe	200	6000	70	2.16	500	1043
Iron	Pure 99.9Fe	25000	350000	0.8	2.16	60	1043
Silicon-iron	96Fe-4Si	500	7000	40	1.95	50-150	1008
Silicon-iron (110) [001]	97Fe-3Si	9000	40000	12	2.01	35-140	1015
Silicon-iron {100} <100>	97Fe-3Si		100000	6	2.01		1015
Mild steel	Fe-0.1C-0.1Si-0.4Mn	800	1100	200			
Hypernik	50Fe-50Ni	4000	70000	4	1.60	22	753
Deltamax {100} <100>	50Fe-50Ni	500	200000	16	1.55		773
Isoperm {100} <100>	50Fe-50Ni	90	100	480	1.60		
78 Permalloy	78Ni-22Fe	4000	100000	4	1.05	50	651
Supermalloy	79Ni-16Fe-5Mo	100000	1000000	0.15	0.79	2	673
Mumetal	77Ni-16Fe-5Cu-2Cr	20000	100000	4	0.75	20	673
Hyperco	64Fe-35Co-0.5Cr	650	10000	80	2.42	300	1243
Permendur	50Fe-50Co	500	6000	160	2.46	1200	1253
2V-Permendur	49Fe-49Co-2V	800	4000	160	2.45	600	1253
Supermendur	49Fe-49Co-2V		60000	16	2.40	1150	1253
25Perminvar	45Ni-30Fe-25Co	400	2000	100	1.55		
7Perminvar	70Ni-23Fe-7Co	850	4000	50	1.25		
Perminvar (magnet. annealed)	43Ni-34Fe-23Co		400000	2.4	1.50		
Alfenol (or Alperm)	84Fe-16Al	3000	55000	3.2	0.8		723
Alfer	87Fe-13Al	700	3700	53	1.20		673
Aluminum-Iron	96.5Fe-3.5Al	500	19000	24	1.90		
Sendust	85Fe-10Si-5Al	36000	120000	1.6	0.89		753

REFERENCES

1. McCurrie, R.A., *Structure and Properties of Ferromagnetic Materials*, Academic Press, London, 1994, p. 42.
2. Gray, D.E., Ed., *American Institute of Physics Handbook, Third Edition*, McGraw Hill, New York, 1972, p. 5-224.

Applications of High-Permeability Materials

Applications	Requirements
POWER APPLICATIONS	
Distribution and power transformers	Low core losses, high permeability, high saturation magnetic polarization
High-quality motors and generators, stators and armatures, switched-mode power supplies	
INSTRUMENT TRANSFORMERS	
Audiofrequency transformers	Low core losses, high permeability, high magnetic polarization
Pulse transformers	High permeability

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PROPERTIES OF MAGNETIC MATERIALS (continued)

Applications of High-Permeability Materials (continued)

Applications	Requirements
CORES FOR INDUCTOR COILS	
Audiofrequency	Low hysteresis, high permeability
Carrier frequency	Very low hysteresis and eddy current loss
Radiofrequency	High permeability at low fields
MISCELLANEOUS	
Relays, switches; Earth leakage circuit	High permeability, low remanence, low coercivity
Magnetic shielding	Low core loss for AC applications
Magnetic recording heads	High initial permeability, low or zero remanence
Magnetic amplifiers; Saturable reactors; Saturable transformers; Transformer cores	Rectangular hysteresis loops, low hysteresis loss
Magnetic shunts for temperature compensation in magnetic circuits	Low Curie temperature, appropriate decrease in permeability with increase in temperature
Electromagnets in indicating instruments, fire detection, quartz watches, electromechanical devices	High permeability, high saturation magnetic polarization
Magnetic yokes in permanent magnet devices, such as lifting and holding magnets, loudspeakers	High permeability, high saturation magnetic polarization

REFERENCE

McCurrie, R.A., *Structure and Properties of Ferromagnetic Materials*, Academic Press, London, 1994. With permission.

Saturation Magnetostriction of Selected Materials

The tabulated parameter λ_s is related to the fractional change in length $\Delta l/l$ by $\Delta l/l = (3/2)\lambda_s(\cos^2\theta - 1/3)$, where θ is the angle of rotation.

Material	$\lambda_s \times 10^6$
Iron	-7
Fe - 3.2% Si	+9
Nickel	-33
Cobalt	-62
45 Permalloy, 45% Ni - 55% Fe	+27
Permalloy, 82% Ni - 18% Fe	0
Permendur, 49% Co - 49% Fe - 2% V	+70
Alfer, 87% Fe - 13% Al	+30
Magnetite, Fe_3O_4	+40
Cobalt ferrite, $CoFe_2O_4$	-110
$SmFe_2$	-1560
$TbFe_2$	+1753
$Tb_{0.3}Dy_{0.7}Fe_{1.93}$ (Terfenol D)	+2000
$Fe_{66}Co_{18}B_{15}Si$ (amorphous)	+35
$Co_{72}Fe_3B_6A_{l3}$ (amorphous)	0

REFERENCE

McCurrie, R.A., *Structure and Properties of Ferromagnetic Materials*, Academic Press, London, 1994, p. 91; additional data provided by A.E. Clark, Adelphi, MD.

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Properties of Various Permanent Magnetic Materials (Hard)

B_r is the remanence
$_BH_c$ is the flux coercivity
$_iH_c$ is the intrinsic coercivity
$(BH)_{max}$ is the maximum energy product
T_C is the Curie temperature
T_{max} is the maximum operating temperature

Composition	B_r/T	$_BH_c/10^3$ A m^{-1}	$_iH_c/10^3$ A m^{-1}	$(BH)_{max}$/ kJ m^{-3}	T_C/°C	T_{max}/°C
Alnico1 20Ni;12Al;5Co	0.72		35	25		
Alnico2 17Ni;10Al;12.5Co;6Cu	0.72		40-50	13-14		
Alnico3 24-30Ni;12-14Al;0-3Cu	0.5-0.6		40-54	10		
Alnico4 21-28Ni;11-13Al;3-5Co;2-4Cu	0.55-0.75		36-56	11-12		
Alnico5 14Ni;8Al;24Co;3Cu	1.25	53	54	40	850	520
Alnico6 16Ni;8Al;24Co;3Cu;2Ti	1.05		75	52		
Alnico8 15Ni;7Al;35Co;4Cu;5Ti	0.83	1.6	160	45		
Alnico9 15Ni;7Al;35Co;4Cu;5Ti	1.10	1.45	1.45	75	850	520
Alnico12 13.5Ni;8Al;24.5Co;2Nb	1.20		64	76.8		
$BaFe_{12}O_{19}$ (Ferroxdur)	0.4	1.6	192	29	450	400
$SrFe_{12}O_{19}$	0.4	2.95	3.3	30	450	400
$LaCo_5$	0.91			164	567	
$CeCo_5$	0.77			117	380	
$PrCo_5$	1.20			286	620	
$NdCo_5$	1.22			295	637	
$SmCo_5$	1.00	7.9	696	196	700	250
$Sm(Co_{0.76}Fe_{0.10}Cu_{0.14})_{6.8}$	1.04	4.8	5	212	800	300
$Sm(Co_{0.65}Fe_{0.28}Cu_{0.05}Zr_{0.02})_{7.7}$	1.2	10	16	264	800	300
$Nd_2Fe_{14}B$ sintered	1.22	8.4	1120	280	300	100
Fe;52Co;14V (Vicalloy II)	1.0	42		28	700	500
Fe;24Cr;15Co;3Mo (anisotropic)	1.54	67		76	630	500
Fe;28Cr;10.5Co (Chromindur II)	0.98	32		16	630	500
Fe;23Cr;15Co;3V;2Ti	1.35	4		44	630	500
Cu;20Ni;20Fe (Cunife)	0.55	4		12	410	350
Cu;21Ni;29Fe (Cunico)	0.34	0.5		8		
Pt;23Co	0.64	4		76	480	350
Mn;29.5Al;0.5C (anisotropic)	0.61	2.16	2.4	56	300	120

REFERENCES

1. McCurrie, R.A., *Structure and Properties of Ferromagnetic Materials*, Academic Press, London, 1994, p. 204.
2. Gray, D.E., Ed., *American Institute of Physics Handbook, Third Edition*, McGraw Hill, New York, 1972, p. 5-165.
3. Jiles, D., *Magnetism and Magnetic Materials*, Chapman & Hall, London, 1991.

Selected Ferrites

J_s is the saturation magnetic polarization
T_C is the Curie temperature
ΔH is the line width

Material	J_s/T	T_C/°C	ΔH/ kA m^{-1}	Applications
Spinels				
γ-Fe_2O_3	0.52	575		
Fe_3O_4	0.60	585		
$NiFe_2O_4$	0.34	575	350	Microwave devices
$MgFe_2O_4$	0.14	440	70	
$NiZnFe_2O_4$	0.50	375	120	Transformer cores
$MnFe_2O_4$	0.50	300	50	Microwave devices

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Selected Ferrites (continued)

Material	J_s/T	T_C/°C	ΔH/ kA m^{-1}	Applications
$NiCoFe_2O_4$	0.31	590	140	Microwave devices
$NiCoAlFe_2O_4$	0.15	450	330	Microwave devices
$NiAl_{0.35}Fe_{1.65}O_4$	0.12	430	67	Microwave devices
$NiAlFe_2O_4$	0.05	1860	32	Microwave devices
$Mg_{0.9}Mn_{0.1}Fe_2O_4$	0.25	290	56	Microwave devices
$Ni_{0.5}Zn_{0.5}Al_{0.8}Fe_{1.2}O_4$	0.14		17	Microwave devices
$CuFe_2O_4$	0.17	455		Electromechanical transducers
$CoFe_2O_4$	0.53	520		
$LiFe_5O_8$	0.39	670		Microwave devices
Garnets				
$Y_3Fe_5O_{12}$	0.178	280	55	Microwave devices
$Y_3Fe_5O_{12}$ (single crys.)	0.178	292	0.5	Microwave devices
$(Y,Al)_3Fe_5O_{12}$	0.12	250	80	Microwave devices
$(Y,Gd)_3Fe_5O_{12}$	0.06	250	150	Microwave devices
$Sm_3Fe_5O_{12}$	0.170	305		Microwave devices
$Eu_3Fe_5O_{12}$	0.116	293		Microwave devices
$GdFe_5O_{12}$	0.017	291		Microwave devices
Hexagonal crystals				
$BaFe_{12}O_{19}$	0.45	430	1.5	Permanent magnets
$Ba_3Co_2Fe_{24}O_{41}$	0.34	470	12	Microwave devices
$Ba_2Zn_2Fe_{12}O_{22}$	0.28	130	25	Microwave devices
$Ba_3Co_{1.35}Zn_{0.65}Fe_{24}O_{41}$		390	16	Microwave devices
$Ba_2Ni_2Fe_{12}O_{22}$	0.16	500	8	Microwave devices
$SrFe_{12}O_{19}$	0.4	450		Permanent magnets

REFERENCE

McCurrie, R.A., *Structure and Properties of Ferromagnetic Materials*, Academic Press, London, 1994.

Spinel Structure (AB_2O_4)

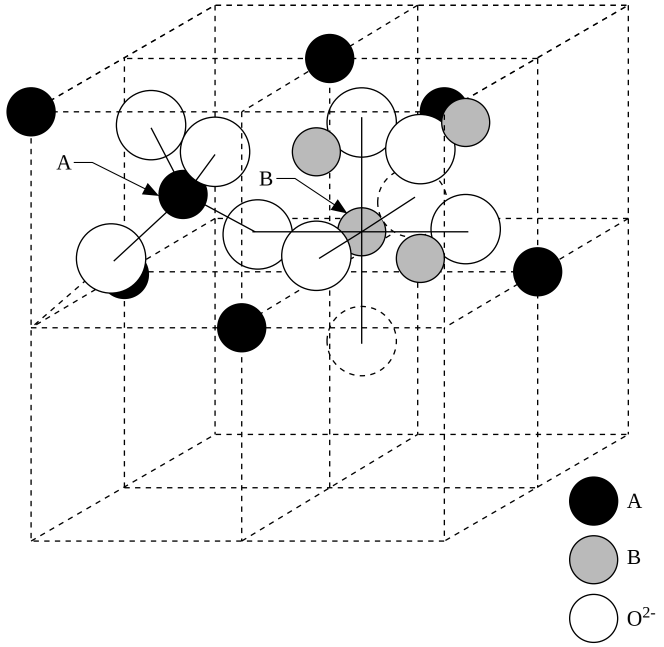

Figure 4. Arrangement of metal ions in the two octants A and B, showing tetrahedrally (A) and octahedrally (B) coordinated sites. (Reprinted from McCurrie, R.A., *Ferromagnetic Materials*, Academic Press, London, 1994. With permission.)

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Selected Antiferromagnetic Solids

T_N is the Néel temperature

Material	Structure	T_N/K
Binary oxides		
MnO	cub(fcc)	122
FeO	cub(fcc)	198
CoO	cub(fcc)	291
NiO	cub(fcc)	525
α-Mn_2O_3	cub	90
CuO	monocl	230
UO_2	cub	30.8
Er_2O_3	cub	3.4
Gd_2O_3	cub	1.6
Perovskites		
$LaCrO_3$	orth	282
$LaMnO_3$	orth	100
$LaFeO_3$	orth	750
$NdCrO_3$	orth	224
$NdFeO_3$	orth	760
$YbCrO_3$	orth	118
$CaMnO_3$	cub	110
$EuTiO_3$	cub	5.3
$YCrO_3$	orth	141
$BiFeO_3$	cub*	673
$KCoF_3$	cub	125
$KMnF_3$	cub*	88.3
$KFeF_3$	cub	115
$KNiF_3$	cub	275
$NaMnF_3$	cub*	60
$NaNiF_3$	orth	149
$RbMnF_3$	cub	82
Spinels		
Co_3O_4	cub	40
$NiCr_2O_4$	tetr	65
$ZnCr_2O_4$	cub	15
$ZnFe_2O_4$	cub	9
$GeFe_2O_4$	cub	10
MgV_2O_4	cub	45
$MnGa_2O_4$	cub	33
NiAs and related structures		
CrAs	orth	300
CrSb	hex	705-723
CrSe	hex	300
MnTe	hex	320-323
NiS	hex	263
CrS	monocl	460
Rutile and related structures		
CoF_2	tetr	38
CrF_2	monocl	53
FeF_2	tetr	79
MnF_2	tetr	67
NiF_2	tetr	83
$CrCl_2$	orth	20
MnO_2	tetr	84
FeOF	tetr	315
Corundum and related structures		
Cr_2O_3	rhomb	318
α-Fe_2O_3	rhomb	948
$FeTiO_3$	rhomb	68
$MnTiO_3$	rhomb	41
$CoTiO_3$	rhomb	38
VF_3 and related structures		
CoF_3	rhomb	460
CrF_3	rhomb	80
FeF_3	rhomb	394
MnF_3	monocl	43
MoF_3	rhomb	185
Miscellaneous		
K_2NiF_4	tetr	97
MnI_2	hex	3.4
$CoUO_4$	orth	12
$CaMn_2O_4$	orth	225
CrN	cub*	273
CeC_2	tetr	33
FeSn	hex	373
Mn_2P	hex	103

* Distorted.

REFERENCES

1. Gray, D.E., Ed., *American Institute of Physics Handbook, Third Edition*, McGraw Hill, New York, 1972, p. 5-168 to 183.
2. Kittel, C., *Introduction to Solid State Physics, 6th Edition*, J. Wiley & Sons, New York, 1986.
3. Ashcroft, N.W., and Mermin, N.D., *Solid State Physics*, Holt, Rinehart, and Winston, New York, 1976, p. 697.

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ELECTRON WORK FUNCTION OF THE ELEMENTS

The electron work function Φ is a measure of the minimum energy required to extract an electron from the surface of a solid. It is defined more precisely as the energy difference between the state in which an electron has been removed to a distance from the surface of a single crystal face that is large enough that the image force is negligible but small compared to the distance to any other face (typically about 10^{-4} cm) and the state in which the electron is in the bulk solid. In general, Φ differs for each face of a monocrystalline sample.

Since Φ is dependent on the cleanliness of the surface, measurements reported in the literature often cover a considerable range. This table contains selected values for the electron work function of the elements which may be regarded as typical values for a reasonably clean surface. The method of measurement is indicated for each value. The following abbreviations appear:

TE — Thermionic emission
PE — Photoelectric effect
FE — Field emission
CPD — Contact potential difference
polycr — Polycrystalline sample
amorp — Amorphous sample

Values in parentheses are only approximate.

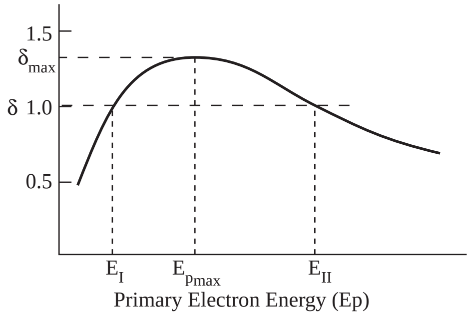
REFERENCES

1. Hölzl, J., and Schulte, F. K., Work Functions of Metals, in *Solid Surface Physics*, Höhler, G., Editor, Springer-Verlag, Berlin, 1979.
2. Riviere, J. C., Work Function: Measurements and Results, in *Solid State Surface Science, Vol.1*, Green, M., Editor, Decker, New York, 1969.
3. Michaelson, H. B., *J. Appl. Phys*., 48, 4729, 1977.

Element	Plane	Φ/eV	Method
Ag	100	4.64	PE
	110	4.52	PE
	111	4.74	PE
Al	100	4.20	PE
	110	4.06	PE
	111	4.26	PE
As	polycr	(3.75)	PE
Au	100	5.47	PE
	110	5.37	PE
	111	5.31	PE
B	polycr	(4.45)	TH
Ba	polycr	2.52	TH
Be	polycr	4.98	PE
Bi	polycr	4.34	PE
C	polycr	(5.0)	CPD
Ca	polycr	2.87	PE
Cd	polycr	4.08	CPD
Ce	polycr	2.9	PE
Co	polycr	5.0	PE
Cr	polycr	4.5	PE
Cs	polycr	1.95	PE
Cu	100	5.10	FE
	110	4.48	PE
	111	4.94	PE
	112	4.53	PE
Eu	polycr	2.5	PE
Fe	100	4.67	PE
	111	4.81	PE
Ga	polycr	4.32	PE
Gd	polycr	2.90	CPD
Ge	polycr	5.0	CPD
Hf	polycr	3.9	PE
Hg	liquid	4.475	PE
In	polycr	4.09	PE
Ir	100	5.67	PE
	110	5.42	PE
	111	5.76	PE
	210	5.00	PE
K	polycr	2.29	PE
La	polycr	3.5	PE
Li	polycr	2.93	FE
Lu	polycr	(3.3)	CPD
Mg	polycr	3.66	PE
Mn	polycr	4.1	PE
Mo	100	4.53	PE
	110	4.95	PE
	111	4.55	PE
	112	4.36	PE
	114	4.50	PE
	332	4.55	PE
Na	polycr	2.36	PE
Nb	001	4.02	TH
	110	4.87	TH
	111	4.36	TH
	112	4.63	TH
	113	4.29	TH
	116	3.95	TH
	310	4.18	TH
Nd	polycr	3.2	PE
Ni	100	5.22	PE
	110	5.04	PE
	111	5.35	PE
Os	polycr	5.93	PE
Pb	polycr	4.25	PE
Pd	polycr	5.22	PE
	111	5.6	PE
Pt	polycr	5.64	PE
	110	5.84	FE
	111	5.93	FE
	320	5.22	FE
	331	5.12	FE
Rb	polycr	2.261	PE
Re	polycr	4.72	TE
Rh	polycr	4.98	PE
Ru	polycr	4.71	PE
Sb	amorp	4.55	
	100	4.7	
Sc	polycr	3.5	PE
Se	polycr	5.9	PE
Si	n	4.85	CPD
	p 100	(4.91)	CPD
	p 111	4.60	PE
Sm	polycr	2.7	PE
Sn	polycr	4.42	CPD
Sr	polycr	(2.59)	TH
Ta	polycr	4.25	TH
	100	4.15	TH
	110	4.80	TH
	111	4.00	TH
Tb	polycr	3.0	PE
Te	polycr	4.95	PE
Th	polycr	3.4	TH
Ti	polycr	4.33	PE
Tl	polycr	(3.84)	CPD
U	polycr	3.63	PE
	100	3.73	PE
	110	3.90	PE
	113	3.67	PE
V	polycr	4.3	PE
W	polycr	4.55	CPD
	100	4.63	FE
	110	5.22	FE
	111	4.45	FE
	113	4.46	FE
	116	4.32	TH
Y	polycr	3.1	PE
Zn	polycr	3.63	PE
	polycr	(4.9)	CPD
Zr	polycr	4.05	PE

SECONDARY ELECTRON EMISSION

The secondary emission yield, or secondary emission ratio, δ, is the average number of secondary electrons emitted from a bombarded material for every incident primary electron. It is a function of the primary electron energy E_p. The maximum yield δ_{max} corresponds to a primary electron energy E_{pmax} (see figure). The two primary electron energies corresponding to a yield of unity are denoted the first and second crossovers (E_I and E_{II}). An insulating target, or a conducting target that is electrically floating, will charge positively or negatively depending on the primary electron energy. For $E_I < E_p < E_{II}$, $\delta > 1$ and the surface charges positively provided there is a collector present that is positive with respect to the target. For $E_p < E_I$ or $E_p > E_{II}$, $\delta < 1$, and the surface charges negatively with respect to the potential of the source of primary electrons.



Element	δ_{max}	E_{pmax} (eV)	E_I (eV)	E_{II} (eV)
Ag	1.5	800	200	>2000
Al	1.0	300	300	300
Au	1.4	800	150	>2000
B	1.2	150	50	600
Ba	0.8	400	None	None
Bi	1.2	550	None	None
Be	0.5	200	None	None
C (diamond)	2.8	750	None	>5000
C (graphite)	1.0	300	300	300
C (soot)	0.45	500	None	None
Cd	1.1	450	300	700
Co	1.2	600	200	None
Cs	0.7	400	None	None
Cu	1.3	600	200	1500
Fe	1.3	400	120	1400
Ga	1.55	500	75	None
Ge	1.15	500	150	900
Hg	1.3	600	350	>1200
K	0.7	200	None	None

Element	δ_{max}	E_{pmax} (eV)	E_I (eV)	E_{II} (eV)
Li	0.5	85	None	None
Mg	0.95	300	None	None
Mo	1.25	375	150	1200
Na	0.82	300	None	None
Nb	1.2	375	150	1050
Ni	1.3	550	150	>1500
Pb	1.1	500	250	1000
Pd	>1.3	>250	120	None
Pt	1.8	700	350	3000
Rb	0.9	350	None	None
Sb	1.3	600	250	2000
Si	1.1	250	125	500
Sn	1.35	500	None	None
Ta	1.3	600	250	>2000
Th	1.1	800	None	None
Ti	0.9	280	None	None
Tl	1.7	650	70	>1500
W	1.4	650	250	>1500
Zr	1.1	350	None	None

Compound	δ_{max}	E_{pmax} (eV)
Alkali halides		
CsCl	6.5	
KBr (crystal)	14	1800
KCl (crystal)	12	1600
KCl (layer)	7.5	1200
KI (crystal)	10	1600
KI (layer)	5.6	
LiF (crystal)	8.5	
LiF (layer)	5.6	700
NaBr (crystal)	24	1800
NaBr (layer)	6.3	
NaCl (crystal)	14	1200

Compound	δ_{max}	E_{pmax} (eV)
NaCl (layer)	6.8	600
NaF (crystal)	14	1200
NaF (layer)	5.7	
NaI (crystal)	19	1300
NaI (layer)	5.5	
RbCl (layer)	5.8	
Oxides		
Ag_2O	1.0	
Al_2O_3 (layer)	2—9	
BaO (layer)	2.3—4.8	400
BeO	3.4	2000
CaO	2.2	500

Compound	δ_{max}	E_{pmax} (eV)
Cu_2O	1.2	400
MgO (crystal)	20—25	1500
MgO (layer)	3—15	400—1500
MoO_2	1.2	
SiO_2 (quartz)	2.1—4	400
SnO_2	3.2	640
Sulfides		
MoS_2	1.1	
PbS	1.2	500
WS_2	1.0	
ZnS	1.8	350
Others		
BaF_2 (layer)	4.5	
CaF_2 (layer)	3.2	
$BiCs_3$	6	1000
BiCs	1.9	1000
GeCs	7	700
Rb_3Sb	7.1	450
$SbCs_3$	6	700
Mica	2.4	350
Glasses	2—3	300—450

OPTICAL PROPERTIES OF SELECTED ELEMENTS

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These tables list the index of refraction n, the extinction coefficient k, and the normal incidence reflection R ($\phi = 0$) as a function of photon energy E, which is expressed in electron volts (eV). To convert the energy in eV to wavelength in μm, use $\lambda = 1.2398/E$. To compute the dielectric function $\tilde{\varepsilon} = \varepsilon_1 + i\varepsilon_2$ from the complex index of refraction $\tilde{N} = n + ik$, use $\varepsilon_1 = n^2 - k^2$ and $\varepsilon_2 = 2nk$.

The optical constants in these tables are abridged from three more extensive tabulations:

- *Optical Properties of Metals* (OPM), Volumes I and II, *Physics Data, Nr.* 18-1 and 18-2, J. H. Weaver, C. Krafka, D. W. Lynch, and E. E. Koch, Fachinformationzentrum, Karlsruhe, Germany.
- *Handbook of Optical Constants* (HOC), Vol. I, 1985, and Vol. II, 1991. Edited by E. D. Palik, published by Academic Press, Inc.
- *American Institute of Physics Handbook* (AIPH), 3rd Edition, Coord. Editor D. E. Gray, published by McGraw-Hill Book Co., New York, 1972.

The first two of these major sources provide detailed comparisons of all optical data available in the literature at the time of the compilation. For critical applications the reader should refer to the original work. References for individual metals and semiconductors are listed at the end of the tables. Generally, tabulated values for the optical properties are accurate to better than 10%. Data in parentheses are extrapolated or interpolated values. For most elements the spectral range covered is from the far infrared (0.010 or 0.10 eV) to the far ultraviolet (10, 30 or 300 eV). The intervals between successive energies in the tables are chosen in such a way that the major spectral features are preserved.

Very small values of k are expressed in exponential notation, e.g., 1.23E-5 means 1.23×10^{-5}.

The following table is convenient for identifying the energy entries in these tables with the corresponding wavelengths:

λ	E/eV	λ	E/eV
1 mm	0.00124	6000 Å	2.066
500 μm	0.00248	5000 Å	2.480
100 μm	0.01240	4000 Å	3.100
50 μm	0.02480	3000 Å	4.133
10 μm	0.12398	2000 Å	6.199
5 μm	0.24797	1000 Å	12.398
1 μm	1.240	400 Å	30.996

Energy (eV)	n	k	R(ϕ = 0)
Aluminium[1]			
0.040	98.595	203.701	0.9923
0.050	74.997	172.199	0.9915
0.060	62.852	150.799	0.9906
0.070	53.790	135.500	0.9899
0.080	45.784	123.734	0.9895
0.090	39.651	114.102	0.9892
0.100	34.464	105.600	0.9889
0.125	24.965	89.250	0.9884
0.150	18.572	76.960	0.9882
0.175	14.274	66.930	0.9879
0.200	11.733	59.370	0.9873
0.250	8.586	48.235	0.9858
0.300	6.759	40.960	0.9844
0.350	5.438	35.599	0.9834
0.400	4.454	31.485	0.9826
0.500	3.072	25.581	0.9817
0.600	2.273	21.403	0.9806
0.700	1.770	18.328	0.9794
0.800	1.444	15.955	0.9778
0.900	1.264	14.021	0.9749
1.000	1.212	12.464	0.9697
1.100	1.201	11.181	0.9630
1.200	1.260	10.010	0.9521
1.300	1.468	8.949	0.9318
1.400	2.237	8.212	0.8852
1.500	2.745	8.309	0.8678
1.600	2.625	8.597	0.8794
1.700	2.143	8.573	0.8972
1.800	1.741	8.205	0.9069
1.900	1.488	7.821	0.9116
2.000	1.304	7.479	0.9148
2.200	1.018	6.846	0.9200
2.400	0.826	6.283	0.9228
2.600	0.695	5.800	0.9238
2.800	0.598	5.385	0.9242
3.000	0.523	5.024	0.9241
3.200	0.460	4.708	0.9243
3.400	0.407	4.426	0.9245
3.600	0.363	4.174	0.9246
3.800	0.326	3.946	0.9247
4.000	0.294	3.740	0.9248
4.200	0.267	3.552	0.9248
4.400	0.244	3.380	0.9249
4.600	0.223	3.222	0.9249
4.800	0.205	3.076	0.9249
5.000	0.190	2.942	0.9244
6.000	0.130	2.391	0.9257
6.500	0.110	2.173	0.9260
7.000	0.095	1.983	0.9262
7.500	0.082	1.814	0.9265
8.000	0.072	1.663	0.9269
8.500	0.063	1.527	0.9272
9.000	0.056	1.402	0.9277
9.500	0.049	1.286	0.9282
10.000	0.044	1.178	0.9286
10.500	0.040	1.076	0.9293
11.000	0.036	0.979	0.9298
11.500	0.033	0.883	0.9283
12.000	0.033	0.791	0.9224
12.500	0.034	0.700	0.9118
13.000	0.038	0.609	0.8960
13.500	0.041	0.517	0.8789
14.000	0.048	0.417	0.8486
14.200	0.053	0.373	0.8312
14.400	0.058	0.327	0.8102
14.600	0.067	0.273	0.7802
14.800	0.086	0.211	0.7202
15.000	0.125	0.153	0.6119
15.200	0.178	0.108	0.4903
15.400	0.234	0.184	0.3881
15.600	0.280	0.073	0.3182
15.800	0.318	0.065	0.2694
16.000	0.351	0.060	0.2326
16.200	0.380	0.055	0.2031
16.400	0.407	0.050	0.1789
16.750	0.448	0.045	0.1460
17.000	0.474	0.042	0.1278
17.250	0.498	0.040	0.1129
17.500	0.520	0.038	0.1005
17.750	0.540	0.036	0.0899
18.000	0.558	0.035	0.0809
18.500	0.591	0.032	0.0664
19.000	0.620	0.030	0.0554
19.500	0.646	0.028	0.0467
20.000	0.668	0.027	0.0398
20.500	0.689	0.025	0.0342
21.000	0.707	0.024	0.0296
21.500	0.724	0.023	0.0258
22.000	0.739	0.022	0.0226
22.500	0.753	0.021	0.0199
23.000	0.766	0.021	0.0177
23.500	0.778	0.020	0.0157
24.000	0.789	0.019	0.0140
24.500	0.799	0.018	0.0126
25.000	0.809	0.018	0.0113

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
25.500	0.817	0.017	0.0102
26.000	0.826	0.016	0.0092
27.000	0.840	0.015	0.0076
28.000	0.854	0.014	0.0063
29.000	0.865	0.014	0.0053
30.000	0.876	0.013	0.0044
35.000	0.915	0.010	0.0020
40.000	0.940	0.008	0.0010
45.000	0.957	0.007	0.0005
50.000	0.969	0.006	0.0003
55.000	0.979	0.005	0.0001
60.000	0.987	0.004	0.0000
65.000	0.995	0.004	0.0000
70.000	1.006	0.004	0.0000
72.500	1.025	0.004	0.0002
75.000	1.011	0.024	0.0002
77.500	1.008	0.025	0.0002
80.000	1.007	0.024	0.0002
85.000	1.007	0.028	0.0002
90.000	1.005	0.031	0.0002
95.000	0.999	0.036	0.0003
100.000	0.991	0.030	0.0002
110.000	0.994	0.025	0.0002
120.000	0.991	0.024	0.0002
130.000	0.987	0.021	0.0001
140.000	0.989	0.016	0.0001
150.000	0.990	0.015	0.0001
160.000	0.989	0.014	0.0001
170.000	0.989	0.011	0.0001
180.000	0.990	0.010	0.0000
190.000	0.990	0.009	0.0000
200.000	0.991	0.007	0.0000
220.000	0.992	0.006	0.0000
240.000	0.993	0.005	0.0000
260.000	0.993	0.004	0.0000
280.000	0.994	0.003	0.0000
300.000	0.995	0.002	0.0000

Carbon (diamond)[2]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.06199	2.3741		0.166
0.06888	2.3741		0.166
0.07749	2.3745		0.166
0.08856	2.3750		0.166
0.1033	2.3757		0.166
0.1240	2.3765		0.166
0.1550	2.3772		0.166
0.1907		3.1 E-05	
0.2066	2.3779	5.7 E-05	0.166
0.22		1.21E-04	
0.23		2.36E-04	
0.24		3.82E-04	
0.25		5.21E-04	
0.26		2.96E-04	
0.27		4.39E-04	
0.28		2.75E-04	
0.29		7.82E-05	
0.30		1.32E-04	
0.31	2.3787	1.30E-04	0.167
0.32		1.11E-04	
0.33		2.99E-05	
0.34		1.89E-05	
0.35		2.11E-05	
0.36		2.47E-05	
0.37		2.80E-05	
0.38		3.11E-05	
0.39		3.67E-05	
0.40		3.58E-05	
0.41		3.25E-05	
0.4133	2.3795		0.167
0.42		2.94E-05	
0.43		2.87E-05	
0.44		3.14E-05	
0.45		3.62E-05	
0.46		3.22E-05	
0.47		1.57E-05	
0.48		6.17E-06	
0.4959	2.3801		0.167
0.6199	2.3813		0.167
0.8266	2.3837		0.167
1.240	2.3905		0.168
1.378	2.3934		0.169
1.459	2.3953		0.169
1.550	2.3975		0.169
1.653	2.4003		0.170
1.771	2.4036		0.170
1.889	2.4073		0.171
1.926	2.4084		0.171
2.066	2.4133		0.171
2.105	2.4147		0.172
2.271	2.4210		0.173
2.480	2.4299		0.174
2.650	2.4380		0.175
2.845		3.82E-07	
3.100	2.4627		0.178
3.434	2.4849		0.182
3.576	2.4955		0.183
3.961		8.97E-07	
4.160	2.5465		0.190
4.511		1.29E-06	
4.8187	2.6205	1.47E-06	0.200
5.00	2.6383		0.203
5.30		2.98E-06	
5.35		6.45E-06	
5.40		1.04E-05	
5.50		3.41E-05	
5.55		5.48E-04	
5.60	2.740	1.48E-03	0.216
5.80	2.780	5.02E-03	0.222
6.00	2.826	7.99E-03	0.228
6.10	2.852	8.62E-03	0.231
6.20	2.879	9.30E-03	0.235
6.30	2.910	9.74E-03	0.239
6.40	2.944	9.87E-03	0.243
6.50	2.985	1.10E-02	0.248
6.60	3.031	1.47E-02	0.254
6.70	3.085	2.20E-02	0.261
6.80	3.146	3.44E-02	0.268
6.90	3.220	5.24E-02	0.277
7.00	3.322	9.35E-02	0.289
7.10	3.444	0.210	0.304
7.15	3.464	0.307	0.308
7.20	3.437	0.388	0.307
7.30	3.376	0.473	0.303
7.40	3.335	0.515	0.300
7.50	3.321	0.533	0.299
7.60	3.306	0.592	0.300
7.80	3.276	0.659	0.300
8.00	3.251	0.712	0.300
8.25	3.232	0.765	0.301
8.50	3.228	0.806	0.303
8.75	3.247	0.855	0.308
9.00	3.272	0.910	0.314
9.25	3.308	0.978	0.322
9.50	3.348	1.055	0.331
9.75	3.398	1.147	0.342
10.00	3.453	1.258	0.355
10.25	3.514	1.403	0.371
10.50	3.565	1.581	0.389
10.75	3.600	1.813	0.411
11.00	3.582	2.078	0.434
11.25	3.507	2.380	0.460
11.50	3.346	2.693	0.488
11.75	3.090	2.986	0.518
12.00	2.736	3.228	0.551
12.20	2.383	3.354	0.580
12.40	1.983	3.382	0.610
12.60	1.532	3.265	0.641
12.80	1.312	2.953	0.627
13.00	1.223	2.722	0.604
13.50	1.129	2.379	0.557
14.00	1.070	2.178	0.526
14.50	1.018	2.034	0.504
15.00	0.972	1.929	0.489
15.50	0.917	1.845	0.482
16.00	0.861	1.767	0.477
16.50	0.805	1.692	0.474
17.00	0.753	1.619	0.471
17.50	0.707	1.546	0.467
18.00	0.665	1.476	0.463
18.50	0.626	1.408	0.459
19.00	0.589	1.341	0.455
19.50	0.557	1.273	0.449
20.00	0.527	1.203	0.442
21.00	0.487	1.052	0.413
22.00	0.518	0.888	0.330
23.00	0.597	0.850	0.270
24.00	0.586	0.829	0.268
25.00	0.562	0.787	0.265
26.00	0.538	0.736	0.260
27.00	0.516	0.679	0.252
28.00	0.501	0.616	0.239
29.00	0.494	0.552	0.221
30.00	0.493	0.490	0.201

Cesium (evaporated)[3]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
2.145	0.264	1.123	0.631
2.271	0.278	0.950	0.561
2.845	0.425	0.438	0.235
3.064	0.540	0.320	0.127
3.397	0.671	0.233	0.057
3.966	0.827	0.174	0.018
4.889	0.916	0.143	0.007

Chromium[4]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.06	21.19	42.00	0.962
0.10	11.81	29.76	0.955
0.14	15.31	26.36	0.936
0.18	8.73	25.37	0.53
0.22	5.30	20.62	0.954
0.26	3.91	17.12	0.951
0.30	3.15	14.28	0.943
0.42	3.47	8.97	0.862
0.54	3.92	7.06	0.788
0.66	3.96	5.95	0.736
0.78	4.13	5.03	0.680

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.90	4.43	4.60	0.650
1.00	4.47	4.43	0.639
1.12	4.53	4.31	0.631
1.24	4.50	4.28	0.629
1.36	4.42	4.30	0.631
1.46	4.31	4.32	0.632
1.77	3.84	4.37	0.639
2.00	3.48	4.36	0.644
2.20	3.18	4.41	0.656
2.40	2.75	4.46	0.677
2.60	2.22	4.36	0.698
2.80	1.80	4.06	0.703
3.00	1.54	3.71	0.695
3.20	1.44	3.40	0.670
3.40	1.39	3.24	0.657
3.60	1.26	3.12	0.661
3.80	1.12	2.95	0.660
4.00	1.02	2.76	0.651
4.20	0.94	2.58	0.639
4.40	0.90	2.42	0.620
4.50	0.89	2.35	0.607
4.60	0.88	2.28	0.598
4.70	0.86	2.21	0.586
4.80	0.86	2.13	0.572
4.90	0.86	2.07	0.557
5.00	0.85	2.01	0.542
5.10	0.86	1.94	0.523
5.20	0.87	1.87	0.503
5.40	0.93	1.80	0.466
5.60	0.95	1.74	0.443
5.80	0.97	1.74	0.437
6.00	0.94	1.73	0.444
6.20	0.89	1.69	0.446
6.40	0.85	1.66	0.447
6.60	0.80	1.59	0.444
6.80	0.75	1.51	0.439
7.00	0.74	1.45	0.425
7.20	0.71	1.39	0.414
7.40	0.69	1.33	0.404
7.60	0.66	1.23	0.378
7.80	0.67	1.15	0.347
8.00	0.68	1.07	0.315
8.20	0.71	1.00	0.278
8.50	0.74	0.92	0.235
9.0	0.83	0.81	0.170
9.50	0.92	0.74	0.132
10.00	0.98	0.73	0.120
10.50	1.01	0.72	0.112
11.00	1.05	0.69	0.103
11.50	1.09	0.69	0.100
12.00	1.13	0.70	0.101
12.50	1.15	0.73	0.108
13.00	1.15	0.77	0.119
13.50	1.12	0.80	0.128
14.00	1.09	0.82	0.135
14.50	1.03	0.82	0.142
15.00	1.00	0.82	0.143
15.50	0.96	0.80	0.141
16.00	0.92	0.77	0.139
16.50	0.31	0.75	0.134
17.00	0.90	0.73	0.132
17.50	0.88	0.72	0.130
18.00	0.87	0.70	0.129
18.50	0.84	0.69	0.130
19.00	0.82	0.68	0.131
20.00	0.77	0.64	0.130
20.5	0.76	0.63	0.129
21.0	0.74	0.58	0.121
21.5	0.72	0.55	0.116
22.0	0.71	0.52	0.112
22.5	0.70	0.50	0.109
23.0	0.69	0.48	0.105
23.5	0.68	0.45	0.101
24.0	0.68	0.43	0.096
24.5	0.67	0.39	0.089
25.0	0.68	0.36	0.080
25.5	0.68	0.33	0.072
26.0	0.70	0.31	0.063
26.5	0.71	0.28	0.055
27.0	0.72	0.26	0.048
27.5	0.73	0.25	0.043
28.0	0.75	0.23	0.037
29.0	0.77	0.22	0.032
30.0	0.78	0.21	0.030

Cobalt, single crystal, $\vec{E} \parallel \hat{c}$[5]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.10	6.71	37.87	0.982
0.15	4.66	25.47	0.973
0.20	3.55	18.78	0.962
0.25	3.98	14.59	0.933
0.30	4.04	12.16	0.907
0.40	4.24	9.13	0.847
0.50	4.41	7.19	0.782
0.60	4.91	6.13	0.729
0.70	5.24	5.85	0.713
0.80	5.17	5.89	0.716
0.90	4.94	5.95	0.720
1.00	4.46	5.86	0.722
1.10	4.07	5.61	0.715
1.20	3.81	5.36	0.706
1.30	3.60	5.20	0.701
1.40	3.37	5.09	0.701
1.50	3.10	4.96	0.701
1.60	2.84	4.77	0.697
1.70	2.66	4.57	0.690
1.80	2.45	4.41	0.687
1.90	2.31	4.18	0.675
2.00	2.21	4.00	0.664
2.10	2.13	3.85	0.654
2.20	2.07	3.70	0.642
2.30	2.01	3.59	0.634
2.40	1.95	3.49	0.627
2.50	1.88	3.40	0.622
2.60	1.81	3.32	0.618
2.70	1.73	3.24	0.615
2.80	1.66	3.13	0.607
2.90	1.61	3.05	0.600
3.00	1.55	2.96	0.594
3.20	1.46	2.80	0.579
3.40	1.38	2.64	0.563
3.60	1.31	2.48	0.544
3.80	1.28	2.33	0.519
4.00	1.26	2.20	0.495
4.20	1.25	2.10	0.471
4.40	1.24	2.01	0.452
4.60	1.24	1.94	0.435
4.80	1.23	1.88	0.423
5.00	1.22	1.83	0.411
5.20	1.21	1.79	0.403
5.40	1.19	1.77	0.399
5.60	1.16	1.75	0.400
5.80	1.10	1.73	0.406
6.00	1.03	1.68	0.407
6.20	0.97	1.62	0.401
6.40	0.94	1.53	0.386
6.60	0.91	1.46	0.368
6.80	0.91	1.38	0.345
7.00	0.91	1.32	0.326
7.00	0.91	1.26	0.305
7.40	0.92	1.21	0.286
7.60	0.93	1.17	0.269
7.80	0.94	1.13	0.253
8.00	0.95	1.09	0.239

Cobalt, single crystal, $\vec{E} \perp \hat{c}$[5]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.10	5.83	32.36	0.979
0.15	4.24	21.37	0.965
0.20	3.87	15.53	0.042
0.30	4.34	10.01	0.865
0.40	4.66	7.39	0.785
0.50	5.17	5.75	0.709
0.60	5.77	5.17	0.682
0.70	6.15	5.20	0.685
0.80	6.08	5.61	0.702
0.90	5.57	5.93	0.715
1.00	4.83	5.94	0.721
1.10	4.31	5.60	0.711
1.20	4.02	5.34	0.701
1.30	3.78	5.16	0.694
1.40	3.55	5.05	0.692
1.50	3.26	4.93	0.692
1.60	3.03	4.74	0.687
1.70	2.83	4.60	0.684
1.80	2.61	4.45	0.683
1.90	2.41	4.27	0.677
2.00	2.25	4.09	0.670
2.10	2.13	3.89	0.659
2.20	2.04	3.72	0.646
2.30	1.99	3.56	0.632
2.40	1.95	3.44	0.620
2.50	1.90	3.34	0.611
2.60	1.86	3.26	0.605
2.70	1.79	3.19	0.602
2.80	1.72	3.11	0.596
2.90	1.66	3.03	0.591
3.00	1.60	2.94	0.586
3.20	1.50	2.78	0.571
3.40	1.42	2.62	0.553
3.60	1.36	2.47	0.533
3.80	1.33	2.33	0.511
4.00	1.31	2.21	0.488
4.20	1.28	2.12	0.471
4.40	1.27	2.03	0.452
4.60	1.26	1.95	0.435
4.80	1.25	1.90	0.423
5.00	1.24	1.84	0.411
5.20	1.22	1.80	0.403
5.40	1.21	1.78	0.399
5.60	1.17	1.76	0.400
5.80	1.11	1.74	0.406
6.00	1.04	1.69	0.407
6.20	0.98	1.62	0.401
6.40	0.94	1.54	0.386
6.60	0.92	1.46	0.368
6.80	0.91	1.38	0.345

Energy (eV)	n	k	$R(\phi = 0)$
7.00	0.91	1.32	0.326
7.20	0.91	1.26	0.305
7.40	0.92	1.21	0.285
7.60	0.93	1.17	0.269
7.80	0.94	1.13	0.253

Copper[6]

Energy (eV)	n	k	$R(\phi = 0)$
0.10	29.69	71.57	0.980
0.50	1.71	17.63	0.979
1.00	0.44	8.48	0.976
1.50	0.26	5.26	0.965
1.70	0.22	4.43	0.958
1.75	0.21	4.25	0.956
1.80	0.21	4.04	0.952
1.85	0.22	3.85	0.947
1.90	0.21	3.67	0.943
2.00	0.27	3.24	0.910
2.10	0.47	2.81	0.814
2.20	0.83	2.60	0.673
2.30	1.04	2.59	0.618
2.40	1.12	2.60	0.602
2.60	1.15	2.50	0.577
2.80	1.17	2.36	0.545
3.00	1.18	2.21	0.509
3.20	1.23	2.07	0.468
3.40	1.27	1.95	0.434
3.60	1.31	1.87	0.407
3.80	1.34	1.81	0.387
4.00	1.34	1.72	0.364
4.20	1.42	1.64	0.336
4.40	1.49	1.64	0.329
4.60	1.52	1.67	0.334
4.80	1.53	1.71	0.345
5.00	1.47	1.78	0.366
5.20	1.38	1.80	0.380
5.40	1.28	1.78	0.389
5.60	1.18	1.74	0.391
5.80	1.10	1.67	0.389
6.00	1.04	1.59	0.380
6.50	0.96	1.37	0.329
7.00	0.97	1.20	0.271
7.50	1.00	1.09	0.230
8.00	1.03	1.03	0.206
8.50	1.03	0.98	0.189
9.00	1.03	0.92	0.171
9.50	1.03	0.87	0.154
10.00	1.04	0.82	0.139
11.00	1.07	0.75	0.118
12.00	1.09	0.73	0.111
13.00	1.08	0.72	0.109
14.00	1.06	0.72	0.111
14.50	1.03	0.72	0.111
15.00	1.01	0.71	0.111
15.50	0.98	0.69	0.109
16.00	0.95	0.67	0.106
17.00	0.91	0.62	0.097
18.00	0.89	0.56	0.084
19.00	0.88	0.51	0.071
20.00	0.88	0.45	0.059
21.00	0.90	0.41	0.048
22.00	0.92	0.38	0.040
23.00	0.94	0.37	0.035
24.00	0.96	0.37	0.035
25.00	0.96	0.40	0.040
26.00	0.92	0.40	0.044
27.00	0.88	0.38	0.043
28.00	0.86	0.35	0.039
29.00	0.85	0.30	0.032
30.00	0.86	0.26	0.025
31.00	0.88	0.24	0.020
32.00	0.89	0.22	0.017
33.00	0.90	0.21	0.015
34.00	0.91	0.20	0.014
35.00	0.92	0.20	0.013
36.00	0.92	0.19	0.012
37.00	0.92	0.19	0.011
38.00	0.93	0.18	0.010
39.00	0.93	0.17	0.009
40.00	0.93	0.17	0.009
41.00	0.94	0.16	0.008
42.00	0.94	0.16	0.007
43.00	0.94	0.15	0.007
44.00	0.95	0.15	0.007
45.00	0.95	0.15	0.006
46.00	0.95	0.15	0.006
47.00	0.95	0.14	0.006
48.00	0.95	0.14	0.006
49.00	0.95	0.14	0.005
50.00	0.95	0.13	0.005
51.00	0.95	0.13	0.005
52.00	0.95	0.13	0.005
53.00	0.96	0.12	0.004
54.00	0.96	0.12	0.004
55.00	0.96	0.12	0.004
56.00	0.96	0.11	0.004
57.00	0.96	0.11	0.004
58.00	0.96	0.11	0.004
59.00	0.97	0.11	0.003
60.00	0.97	0.11	0.003
61.00	0.97	0.11	0.003
62.00	0.97	0.11	0.003
63.00	0.96	0.10	0.003
64.00	0.96	0.10	0.003
65.00	0.97	0.10	0.003
66.00	0.97	0.10	0.003
67.00	0.97	0.09	0.003
68.00	0.97	0.09	0.002
69.00	0.97	0.09	0.002
70.00	0.97	0.09	0.002
75.00	0.98	0.09	0.002
80.00	0.98	0.09	0.002
85.00	0.97	0.09	0.002
90.00	0.96	0.08	0.002

Gallium (liquid)[7]

Energy (eV)	n	k	$R(\phi = 0)$
1.425	2.40	9.20	0.900
1.550	2.09	8.50	0.898
1.771	1.65	7.60	0.898
2.066	1.25	6.60	0.897
2.480	0.89	5.60	0.898
3.100	0.59	4.50	0.896

Germanium, single crystal[8]

Energy (eV)	n	k	$R(\phi = 0)$
0.01240	(4.0065)	3.00E-03	0.361
0.01364	4.0063	2.40E-03	0.361
0.01488	(4.0060)	1.70E-03	0.361
0.01612	(4.0060)	1.55E-03	0.361
0.01736	(4.0060)	1.50E-03	0.361
0.01860		1.50E-03	
0.01984		1.60E-03	
0.02108		1.60E-03	
0.02232		1.55E-03	
0.02356		1.53E-03	
0.02480		1.50E-03	
0.02604		1.25E-03	
0.02728		8.50E-04	
0.02852		6.50E-04	
0.02976		7.00E-04	
0.03100	3.9827	8.50E-04	0.358
0.03224		1.55E-03	
0.03348		2.75E-03	
0.03472		3.55E-03	
0.03596	(3.9900)	3.05E-03	0.359
0.03720		2.75E-03	
0.03844		2.70E-03	
0.03968	(3.9930)	2.90E-03	0.359
0.04092		2.95E-03	
0.04215		3.20E-03	
0.04339		6.30E-03	
0.04463		3.40E-03	
0.04587	(3.9955)	2.50E-03	0.360
0.04711		2.10E-03	
0.04835		2.00E-03	
0.04959		8.00E-04	
0.05083		1.40E-03	
0.05207		1.35E-03	
0.05331		1.10E-03	
0.05455		8.00E-04	
0.05579		6.00E-04	
0.05703		9.0 E-04	
0.05827		6.5 E-04	
0.05951		4.6 E-04	
0.06075		4.0 E-04	
0.06199	3.9992	3.98E-04	0.360
0.06323		4.0 E-04	
0.06447		4.3 E-04	
0.06571		4.4 E-04	
0.06695	(4.0000)	4.3 E-04	0.360
0.06819		3.1 E-04	
0.06943		3.3 E-04	
0.07067		3.8 E-04	
0.07191		3.3 E-04	
0.07315		2.5 E-04	
0.07439		1.9 E-04	
0.07514		1.58E-04	
0.07749	4.0009	9.55E-05	0.360
0.07999	4.0011	1.71E-04	0.360
0.08266	4.0013	9.78E-05	0.360
0.08551	4.0015	5.77E-05	0.360
0.08920		3.98E-05	
0.09460		4.59E-05	
0.09840		3.51E-05	
0.1	4.0063	3.70E-05	0.361
0.2	4.0108		0.361
0.3	4.0246		0.362
0.4	4.0429		0.364
0.5	(4.074)		0.367
0.6	(4.104)	6.58E-07	0.370
0.7	4.180	1.27E-04	0.377
0.8	4.275	5.67E-03	0.385
0.9	4.285	7.45E-02	0.386
1.0	4.325	8.09E-02	0.390
1.1	4.385	0.103	0.395
1.2	4.420	0.123	0.398
1.3	4.495	0.167	0.405

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
1.4	4.560	0.190	0.411
1.5	4.635	0.298	0.418
1.6	4.763	0.345	0.428
1.7	4.897	0.401	0.439
1.8	5.067	0.500	0.453
1.9	5.380	0.540	0.475
2.0	5.588	0.933	0.495
2.1	5.748	1.634	0.523
2.2	5.283	2.049	0.516
2.3	5.062	2.318	0.519
2.4	4.610	2.455	0.508
2.5	4.340	2.384	0.492
2.6	4.180	2.309	0.480
2.7	4.082	2.240	0.471
2.8	4.035	2.181	0.464
2.9	4.037	2.140	0.461
3.0	4.082	2.145	0.463
3.1	4.141	2.215	0.471
3.2	4.157	2.340	0.482
3.3	4.128	2.469	0.490
3.4	4.070	2.579	0.497
3.5	4.020	2.667	0.502
3.6	3.985	2.759	0.509
3.7	3.958	2.863	0.517
3.8	3.936	2.986	0.527
3.9	3.920	3.137	0.539
4.0	3.905	3.336	0.556
4.1	3.869	3.614	0.579
4.2	3.745	4.009	0.612
4.3	3.338	4.507	0.659
4.4	2.516	4.669	0.705
4.5	1.953	4.297	0.713
4.6	1.720	3.960	0.702
4.7	1.586	3.709	0.690
4.8	1.498	3.509	0.677
4.9	1.435	3.342	0.664
5.0	1.394	3.197	0.650
5.1	1.370	3.073	0.636
5.2	1.364	2.973	0.622
5.3	1.371	2.897	0.609
5.4	1.383	2.854	0.600
5.5	1.380	2.842	0.598
5.6	1.360	2.846	0.602
5.7	1.293	2.163	0.479
5.8	1.209	2.873	0.632
5.9	1.108	2.813	0.641
6.0	1.30	2.34	0.517
6.5	1.10	2.05	0.489
7.0	1.00	1.80	0.448
7.5		1.60	
8.0	0.92	1.40	0.348
8.5	0.92	1.20	0.282
9.0	0.92	1.14	0.262
9.5		1.00	
10.0	0.93	0.86	0.167
20.0		0.237	
22.0		0.179	
24.0		0.144	
26.0		0.110	
28.0		0.0747	
30.0		0.1020	
32.0		0.0999	
34.0		0.0856	
36.0		0.0740	
38.0		0.0651	
40.0		0.0604	

Gold, electropolished, Au (110)[9]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.10	8.17	82.83	0.995
0.20	2.13	41.73	0.995
0.30	0.99	27.82	0.995
0.40	0.59	20.83	0.995
0.50	0.39	16.61	0.994
0.60	0.28	13.78	0.994
0.70	0.22	11.75	0.994
0.80	0.18	10.21	0.993
0.90	0.15	9.01	0.993
1.00	0.13	8.03	0.992
1.20	0.10	6.54	0.991
1.40	0.08	5.44	0.989
1.60	0.08	4.56	0.986
1.80	0.09	3.82	0.979
2.00	0.13	3.16	0.953
2.10	0.18	2.84	0.925
2.20	0.24	2.54	0.880
2.40	0.50	1.86	0.647
2.50	0.82	1.59	0.438
2.60	1.24	1.54	0.331
2.70	1.43	1.72	0.356
2.80	1.46	1.77	0.368
2.90	1.50	1.79	0.368
3.00	1.54	1.80	0.369
3.10	1.54	1.81	0.371
3.20	1.54	1.80	0.368
3.30	1.55	1.78	0.362
3.40	1.56	1.76	0.356
3.50	1.58	1.73	0.349
3.60	1.62	1.73	0.346
3.70	1.64	1.75	0.351
3.80	1.63	1.79	0.360
3.90	1.59	1.81	0.366
4.00	1.55	1.81	0.369
4.10	1.51	1.79	0.368
4.20	1.48	1.78	0.367
4.30	1.45	1.77	0.368
4.40	1.41	1.76	0.370
4.50	1.35	1.74	0.370
4.60	1.30	1.69	0.364
4.70	1.27	1.64	0.354
4.80	1.25	1.59	0.344
4.90	1.23	1.54	0.332
5.00	1.22	1.49	0.319
5.20	1.21	1.40	0.295
5.40	1.21	1.33	0.275
5.60	1.21	1.27	0.256
5.80	1.21	1.20	0.236
6.00	1.22	1.14	0.218
6.20	1.24	1.09	0.203
6.40	1.25	1.05	0.190
6.60	1.27	1.01	0.177
6.80	1.30	0.97	0.167
7.00	1.34	0.95	0.162
7.20	1.36	0.95	0.161
7.40	1.38	0.96	0.164
7.60	1.38	0.98	0.169
7.80	1.35	0.99	0.171
8.00	1.31	0.96	0.165
8.20	1.30	0.92	0.155
8.40	1.30	0.89	0.147
8.60	1.31	0.88	0.144
8.80	1.31	0.86	0.140
9.00	1.30	0.83	0.133
9.20	1.31	0.81	0.126
9.40	1.33	0.78	0.122
9.60	1.36	0.78	0.121
9.80	1.37	0.79	0.124
10.00	1.37	0.80	0.126
10.20	1.36	0.80	0.127
10.40	1.35	0.80	0.125
10.60	1.34	0.79	0.123
10.80	1.34	0.77	0.120
11.00	1.34	0.76	0.116
11.20	1.34	0.74	0.113
11.40	1.35	0.73	0.111
11.60	1.36	0.72	0.109
11.80	1.38	0.71	0.108
12.00	1.39	0.71	0.109
12.40	1.44	0.73	0.115
12.80	1.45	0.79	0.127
13.20	1.42	0.84	0.137
13.60	1.37	0.86	0.140
14.00	1.33	0.86	0.140
14.40	1.29	0.86	0.139
14.80	1.26	0.84	0.135
15.20	1.24	0.83	0.132
15.60	1.22	0.81	0.127
16.00	1.21	0.79	0.123
16.40	1.20	0.78	0.119
16.80	1.19	0.76	0.116
17.20	1.19	0.75	0.114
17.60	1.19	0.74	0.111
18.00	1.19	0.74	0.109
18.40	1.19	0.73	0.109
18.80	1.20	0.74	0.110
19.20	1.21	0.76	0.116
19.60	1.21	0.80	0.125
20.00	1.18	0.83	0.133
20.40	1.14	0.85	0.141
20.80	1.10	0.87	0.149
21.20	1.05	0.88	0.156
21.60	1.00	0.88	0.162
22.00	0.94	0.86	0.164
22.40	0.89	0.83	0.163
22.80	0.85	0.79	0.157
23.20	0.82	0.75	0.149
23.60	0.80	0.70	0.138
24.00	0.80	0.66	0.125
24.40	0.80	0.62	0.113
24.80	0.80	0.58	0.101
25.20	0.82	0.56	0.090
25.60	0.83	0.54	0.084
26.00	0.84	0.52	0.079
26.40	0.85	0.51	0.074
26.80	0.85	0.50	0.071
27.20	0.86	0.49	0.068
27.60	0.86	0.49	0.065
28.00	0.87	0.48	0.063
28.40	0.88	0.48	0.062
28.80	0.88	0.48	0.062
29.20	0.88	0.48	0.062
29.60	0.87	0.48	0.064
30.00	0.86	0.48	0.064

Hafnium, single crystal, $\vec{E} \parallel \hat{c}$[10]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.52	1.48	4.11	0.747

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.56	1.84	3.29	0.615
0.60	2.34	2.62	0.486
0.66	3.21	2.13	0.428
0.70	3.70	2.03	0.441
0.76	4.31	2.10	0.476
0.80	4.61	2.31	0.504
0.86	4.71	2.70	0.533
0.90	4.64	2.85	0.541
0.95	4.54	2.96	0.545
1.00	4.45	3.00	0.545
1.10	4.28	3.08	0.547
1.20	4.08	3.10	0.544
1.30	3.87	3.04	0.536
1.40	3.72	2.95	0.525
1.50	3.60	2.85	0.514
1.60	3.52	2.73	0.500
1.70	3.52	2.61	0.488
1.80	3.57	2.56	0.485
1.90	3.63	2.59	0.489
2.00	3.65	2.67	0.498
2.10	3.64	2.81	0.511
2.20	3.53	2.99	0.526
2.30	3.34	3.09	0.534
2.40	3.15	3.11	0.537
2.50	2.99	3.13	0.540
2.60	2.83	3.12	0.542
2.70	2.68	3.10	0.542
2.80	2.54	3.08	0.543
2.90	2.40	3.04	0.544
3.00	2.27	3.00	0.544
3.10	2.14	2.95	0.544
3.20	2.00	2.89	0.544
3.30	1.87	2.79	0.538
3.40	1.78	2.68	0.528
3.50	1.71	2.58	0.517
3.60	1.66	2.48	0.503
3.70	1.63	2.40	0.491
3.80	1.60	2.33	0.481
3.90	1.56	2.27	0.473
4.00	1.52	2.21	0.466
4.10	1.48	2.14	0.455
4.20	1.45	2.07	0.442
4.30	1.43	2.01	0.431
4.40	1.41	1.95	0.420
4.50	1.39	1.89	0.407
4.60	1.39	1.83	0.394
4.70	1.39	1.79	0.382
4.80	1.38	1.75	0.373
4.90	1.38	1.71	0.364
5.00	1.37	1.68	0.356
5.20	1.36	1.61	0.341
5.40	1.35	1.55	0.324
5.60	1.35	1.51	0.314
5.80	1.32	1.48	0.308
6.00	1.28	1.41	0.295
6.20	1.26	1.35	0.278
6.40	1.26	1.28	0.258
6.60	1.27	1.22	0.240
6.80	1.28	1.16	0.224
7.00	1.31	1.13	0.212
7.20	1.33	1.10	0.204
7.40	1.34	1.07	0.197
7.60	1.36	1.05	0.191
7.80	1.37	1.02	0.183
8.00	1.40	1.01	0.179
8.20	1.43	1.01	0.178
8.40	1.45	1.01	0.180
8.60	1.47	1.02	0.183
8.80	1.48	1.04	0.186
9.00	1.49	1.07	0.193
9.20	1.50	1.10	0.201
9.40	1.48	1.14	0.211
9.60	1.46	1.18	0.222
9.80	1.41	1.21	0.230
10.00	1.36	1.22	0.235
10.20	1.32	1.22	0.238
10.40	1.28	1.22	0.240
10.60	1.24	1.21	0.241
10.80	1.20	1.20	0.242
11.00	1.16	1.19	0.242
11.20	1.13	1.17	0.241
11.40	1.10	1.16	0.241
11.60	1.07	1.14	0.239
11.80	1.04	1.12	0.238
12.00	1.02	1.10	0.236
12.40	0.96	1.06	0.232
12.80	0.92	1.01	0.225
13.20	0.88	0.96	0.218
13.60	0.84	0.90	0.205
14.00	0.83	0.83	0.186
14.40	0.83	0.80	0.172
14.80	0.81	0.76	0.167
15.20	0.79	0.70	0.153
15.60	0.79	0.64	0.132
16.00	0.83	0.60	0.111
16.40	0.81	0.60	0.114
16.80	0.79	0.55	0.105
17.20	0.79	0.50	0.089
17.60	0.80	0.46	0.077
18.00	0.81	0.42	0.064
18.40	0.84	0.38	0.051
18.80	0.87	0.34	0.040
19.00	0.89	0.33	0.036
19.60	0.93	0.32	0.030
20.00	0.94	0.31	0.027
20.60	0.97	0.30	0.023
21.00	0.99	0.29	0.022
21.60	1.01	0.28	0.020
22.00	1.03	0.28	0.020
22.60	1.06	0.28	0.020
23.00	1.07	0.28	0.021
23.60	1.09	0.29	0.022
24.00	1.09	0.30	0.023
24.60	1.10	0.31	0.024

Hafnium, single crystal, $\vec{E} \perp \hat{c}$ [10]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.52	2.25	4.65	0.723
0.56	2.34	3.66	0.623
0.60	2.84	2.89	0.512
0.66	3.71	2.35	0.469
0.70	4.26	2.21	0.482
0.76	4.97	2.33	0.521
0.80	5.41	2.62	0.554
0.86	5.46	3.36	0.593
0.90	5.22	3.62	0.601
0.95	4.95	3.72	0.602
1.00	4.76	3.76	0.602
1.10	4.43	3.80	0.601
1.20	4.07	3.74	0.594
1.30	3.79	3.55	0.578
1.40	3.61	3.36	0.561
1.50	3.55	3.13	0.540
1.60	3.58	3.01	0.529
1.70	3.63	2.98	0.526
1.80	3.66	3.02	0.530
1.90	3.63	3.14	0.541
2.00	3.51	3.26	0.551
2.10	3.35	3.33	0.558
2.20	3.18	3.36	0.563
2.30	2.99	3.39	0.568
2.40	2.78	3.35	0.569
2.50	2.65	3.26	0.562
2.60	2.54	3.22	0.560
2.70	2.42	3.17	0.559
2.80	2.31	3.13	0.558
2.90	2.20	3.08	0.558
3.00	2.08	3.05	0.561
3.10	1.94	2.98	0.560
3.20	1.83	2.88	0.555
3.30	1.74	2.78	0.547
3.40	1.68	2.69	0.538
3.50	1.62	2.61	0.529
3.60	1.57	2.52	0.519
3.70	1.53	2.45	0.510
3.80	1.49	2.38	0.501
3.90	1.45	2.32	0.493
4.00	1.41	2.25	0.484
4.10	1.38	2.18	0.474
4.20	1.35	2.11	0.462
4.30	1.33	2.05	0.451
4.40	1.31	1.99	0.438
4.50	1.30	1.93	0.427
4.60	1.29	1.88	0.415
4.70	1.28	1.82	0.402
4.80	1.28	1.77	0.389
4.90	1.27	1.73	0.379
5.00	1.27	1.69	0.367
5.20	1.27	1.62	0.349
5.40	1.27	1.57	0.335
5.60	1.26	1.52	0.322
5.80	1.24	1.48	0.313
6.00	1.21	1.42	0.302
6.20	1.19	1.36	0.285
6.40	1.18	1.29	0.265
6.60	1.19	1.22	0.244
6.80	1.21	1.18	0.230
7.00	1.22	1.14	0.217
7.20	1.23	1.10	0.206
7.40	1.26	1.06	0.194
7.60	1.28	1.04	0.187
7.80	1.30	1.02	0.180
8.00	1.33	1.00	0.174
8.20	1.35	0.99	0.173
8.40	1.38	0.99	0.173
8.60	1.40	1.00	0.174
8.80	1.42	1.02	0.178
9.00	1.43	1.04	0.184
9.20	1.45	1.08	0.193
9.40	1.43	1.12	0.204
9.60	1.40	1.16	0.214
9.80	1.37	1.19	0.223
10.00	1.32	1.21	0.230
10.20	1.27	1.21	0.234
10.40	1.23	1.20	0.235
10.60	1.19	1.20	0.237

Energy (eV)	*n*	*k*	$R(\phi = 0)$
10.80	1.15	1.19	0.237
11.00	1.12	1.17	0.237
11.20	1.08	1.16	0.237
11.40	1.05	1.14	0.236
11.60	1.03	1.12	0.235
11.80	1.00	1.10	0.233
12.00	0.97	1.08	0.231
12.40	0.92	1.04	0.226
12.80	0.88	0.99	0.219
13.20	0.83	0.94	0.211
13.60	0.80	0.88	0.196
14.00	0.79	0.81	0.177
14.40	0.80	0.77	0.160
14.80	0.77	0.73	0.154
15.20	0.76	0.68	0.140
15.60	0.76	0.61	0.119
16.00	0.81	0.58	0.099
16.40	0.78	0.57	0.102
16.80	0.77	0.53	0.092
17.20	0.77	0.48	0.077
17.60	0.79	0.44	0.065
18.00	0.80	0.39	0.053
18.40	0.82	0.36	0.041
18.80	0.86	0.33	0.032
19.00	0.88	0.32	0.030
19.60	0.91	0.31	0.025
20.00	0.93	0.30	0.023
20.60	0.96	0.29	0.021
21.00	0.97	0.29	0.020
21.60	1.00	0.28	0.019
22.00	1.01	0.28	0.019
22.60	1.03	0.27	0.018
23.00	1.05	0.28	0.019
23.60	1.06	0.28	0.020
24.00	1.07	0.29	0.021
24.60	1.09	0.30	0.022

Iridium[11]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.10	28.49	60.62	0.975
0.15	15.32	45.15	0.973
0.20	9.69	35.34	0.972
0.25	6.86	28.84	0.969
0.30	5.16	24.25	0.967
0.35	4.11	20.79	0.964
0.40	3.42	18.06	0.960
0.45	3.05	15.82	0.954
0.50	2.98	14.06	0.944
0.60	2.79	11.58	0.925
0.70	2.93	9.78	0.895
0.80	3.14	8.61	0.862
0.90	3.19	7.88	0.840
1.00	3.15	7.31	0.822
1.10	3.04	6.84	0.808
1.20	2.96	6.41	0.791
1.30	2.85	6.07	0.779
1.40	2.72	5.74	0.767
1.50	2.65	5.39	0.750
1.60	2.68	5.08	0.728
1.70	2.69	4.92	0.716
1.80	2.64	4.81	0.710
1.90	2.57	4.68	0.704
2.00	2.50	4.57	0.699
2.10	2.40	4.48	0.697
2.20	2.29	4.38	0.695
2.30	2.18	4.26	0.692
2.40	2.07	4.14	0.689
2.50	1.98	4.00	0.682
2.60	1.91	3.86	0.673
2.70	1.85	3.73	0.665
2.80	1.81	3.61	0.655
2.90	1.77	3.51	0.646
3.00	1.73	3.43	0.640
3.20	1.62	3.26	0.629
3.40	1.53	3.05	0.610
3.60	1.52	2.81	0.573
3.80	1.61	2.69	0.541
4.00	1.64	2.68	0.535
4.20	1.58	2.71	0.549
4.40	1.45	2.68	0.561
4.60	1.31	2.60	0.567
4.80	1.18	2.49	0.570
5.00	1.10	2.35	0.559
5.20	1.04	2.22	0.543
5.40	1.00	2.09	0.522
5.60	0.98	1.98	0.499
5.80	0.96	1.86	0.474
6.00	0.95	1.78	0.454
6.20	0.94	1.68	0.427
6.40	0.94	1.59	0.401
6.60	0.94	1.50	0.375
6.80	0.95	1.42	0.345
7.00	0.97	1.34	0.318
7.20	0.99	1.27	0.290
7.40	1.02	1.20	0.262
7.60	1.03	1.14	0.241
7.80	1.08	1.06	0.208
8.00	1.13	1.03	0.191
8.20	1.18	1.00	0.179
8.40	1.22	0.98	0.171
8.60	1.26	0.96	0.164
8.80	1.29	0.95	0.160
9.00	1.33	0.94	0.157
9.20	1.36	0.95	0.159
9.40	1.39	0.95	0.161
9.60	1.42	0.97	0.163
9.80	1.44	0.99	0.169
10.00	1.45	1.01	0.175
10.20	1.45	1.04	0.182
10.40	1.44	1.07	0.187
10.60	1.43	1.09	0.193
10.80	1.41	1.12	0.200
11.00	1.38	1.13	0.206
11.20	1.34	1.14	0.208
11.40	1.31	1.13	0.208
11.60	1.28	1.12	0.206
11.80	1.25	1.10	0.203
12.00	1.24	1.08	0.199
12.40	1.21	1.05	0.191
12.80	1.19	1.01	0.181
13.20	1.18	0.98	0.173
13.60	1.17	0.95	0.165
14.00	1.16	0.91	0.155
14.40	1.17	0.88	0.147
14.80	1.18	0.87	0.142
15.20	1.19	0.84	0.136
15.60	1.20	0.83	0.133
16.00	1.21	0.83	0.131
16.40	1.23	0.82	0.129
16.80	1.25	0.82	0.127
17.20	1.28	0.83	0.131
17.60	1.30	0.87	0.140
18.00	1.30	0.93	0.154
18.40	1.27	0.97	0.166
18.80	1.24	1.00	0.176
19.20	1.20	1.03	0.187
19.60	1.15	1.05	0.197
20.00	1.10	1.06	0.205
20.50	1.04	1.05	0.210
21.00	0.99	1.04	0.215
21.50	0.94	1.02	0.220
22.00	0.89	1.00	0.222
22.50	0.84	0.99	0.228
23.00	0.79	0.96	0.232
23.50	0.76	0.92	0.228
24.00	0.73	0.87	0.223
24.50	0.70	0.83	0.218
25.00	0.69	0.79	0.209
25.50	0.68	0.76	0.200
26.00	0.67	0.72	0.192
26.50	0.67	0.69	0.181
27.00	0.66	0.66	0.174
27.50	0.66	0.63	0.166
28.00	0.66	0.61	0.158
28.50	0.66	0.59	0.151
29.00	0.65	0.57	0.148
29.50	0.64	0.55	0.145
30.00	0.64	0.53	0.140
32.00	0.62	0.44	0.119
34.00	0.64	0.35	0.091
36.00	0.69	0.27	0.059
38.00	0.73	0.24	0.044
40.00	0.76	0.22	0.034

Iron[5]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.10	6.41	33.07	0.978
0.15	6.26	22.82	0.956
0.20	3.68	18.23	0.958
0.26	4.98	13.68	0.911
0.30	4.87	12.05	0.892
0.36	4.68	10.44	0.867
0.40	4.42	9.75	0.858
0.50	4.14	8.02	0.817
0.60	3.93	6.95	0.783
0.70	3.78	6.17	0.752
0.80	3.65	5.60	0.725
0.90	3.52	5.16	0.700
1.00	3.43	4.79	0.678
1.10	3.33	4.52	0.660
1.20	3.24	4.26	0.641
1.30	3.16	4.07	0.626
1.40	3.12	3.87	0.609
1.50	3.05	3.77	0.601
1.60	3.00	3.60	0.585
1.70	2.98	3.52	0.577
1.80	2.92	3.46	0.573
1.90	2.89	3.37	0.563
2.00	2.85	3.36	0.563
2.10	2.80	3.34	0.562
2.20	2.74	3.33	0.563
2.30	2.65	3.34	0.567
2.40	2.56	3.31	0.567
2.50	2.46	3.31	0.570
2.60	2.34	3.30	0.576
2.70	2.23	3.25	0.575
2.80	2.12	3.23	0.580

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
2.90	2.01	3.17	0.580
3.00	1.88	3.12	0.583
3.10	1.78	3.04	0.580
3.20	1.70	2.96	0.576
3.30	1.62	2.87	0.572
3.40	1.55	2.79	0.565
3.50	1.50	2.70	0.556
3.60	1.47	2.63	0.548
3.70	1.43	2.56	0.542
3.83	1.38	2.49	0.534
4.00	1.30	2.39	0.527
4.17	1.26	2.27	0.510
4.33	1.23	2.18	0.494
4.50	1.20	2.10	0.482
4.67	1.16	2.02	0.470
4.83	1.14	1.93	0.451
5.00	1.14	1.87	0.435
5.17	1.12	1.81	0.425
5.33	1.11	1.75	0.408
5.50	1.09	1.17	0.401
5.67	1.09	1.65	0.383
5.83	1.10	1.61	0.373
6.00	1.09	1.59	0.366
6.17	1.08	1.57	0.365
6.33	1.04	1.55	0.365
6.50	1.02	1.51	0.358
6.67	1.00	1.47	0.351
6.83	0.97	1.43	0.346
7.00	0.96	1.39	0.333
7.17	0.94	1.35	0.327
7.33	0.94	1.30	0.311
7.50	0.94	1.26	0.298
7.67	0.94	1.23	0.288
7.83	0.94	1.21	0.279
8.00	0.94	1.18	0.272
8.17	0.94	1.16	0.265
8.33	0.94	1.14	0.258
8.50	0.94	1.12	0.251
8.67	0.94	1.10	0.246
8.83	0.92	1.08	0.240
9.00	0.93	1.07	0.236
9.17	0.92	1.06	0.233
9.33	0.91	1.04	0.231
9.50	0.90	1.02	0.226
9.67	0.90	1.00	0.221
9.83	0.89	0.99	0.218
10.00	0.88	0.97	0.213
10.17	0.87	0.94	0.203
10.33	0.87	0.91	0.196
10.50	0.87	0.89	0.189
10.67	0.88	0.87	0.179
10.83	0.89	0.85	0.170
11.00	0.91	0.83	0.162
11.17	0.92	0.83	0.159
11.33	0.93	0.84	0.159
11.50	0.93	0.84	0.160
11.67	0.93	0.84	0.162
11.83	0.92	0.84	0.163
12.00	0.91	0.84	0.163
12.17	0.90	0.84	0.165
12.33	0.89	0.83	0.164
12.50	0.98	0.83	0.165
12.67	0.87	0.82	0.166
12.83	0.86	0.81	0.166
13.00	0.85	0.80	0.162
13.17	0.84	0.79	0.161
13.33	0.84	0.78	0.160
13.50	0.83	0.77	0.159
13.67	0.82	0.76	0.157
13.83	0.81	0.75	0.154
14.00	0.81	0.73	0.151
14.17	0.80	0.72	0.149
14.33	0.80	0.71	0.146
14.50	0.79	0.79	0.144
14.67	0.79	0.69	0.141
14.83	0.78	0.67	0.138
15.00	0.78	0.66	0.135
15.17	0.78	0.65	0.131
15.33	0.78	0.64	0.238
15.50	0.77	0.63	0.126
15.67	0.77	0.62	0.123
15.83	0.77	0.61	0.119
16.00	0.77	0.60	0.116
16.17	0.78	0.58	0.112
16.33	0.78	0.58	0.110
16.50	0.78	0.57	0.107
16.67	0.77	0.56	0.106
16.83	0.78	0.55	0.103
17.00	0.78	0.55	0.102
17.17	0.78	0.54	0.100
17.33	0.78	0.54	0.098
17.50	0.77	0.53	0.097
17.67	0.77	0.52	0.095
17.83	0.78	0.51	0.092
18.00	0.78	0.51	0.091
18.17	0.78	0.51	0.090
18.33	0.78	0.50	0.089
18.50	0.77	0.50	0.089
18.67	0.77	0.50	0.088
18.83	0.77	0.49	0.087
19.00	0.77	0.49	0.087
19.17	0.76	0.49	0.088
19.33	0.76	0.48	0.087
19.50	0.75	0.47	0.086
19.67	0.75	0.47	0.085
19.83	0.75	0.46	0.084
20.00	0.74	0.45	0.083
20.17	0.74	0.44	0.081
20.33	0.74	0.44	0.081
20.50	0.74	0.42	0.080
20.67	0.73	0.43	0.079
20.83	0.73	0.42	0.078
21.00	0.73	0.41	0.077
21.17	0.72	0.40	0.076
21.33	0.72	0.39	0.074
21.50	0.72	0.38	0.073
21.67	0.72	0.38	0.071
21.83	0.72	0.37	0.070
22.00	0.72	0.36	0.068
22.17	0.71	0.35	0.067
22.33	0.72	0.34	0.064
22.50	0.72	0.34	0.063
22.67	0.72	0.33	0.062
22.83	0.72	0.32	0.059
23.00	0.72	0.31	0.058
23.17	0.72	0.30	0.056
23.33	0.72	0.29	0.054
23.50	0.73	0.28	0.050
23.67	0.73	0.28	0.049
23.83	0.74	0.27	0.047
24.00	0.74	0.27	0.045
24.17	0.74	0.26	0.044
24.33	0.74	0.26	0.043
24.50	0.74	0.25	0.042
24.67	0.75	0.25	0.040
24.83	0.75	0.24	0.039
25.00	0.75	0.24	0.038
26.00	0.76	0.21	0.031
27.00	0.78	0.18	0.026
28.00	0.79	0.16	0.021
29.00	0.81	0.14	0.017
30.00	0.82	0.13	0.014

Lithium[12]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.14	0.659	38.0	0.998
0.54	0.661	12.6	0.984
0.75	0.561	7.68	0.963
1.05	0.448	5.58	0.946
1.35	0.338	4.36	0.935
1.65	0.265	3.55	0.925
1.95	0.221	2.94	0.913
2.25	0.206	2.48	0.892
2.55	0.217	2.11	0.854
2.85	0.247	1.82	0.797
3.15	0.304	1.60	0.715
3.45	0.334	1.45	0.656
3.75	0.345	1.32	0.611
4.05	0.346	1.21	0.578
4.35	0.333	1.11	0.557
4.65	0.317	1.01	0.540
4.95	0.302	0.906	0.520
5.25	0.299	0.795	0.484
5.55	0.310	0.688	0.434
5.85	0.342	0.594	0.365
6.15	0.376	0.522	0.306
6.45	0.408	0.460	0.256
6.75	0.440	0.407	0.214
7.05	0.466	0.364	0.183
7.35	0.492	0.320	0.155
7.65	0.517	0.282	0.131
7.95	0.545	0.246	0.109
8.25	0.572	0.214	0.091
8.55	0.601	0.189	0.075
8.85	0.624	0.163	0.063
9.15	0.657	0.144	0.050
9.45	0.680	0.130	0.042
9.75	0.708	0.119	0.034
10.1	0.726	0.108	0.029
10.4	0.743	0.102	0.025
10.6	0.753	0.080	0.022

Magnesium (evaporated)[13]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
2.145	0.48	3.71	0.880
2.270	0.57	3.47	0.843
2.522	0.53	2.92	0.805
2.845	0.52	2.65	0.777
3.064	0.52	2.05	0.681
5.167	0.10	1.60	0.894
5.636	0.15	1.50	0.832
6.200	0.20	1.40	0.765
6.889	0.25	1.30	0.693
7.750	0.20	1.20	0.722
8.857	0.15	0.95	0.730
10.335	0.25	0.40	0.419

Manganese[14]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.64	3.89	5.95	0.738
0.77	3.78	5.41	0.710
0.89	3.65	5.02	0.688
1.02	3.48	4.74	0.673
1.14	3.30	4.53	0.662
1.26	3.10	4.35	0.653
1.39	2.97	4.18	0.643
1.51	2.83	4.03	0.634
1.64	2.70	3.91	0.627
1.76	2.62	3.78	0.617
1.88	2.56	3.65	0.606
2.01	2.51	3.54	0.596
2.13	2.47	3.43	0.585
2.26	2.39	3.33	0.577
2.38	2.32	3.23	0.567
2.50	2.25	3.14	0.559
2.63	2.19	3.06	0.552
2.75	2.11	2.98	0.545
2.88	2.06	2.90	0.536
3.00	2.00	2.82	0.528
3.12	1.96	2.74	0.518
3.25	1.92	2.67	0.509
3.37	1.89	2.59	0.498
3.50	1.89	2.51	0.484
3.62	1.87	2.45	0.475
3.74	1.86	2.38	0.463
3.87	1.86	2.32	0.451
3.99	1.86	2.25	0.438
4.12	1.86	2.19	0.427
4.24	1.85	2.14	0.417
4.36	1.85	2.08	0.406
4.49	1.86	2.03	0.395
4.61	1.85	1.99	0.388
4.74	1.84	1.94	0.378
4.86	1.83	1.91	0.372
4.98	1.82	1.86	0.362
5.11	1.82	1.82	0.354
5.23	1.81	1.79	0.348
5.36	1.78	1.76	0.342
5.48	1.74	1.73	0.337
5.60	1.73	1.70	0.331
5.73	1.72	1.67	0.325
5.85	1.70	1.64	0.319
5.98	1.67	1.61	0.313
6.10	1.63	1.58	0.307
6.22	1.62	1.55	0.301
6.35	1.59	1.52	0.295
6.47	1.55	1.50	0.292
6.60	1.48	1.47	0.288

Mercury (liquid)[15]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.2	13.99	14.27	0.869
0.3	11.37	11.95	0.846
0.4	9.741	10.65	0.830
0.5	8.528	9.805	0.818
0.6	7.574	9.195	0.808
0.8	6.086	8.312	0.796
1.0	4.962	7.643	0.789
1.2	4.050	7.082	0.786
1.4	3.324	6.558	0.785
1.6	2.746	6.054	0.783
1.8	2.284	5.582	0.782
2.0	1.910	5.150	0.782
2.2	1.620	4.751	0.780
2.4	1.384	4.407	0.779
2.6	1.186	4.090	0.779
2.8	1.027	3.802	0.779
3.0	0.898	3.538	0.777
3.2	0.798	3.294	0.773
3.4	0.713	3.074	0.770
3.6	0.644	2.860	0.763
3.8	0.589	2.665	0.755
4.0	0.542	2.502	0.749
4.2	0.507	2.341	0.738
4.4	0.477	2.195	0.727
4.6	0.452	2.058	0.715
4.8	0.431	1.929	0.701
5.0	0.414	1.806	0.685
5.2	0.401	1.687	0.666
5.4	0.394	1.569	0.642
5.6	0.386	1.454	0.617
5.7	0.386	1.396	0.601
5.8	0.386	1.341	0.585
5.9	0.385	1.287	0.569
6.0	0.386	1.232	0.551
6.1	0.388	1.176	0.531
6.2	0.390	1.118	0.510
6.3	0.399	1.058	0.481
6.4	0.412	1.002	0.450
6.5	0.428	0.949	0.418
6.6	0.436	0.898	0.392
6.7	0.438	0.836	0.367
6.8	0.459	0.756	0.320
6.9	0.510	0.676	0.255
7.0	0.585	0.617	0.191
7.1	0.663	0.589	0.148
7.2	0.717	0.584	0.128
7.3	0.769	0.575	0.111
7.4	0.817	0.574	0.100
7.5	0.860	0.580	0.094
7.6	0.893	0.597	0.093
7.8	0.929	0.623	0.096
8.0	0.946	0.639	0.098
8.2	0.952	0.645	0.099
8.4	0.953	0.638	0.097
8.6	0.956	0.624	0.093
8.8	0.965	0.607	0.087
9.0	0.975	0.588	0.082
9.2	0.988	0.568	0.076
9.4	1.009	0.548	0.069
9.6	1.044	0.541	0.066
9.8	1.061	0.557	0.069
10.0	1.062	0.567	0.071
10.2	1.054	0.569	0.072
10.4	1.045	0.561	0.070
10.6	1.041	0.550	0.068
10.8	1.039	0.537	0.065
11.0	1.039	0.523	0.062
11.5	1.050	0.491	0.055
12.0	1.064	0.467	0.050
12.5	1.078	0.445	0.045
13.0	1.092	0.430	0.042
13.5	1.104	0.416	0.040
14.0	1.115	0.404	0.038
14.5	1.125	0.394	0.037
15.0	1.135	0.383	0.035
15.5	1.146	0.374	0.034
16.0	1.159	0.368	0.034
16.5	1.170	0.367	0.034
17.0	1.177	0.367	0.034
17.5	1.184	0.366	0.034
18.0	1.191	0.367	0.035
18.5	1.195	0.367	0.035
19.0	1.200	0.366	0.035
19.5	1.208	0.364	0.035

Molybdenum[16]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.10	18.53	68.51	0.985
0.15	8.78	47.54	0.985
0.20	5.10	35.99	0.985
0.25	3.36	28.75	0.984
0.30	2.44	23.80	0.983
0.34	2.00	20.84	0.982
0.38	1.70	18.44	0.980
0.42	1.57	16.50	0.978
0.46	1.46	14.91	0.975
0.50	1.37	13.55	0.971
0.54	1.35	12.36	0.966
0.58	1.34	11.34	0.960
0.62	1.38	10.44	0.952
0.66	1.43	9.67	0.942
0.70	1.48	8.99	0.932
0.74	1.51	8.38	0.921
0.78	1.60	7.83	0.906
0.82	1.64	7.35	0.892
0.86	1.70	6.89	0.876
9.90	1.74	6.48	0.859
1.00	1.94	5.58	0.805
1.10	2.15	4.85	0.743
1.20	2.44	4.22	0.671
1.30	2.77	3.74	0.608
1.40	3.15	3.40	0.562
1.50	3.53	3.30	0.550
1.60	3.77	3.41	0.562
1.70	3.84	3.51	0.570
1.80	3.81	3.58	0.576
1.90	3.74	3.58	0.576
2.00	3.68	3.52	0.571
2.10	3.68	3.45	0.565
2.20	3.76	3.41	0.562
2.30	3.79	3.61	0.578
2.40	3.59	3.78	0.594
2.50	3.36	3.73	0.591
2.60	3.22	3.61	0.582
2.70	3.13	3.51	0.573
2.80	3.08	3.42	0.565
2.90	3.05	3.33	0.566
3.00	3.04	3.27	0.550
3.10	3.03	3.21	0.544
3.20	3.05	3.18	0.540
3.30	3.06	3.18	0.540
3.40	3.06	3.19	0.541
3.50	3.06	3.21	0.543
3.60	3.05	3.23	0.546
3.70	3.04	3.27	0.550
3.80	3.04	3.31	0.554
3.90	3.04	3.40	0.564
4.00	3.01	3.51	0.576
4.20	2.77	3.77	0.610
4.40	2.39	3.88	0.640
4.60	2.06	3.84	0.658
4.80	1.75	3.76	0.678
5.00	1.46	3.62	0.695
5.20	1.22	3.42	0.706

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
5.40	1.07	3.20	0.706
5.60	0.96	2.99	0.700
5.80	0.89	2.80	0.688
6.00	0.85	2.64	0.674
6.20	0.81	2.50	0.660
6.40	0.79	2.36	0.641
6.60	0.78	2.24	0.619
6.80	0.78	2.13	0.592
7.00	0.80	2.04	0.568
7.20	0.81	1.98	0.548
7.40	0.81	1.95	0.542
7.60	0.75	1.90	0.552
7.80	0.71	1.81	0.542
8.00	0.69	1.73	0.530
8.20	0.67	1.65	0.512
8.40	0.66	1.57	0.495
8.60	0.65	1.49	0.475
8.80	0.65	1.41	0.450
9.00	0.65	1.33	0.420
9.20	0.67	1.25	0.385
9.40	0.69	1.19	0.355
9.60	0.71	1.12	0.320
9.80	0.74	1.05	0.285
10.00	0.77	0.99	0.250
10.20	0.81	0.93	0.217
10.40	0.86	0.88	0.188
10.60	0.91	0.83	0.162
10.80	0.98	0.79	0.138
11.00	1.05	0.77	0.125
11.20	1.12	0.78	0.123
11.40	1.18	0.80	0.125
11.60	1.23	0.85	0.135
11.80	1.25	0.89	0.145
12.00	1.26	0.92	0.154
12.40	1.25	0.98	0.168
12.80	1.23	1.00	0.178
13.20	1.20	1.02	0.185
13.60	1.17	1.02	0.187
14.00	1.15	1.01	0.185
14.40	1.13	1.00	0.182
14.80	1.13	0.99	0.179
15.00	1.14	0.99	0.179
15.60	1.15	1.01	0.184
16.00	1.14	1.04	0.194
16.60	1.10	1.10	0.216
17.00	1.04	1.12	0.233
17.60	0.94	1.14	0.257
18.00	0.87	1.12	0.270
18.60	0.77	1.08	0.283
19.00	0.71	1.02	0.284
19.60	0.66	0.94	0.275
20.00	0.64	0.89	0.264
20.60	0.62	0.81	0.245
21.00	0.61	0.77	0.234
21.60	0.61	0.71	0.215
22.00	0.60	0.69	0.207
22.60	0.59	0.63	0.195
23.00	0.58	0.60	0.185
23.60	0.58	0.53	0.166
24.00	0.58	0.49	0.151
24.60	0.60	0.43	0.124
25.00	0.62	0.39	0.106
25.60	0.66	0.35	0.085
26.00	0.68	0.33	0.072
26.50	0.71	0.31	0.060
27.00	0.73	0.29	0.050
27.50	0.76	0.28	0.041
28.00	0.79	0.27	0.036
28.50	0.81	0.26	0.031
29.00	0.83	0.26	0.028
29.50	0.86	0.26	0.025
30.00	0.88	0.26	0.023
31.00	0.92	0.29	0.024
32.00	0.92	0.32	0.030
33.00	0.90	0.33	0.032
34.00	0.91	0.34	0.034
35.00	0.87	0.37	0.043
36.00	0.82	0.34	0.043
37.00	0.81	0.30	0.038
38.00	0.81	0.27	0.033
39.00	0.82	0.25	0.029
40.00	0.83	0.23	0.025
Nickel[17]			
0.10	9.54	45.82	0.983
0.15	5.45	30.56	0.978
0.20	4.12	22.48	0.969
0.25	4.25	17.68	0.950
0.30	4.19	15.05	0.934
0.35	4.03	13.05	0.918
0.40	3.84	11.43	0.900
0.50	4.03	9.64	0.864
0.60	3.84	8.35	0.835
0.70	3.59	7.48	0.813
0.80	3.38	6.82	0.794
0.90	3.18	6.23	0.774
1.00	3.06	5.74	0.753
1.10	2.97	5.38	0.734
1.20	2.85	5.10	0.721
1.30	2.74	4.85	0.708
1.40	2.65	4.63	0.695
1.50	2.53	4.47	0.688
1.60	2.43	4.31	0.679
1.70	2.28	4.18	0.677
1.80	2.14	4.01	0.670
1.90	2.02	3.82	0.659
2.00	1.92	3.65	0.649
2.10	1.85	3.48	0.634
2.20	1.80	3.33	0.620
2.30	1.75	3.19	0.605
2.40	1.71	3.06	0.590
2.50	1.67	2.93	0.575
2.60	1.65	2.81	0.557
2.70	1.64	2.71	0.542
2.80	1.63	2.61	0.525
2.90	1.62	2.52	0.509
3.00	1.61	2.44	0.495
3.10	1.61	2.36	0.480
3.20	1.61	2.30	0.467
3.30	1.61	2.23	0.454
3.40	1.62	2.17	0.441
3.50	1.63	2.11	0.428
3.60	1.64	2.07	0.416
3.70	1.66	2.02	0.405
3.80	1.69	1.99	0.397
3.90	1.72	1.98	0.393
4.00	1.73	1.98	0.392
4.20	1.74	2.01	0.396
4.40	1.71	2.06	0.409
4.60	1.63	2.09	0.421
4.80	1.53	2.11	0.435
5.00	1.40	2.10	0.449
5.20	1.27	2.04	0.454
5.40	1.16	1.94	0.449
5.60	1.09	1.83	0.435
5.80	1.04	1.73	0.417
6.20	1.00	1.54	0.371
6.40	1.01	1.46	0.345
6.60	1.01	1.40	0.325
6.80	1.02	1.35	0.308
7.00	1.03	1.30	0.291
7.20	1.03	1.27	0.282
7.40	1.03	1.24	0.273
7.60	1.02	1.22	0.265
7.80	1.01	1.18	0.256
8.00	1.01	1.15	0.248
8.20	1.00	1.13	0.242
8.40	0.99	1.11	0.235
8.60	0.98	1.08	0.228
8.80	0.97	1.05	0.220
9.00	0.97	1.01	0.211
9.20	0.96	0.99	0.203
9.40	0.95	0.96	0.194
9.60	0.95	0.93	0.185
9.80	0.95	0.89	0.175
10.00	0.95	0.87	0.166
10.20	0.95	0.83	0.155
10.40	0.95	0.80	0.145
10.60	0.97	0.76	0.129
10.80	0.99	0.75	0.123
11.00	1.01	0.73	0.115
11.25	1.04	0.72	0.111
11.50	1.05	0.71	0.109
11.75	1.07	0.71	0.108
12.00	1.07	0.71	0.108
12.25	1.07	0.71	0.107
12.50	1.08	0.71	0.106
12.75	1.08	0.71	0.106
13.00	1.08	0.71	0.105
13.25	1.08	0.71	0.105
13.50	1.07	0.70	0.105
13.75	1.07	0.70	0.105
14.00	1.07	0.71	0.106
14.25	1.06	0.70	0.106
14.50	1.05	0.70	0.106
14.75	1.04	0.70	0.107
15.00	1.03	0.70	0.107
15.25	1.02	0.69	0.106
15.50	1.01	0.69	0.105
15.75	1.00	0.68	0.104
16.00	0.99	0.67	0.103
16.50	0.98	0.66	0.101
17.00	0.96	0.64	0.098
17.50	0.94	0.63	0.096
18.00	0.92	0.61	0.092
18.50	0.91	0.58	0.087
19.00	0.90	0.56	0.082
19.50	0.90	0.54	0.077
20.00	0.89	0.51	0.071
20.50	0.89	0.49	0.066
21.00	0.90	0.47	0.061
21.50	0.91	0.46	0.057
22.00	0.91	0.45	0.055
22.50	0.91	0.44	0.053
23.00	0.92	0.44	0.051

Energy (eV)	n	k	R(ϕ = 0)
23.50	0.91	0.44	0.052
24.00	0.90	0.43	0.051
24.50	0.90	0.43	0.051
25.00	0.89	0.42	0.050
26.00	0.88	0.39	0.046
27.00	0.87	0.37	0.042
28.00	0.87	0.35	0.040
29.00	0.86	0.34	0.037
30.00	0.86	0.32	0.034
35.00	0.86	0.24	0.022
40.00	0.87	0.18	0.014
45.00	0.88	0.13	0.008
50.00	0.92	0.10	0.004
60.00	0.96	0.08	0.002
65.00	0.98	0.09	0.002
68.00	0.96	0.12	0.004
70.00	0.94	0.11	0.004
75.00	0.94	0.09	0.003
80.00	0.94	0.07	0.002
90.00	0.94	0.06	0.002
Niobium[18]			
0.12	15.99	53.20	0.979
0.20	7.25	34.14	0.976
0.24	5.47	28.88	0.975
0.28	4.26	24.95	0.974
0.35	3.11	20.03	0.970
0.45	2.28	15.58	0.964
0.55	1.83	12.67	0.956
0.65	1.57	10.59	0.947
0.75	1.41	9.00	0.935
0.85	1.35	7.74	0.918
0.95	1.35	6.70	0.893
1.05	1.44	5.86	0.857
1.15	1.55	5.18	0.814
1.25	1.65	4.63	0.768
1.35	1.76	4.13	0.715
1.45	1.95	3.68	0.650
1.55	2.15	3.37	0.595
1.65	2.36	3.13	0.552
1.75	2.54	2.99	0.527
1.85	2.69	2.89	0.510
1.95	2.82	2.86	0.505
2.05	2.89	2.87	0.505
2.15	2.92	2.87	0.505
2.25	2.93	2.87	0.505
2.35	2.92	2.88	0.506
2.45	2.89	2.90	0.509
2.55	2.83	2.92	0.512
2.65	2.74	2.90	0.511
2.75	2.66	2.86	0.507
2.85	2.58	2.80	0.500
3.00	2.51	2.68	0.485
3.10	2.48	2.60	0.475
3.20	2.45	2.53	0.465
3.30	2.44	2.45	0.453
3.40	2.46	2.38	0.442
3.50	2.48	2.33	0.435
3.60	2.52	2.29	0.428
3.70	2.56	2.27	0.426
3.80	2.59	2.28	0.427
3.90	2.62	2.29	0.429
4.00	2.64	2.33	0.434
4.20	2.64	2.42	0.447
4.40	2.53	2.56	0.467

Energy (eV)	n	k	R(ϕ = 0)
4.60	2.39	2.56	0.470
4.80	2.32	2.52	0.465
5.00	2.26	2.57	0.475
5.20	2.16	2.62	0.487
5.40	2.00	2.68	0.505
5.60	1.81	2.67	0.518
5.80	1.63	2.60	0.522
6.00	1.49	2.49	0.520
6.20	1.38	2.38	0.512
6.40	1.31	2.25	0.496
6.60	1.26	2.14	0.480
6.80	1.24	2.04	0.460
7.00	1.23	1.96	0.441
7.20	1.22	1.91	0.430
7.40	1.20	1.88	0.427
7.60	1.14	1.85	0.430
7.80	1.07	1.78	0.428
8.00	1.02	1.69	0.412
8.20	1.00	1.60	0.390
8.40	0.99	1.51	0.365
8.60	0.99	1.43	0.340
8.70	0.99	1.39	0.328
8.80	1.00	1.36	0.315
9.00	1.01	1.29	0.290
9.20	1.04	1.22	0.265
9.40	1.07	1.18	0.245
9.60	1.10	1.13	0.227
9.80	1.13	1.09	0.209
10.00	1.18	1.05	0.194
10.20	1.23	1.04	0.187
10.40	1.27	1.04	0.185
10.60	1.30	1.06	0.190
10.80	1.32	1.08	0.195
11.00	1.32	1.10	0.200
11.20	1.31	1.12	0.204
11.40	1.30	1.13	0.207
11.60	1.28	1.13	0.209
11.80	1.27	1.13	0.210
12.00	1.25	1.12	0.209
12.40	1.24	1.10	0.204
12.80	1.24	1.09	0.200
13.20	1.24	1.09	0.201
13.60	1.23	1.12	0.208
14.00	1.20	1.13	0.216
14.40	1.16	1.15	0.225
14.80	1.11	1.16	0.234
15.00	1.08	1.16	0.238
15.60	0.99	1.14	0.247
16.00	0.92	1.11	0.250
16.60	0.85	1.04	0.245
17.00	0.80	0.99	0.240
17.20	0.79	0.96	0.236
17.40	0.77	0.93	0.230
17.80	0.75	0.87	0.217
18.00	0.74	0.85	0.209
18.60	0.73	0.77	0.185
19.00	0.72	0.72	0.170
19.60	0.72	0.66	0.150
20.00	0.72	0.62	0.137
20.60	0.71	0.55	0.119
21.00	0.72	0.50	0.100
21.60	0.75	0.43	0.075
22.00	0.78	0.40	0.063
22.60	0.82	0.35	0.045
23.00	0.85	0.33	0.038

Energy (eV)	n	k	R(ϕ = 0)
23.60	0.88	0.30	0.029
24.00	0.91	0.29	0.025
24.60	0.94	0.28	0.022
25.00	0.96	0.27	0.020
25.60	0.99	0.26	0.018
26.00	1.00	0.26	0.017
26.60	1.03	0.25	0.016
27.00	1.04	0.25	0.015
27.60	1.06	0.25	0.015
28.00	1.08	0.24	0.015
28.60	1.11	0.24	0.016
29.00	1.13	0.25	0.017
29.60	1.16	0.26	0.020
30.00	1.18	0.28	0.023
31.00	1.18	0.31	0.026
32.00	1.20	0.34	0.031
33.00	1.21	0.38	0.038
34.00	1.20	0.42	0.044
35.20	1.17	0.47	0.051
36.00	1.15	0.50	0.056
37.50	1.07	0.53	0.064
39.50	0.95	0.50	0.063
40.50	0.92	0.47	0.059
Osmium (Polycrystalline)[9]			
0.10	4.08	50.23	0.994
0.15	2.90	33.60	0.990
0.20	2.44	25.11	0.985
0.25	2.35	19.99	0.977
0.30	2.23	16.54	0.969
0.35	2.33	14.06	0.955
0.40	2.45	12.32	0.940
0.45	2.43	11.02	0.927
0.50	2.41	9.97	0.913
0.55	2.33	9.12	0.901
0.60	2.21	8.37	0.890
0.65	2.11	7.68	0.877
0.70	2.02	7.04	0.862
0.75	2.00	6.46	0.842
0.80	2.00	5.95	0.820
0.85	2.01	5.51	0.796
0.90	2.03	5.10	0.769
0.95	2.05	4.74	0.742
1.00	2.09	4.41	0.712
1.10	2.15	3.84	0.651
1.20	2.16	3.35	0.592
1.30	2.25	2.77	0.506
1.40	2.49	2.23	0.419
1.50	2.84	1.80	0.369
1.60	3.36	1.62	0.379
1.70	3.70	1.75	0.411
1.80	3.78	1.83	0.423
1.90	3.81	1.75	0.418
2.00	3.98	1.60	0.418
2.10	4.26	1.54	0.432
2.20	4.58	1.62	0.457
2.30	4.84	1.76	0.479
2.40	5.10	2.01	0.506
2.50	5.28	2.38	0.532
2.60	5.36	2.82	0.557
2.70	5.30	3.29	0.580
2.80	5.07	3.78	0.603
2.90	4.65	4.18	0.624
3.00	4.05	4.40	0.639
3.20	3.29	3.96	0.614

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
3.40	2.93	3.79	0.607
3.60	2.75	3.45	0.577
3.80	2.73	3.32	0.562
4.00	2.71	3.34	0.565
4.20	2.53	3.44	0.584
4.40	2.24	3.44	0.599
4.60	2.01	3.31	0.598
4.80	1.88	3.19	0.592
5.00	1.74	3.12	0.596
5.20	1.58	3.00	0.597
5.40	1.46	2.88	0.593
5.60	1.36	2.77	0.589
5.80	1.27	2.65	0.582
6.00	1.20	2.54	0.575
6.20	1.13	2.44	0.571
6.40	1.06	2.33	0.562
6.60	1.01	2.21	0.548
6.80	0.97	2.11	0.532
7.00	0.95	2.00	0.514
7.20	0.92	1.91	0.497
7.40	0.91	1.81	0.476
7.60	0.90	1.72	0.451
7.80	0.90	1.63	0.426
8.00	0.91	1.55	0.400
8.20	0.91	1.48	0.375
8.40	0.94	1.40	0.344
8.60	0.96	1.34	0.319
8.80	0.98	1.29	0.296
9.00	1.01	1.24	0.274
9.20	1.04	1.19	0.255
9.40	1.08	1.16	0.238
9.60	1.10	1.14	0.229
9.80	1.13	1.11	0.217
10.00	1.16	1.10	0.209
10.20	1.19	1.08	0.203
10.30	1.20	1.08	0.201
10.40	1.22	1.08	0.200
10.50	1.23	1.09	0.201
10.60	1.24	1.10	0.203
10.80	1.25	1.11	0.206
11.00	1.24	1.13	0.213
11.20	1.23	1.14	0.217
11.40	1.19	1.15	0.223
11.60	1.17	1.12	0.216
11.80	1.16	1.10	0.211
12.00	1.15	1.08	0.205
12.40	1.14	1.03	0.191
12.80	1.15	1.01	0.183
13.20	1.16	0.98	0.174
13.60	1.17	0.97	0.170
14.00	1.17	0.96	0.169
14.40	1.16	0.94	0.165
14.80	1.16	0.91	0.156
15.20	1.17	0.89	0.148
15.60	1.20	0.86	0.140
16.00	1.25	0.87	0.140
16.40	1.28	0.90	0.147
16.80	1.28	0.94	0.157
17.20	1.27	0.97	0.167
17.60	1.26	1.01	0.178
18.00	1.23	1.04	0.189
18.40	1.19	1.08	0.200
18.80	1.14	1.10	0.210
19.20	1.10	1.10	0.219
19.60	1.05	1.11	0.227
20.00	0.96	1.10	0.239
20.40	0.93	1.09	0.240
20.80	0.89	1.05	0.240
21.20	0.86	1.02	0.237
21.60	0.83	0.99	0.235
22.00	0.80	0.96	0.230
22.40	0.78	0.93	0.226
22.80	0.77	0.90	0.220
23.20	0.75	0.88	0.217
23.60	0.75	0.86	0.211
24.00	0.73	0.84	0.209
24.40	0.72	0.82	0.207
24.80	0.70	0.80	0.205
25.20	0.69	0.77	0.202
25.60	0.67	0.75	0.199
26.00	0.66	0.72	0.195
26.40	0.65	0.69	0.189
26.80	0.63	0.66	0.183
27.20	0.65	0.62	0.165
28.00	0.64	0.59	0.156
28.40	0.64	0.57	0.148
28.80	0.65	0.55	0.140
29.20	0.65	0.53	0.134
29.60	0.65	0.51	0.128
30.00	0.65	0.49	0.121
31.00	0.65	0.45	0.111
32.00	0.66	0.41	0.095
33.00	0.68	0.37	0.079
34.00	0.70	0.34	0.068
35.00	0.72	0.31	0.057
36.00	0.74	0.29	0.048
37.00	0.77	0.27	0.040
38.00	0.79	0.26	0.035
39.00	0.81	0.26	0.031
40.00	0.84	0.26	0.026

Palladium[19]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.10	4.13	54.15	0.994
0.15	3.13	35.82	0.990
0.20	3.07	26.59	0.983
0.26	3.11	20.15	0.971
0.30	3.56	17.27	0.955
0.36	3.98	14.41	0.932
0.40	4.27	13.27	0.916
0.46	4.27	12.11	0.902
0.50	4.10	11.44	0.896
0.56	3.92	10.49	0.883
0.60	3.80	9.96	0.876
0.72	3.51	8.70	0.854
0.80	3.35	8.06	0.840
1.00	2.99	6.89	0.811
1.10	2.81	6.46	0.800
1.20	2.65	6.10	0.790
1.30	2.50	5.78	0.781
1.40	2.34	5.50	0.774
1.50	2.17	5.22	0.767
1.60	2.08	4.95	0.755
1.70	2.00	4.72	0.745
1.80	1.92	4.54	0.737
1.90	1.82	4.35	0.729
2.00	1.75	4.18	0.721
2.10	1.67	4.03	0.714
2.20	1.60	3.88	0.707
2.30	1.53	3.75	0.700
2.40	1.47	3.61	0.693
2.50	1.41	3.48	0.685
2.60	1.37	3.36	0.676
2.70	1.32	3.25	0.668
2.80	1.29	3.13	0.658
2.90	1.26	3.03	0.648
3.00	1.23	2.94	0.639
3.10	1.20	2.85	0.630
3.20	1.17	2.77	0.622
3.30	1.14	2.68	0.613
3.40	1.12	2.60	0.602
3.50	1.10	2.52	0.591
3.60	1.08	2.45	0.581
3.70	1.07	2.38	0.570
3.80	1.06	2.31	0.558
3.90	1.05	2.25	0.547
4.00	1.03	2.19	0.537
4.20	1.04	2.09	0.510
4.40	1.03	2.01	0.493
4.60	1.03	1.94	0.476
4.80	1.01	1.90	0.470
5.00	0.96	1.86	0.472
5.20	0.90	1.79	0.474
5.40	0.85	1.70	0.463
5.60	0.81	1.62	0.449
5.80	0.78	1.54	0.437
6.00	0.76	1.45	0.418
6.20	0.74	1.37	0.397
6.40	0.73	1.29	0.375
6.60	0.72	1.21	0.350
6.80	0.73	1.13	0.316
7.00	0.73	1.05	0.287
7.20	0.75	0.98	0.255
7.40	0.77	0.91	0.223
7.60	0.79	0.85	0.195
7.80	0.83	0.78	0.163
8.00	0.88	0.73	0.133
8.20	0.94	0.70	0.117
8.40	0.96	0.70	0.114
8.60	1.00	0.65	0.097
8.80	1.04	0.65	0.094
9.00	1.07	0.64	0.090
9.50	1.12	0.65	0.089
10.00	1.14	0.65	0.088
10.50	1.16	0.65	0.087
11.00	1.18	0.64	0.086
11.50	1.19	0.65	0.087
12.00	1.20	0.66	0.089
12.50	1.19	0.67	0.091
13.00	1.18	0.67	0.091
13.50	1.18	0.67	0.092
14.00	1.17	0.67	0.093
14.50	1.15	0.68	0.095
15.00	1.13	0.69	0.098
15.50	1.10	0.68	0.096
16.00	1.08	0.66	0.092
16.50	1.06	0.63	0.086
17.00	1.07	0.61	0.081
17.50	1.06	0.61	0.080
18.00	1.07	0.59	0.077
18.50	1.07	0.59	0.077
19.00	1.08	0.59	0.077
19.50	1.08	0.61	0.080
20.00	1.07	0.65	0.090
20.50	1.03	0.67	0.098
21.00	0.99	0.67	0.103

Energy (eV)	n	k	$R(\phi = 0)$
21.50	0.95	0.66	0.103
22.00	0.91	0.64	0.103
22.50	0.88	0.62	0.101
23.00	0.86	0.59	0.097
23.50	0.85	0.56	0.091
24.00	0.84	0.54	0.086
25.00	0.81	0.51	0.084
26.40	0.80	0.43	0.066
27.80	0.81	0.38	0.052
29.20	0.82	0.35	0.046
Platinum[20]			
0.10	13.21	44.72	0.976
0.15	8.18	31.16	0.969
0.20	5.90	23.95	0.962
0.25	4.70	19.40	0.954
0.30	3.92	16.16	0.945
0.35	3.28	13.66	0.936
0.40	2.81	11.38	0.922
0.45	3.03	9.31	0.882
0.50	3.91	7.71	0.813
0.55	4.58	7.14	0.777
0.60	5.13	6.75	0.753
0.65	5.52	6.66	0.746
0.70	5.71	6.83	0.751
0.75	5.57	7.02	0.759
0.80	5.31	7.04	0.762
0.85	5.05	6.98	0.763
0.90	4.77	6.91	0.765
0.95	4.50	6.77	0.763
1.00	4.25	6.62	0.762
1.10	3.86	6.24	0.753
1.20	3.55	5.92	0.746
1.30	3.29	5.61	0.736
1.40	3.10	5.32	0.725
1.50	2.92	5.07	0.716
1.60	2.76	4.84	0.706
1.70	2.63	4.64	0.697
1.80	2.51	4.43	0.686
1.90	2.38	4.26	0.678
2.00	2.30	4.07	0.664
2.10	2.23	3.92	0.654
2.20	2.17	3.77	0.642
2.30	2.10	3.67	0.636
2.40	2.03	3.54	0.626
2.50	1.96	3.42	0.616
2.60	1.91	3.30	0.605
2.70	1.87	3.20	0.595
2.80	1.83	3.10	0.585
2.90	1.79	3.01	0.575
3.00	1.75	2.92	0.565
3.20	1.68	2.76	0.546
3.40	1.63	2.62	0.527
3.60	1.58	2.48	0.507
3.80	1.53	2.37	0.491
4.00	1.49	2.25	0.472
4.20	1.45	2.14	0.452
4.40	1.43	2.04	0.432
4.60	1.39	1.95	0.415
4.80	1.38	1.85	0.392
5.00	1.36	1.76	0.372
5.20	1.36	1.67	0.350
5.40	1.36	1.61	0.332
5.60	1.36	1.54	0.315
5.80	1.36	1.47	0.295
6.00	1.38	1.40	0.276
6.20	1.39	1.35	0.261
6.40	1.42	1.29	0.246
6.60	1.45	1.26	0.236
6.80	1.48	1.24	0.231
7.00	1.50	1.24	0.230
7.20	1.50	1.25	0.231
7.40	1.49	1.23	0.228
7.60	1.48	1.22	0.225
7.80	1.48	1.20	0.221
8.00	1.47	1.18	0.216
8.20	1.47	1.17	0.212
8.40	1.47	1.15	0.209
8.60	1.47	1.14	0.205
8.80	1.47	1.13	0.202
9.00	1.48	1.12	0.200
9.20	1.49	1.11	0.198
9.40	1.49	1.12	0.200
9.60	1.49	1.13	0.203
9.80	1.48	1.15	0.207
10.00	1.46	1.15	0.209
10.20	1.43	1.16	0.211
10.40	1.40	1.15	0.210
10.60	1.37	1.14	0.207
10.80	1.35	1.12	0.203
11.00	1.33	1.10	0.199
11.20	1.31	1.08	0.194
11.40	1.30	1.06	0.188
11.60	1.29	1.04	0.183
11.80	1.29	1.01	0.177
12.00	1.29	1.00	0.173
12.40	1.29	0.97	0.165
12.80	1.29	0.94	0.158
13.20	1.31	0.93	0.155
13.60	1.31	0.93	0.155
14.00	1.31	0.93	0.155
14.40	1.30	0.93	0.156
14.80	1.27	0.93	0.157
15.20	1.27	0.93	0.155
15.60	1.25	0.92	0.151
16.00	1.24	0.89	0.146
16.50	1.24	0.87	0.142
17.00	1.25	0.86	0.138
17.50	1.27	0.85	0.135
18.00	1.31	0.88	0.142
18.50	1.30	0.94	0.157
19.00	1.28	0.99	0.171
19.50	1.23	1.03	0.184
20.00	1.18	1.06	0.197
20.50	1.11	1.09	0.212
21.00	1.03	1.10	0.226
21.50	0.94	1.08	0.238
22.00	0.87	1.04	0.240
22.50	0.81	0.98	0.235
23.00	0.77	0.92	0.226
23.50	0.75	0.87	0.213
24.00	0.74	0.82	0.201
24.50	0.73	0.77	0.187
25.00	0.73	0.73	0.174
25.50	0.73	0.70	0.162
26.00	0.74	0.67	0.150
26.50	0.74	0.65	0.142
27.00	0.74	0.63	0.136
27.50	0.74	0.62	0.130
28.00	0.75	0.60	0.125
28.50	0.75	0.59	0.121
29.00	0.75	0.58	0.118
29.50	0.74	0.58	0.120
30.00	0.73	0.58	0.124
Potassium[21]			
0.55	0.139	7.10	0.989
0.58	0.119	6.72	0.990
0.63	0.106	6.32	0.990
0.67	0.091	5.79	0.990
0.73	0.079	5.30	0.989
0.81	0.066	4.75	0.989
0.92	0.056	4.19	0.988
1.05	0.044	3.58	0.987
1.23	0.040	3.04	0.985
1.44	0.040	2.56	0.979
1.65	0.044	2.19	0.970
1.87	0.050	1.84	0.955
2.07	0.053	1.62	0.943
2.27	0.049	1.43	0.938
2.45	0.046	1.28	0.933
2.64	0.043	1.14	0.928
2.82	0.043	1.02	0.919
2.95	0.041	0.898	0.913
3.06	0.041	0.799	0.905
3.40	0.052	0.549	0.852
3.71	0.089	0.288	0.719
3.97	0.287	0.091	0.310
4.00	0.34	0.08	0.245
4.065	0.38	0.07	0.204
4.133	0.41	0.07	0.177
4.203	0.45	0.06	0.145
4.275	0.48	0.06	0.125
4.350	0.52	0.05	0.101
4.428	0.55	0.05	0.085
4.509	0.58	0.05	0.072
4.592	0.61	0.05	0.060
4.679	0.64	0.04	0.049
4.769	0.66	0.04	0.043
4.862	0.68	0.04	0.037
4.959	0.70	0.04	0.032
5.061	0.72	0.04	0.027
5.166	0.74	0.04	0.023
5.276	0.76	0.04	0.019
5.391	0.78	0.04	0.016
5.510	0.79	0.05	0.015
5.637	0.81	0.05	0.012
5.767	0.83	0.05	0.009
6.048	0.85	0.05	0.007
6.199	0.87	0.05	0.006
6.358	0.88	0.05	0.005
6.526	0.90	0.06	0.004
6.702	0.91	0.06	0.003
6.888	0.92	0.06	0.003
7.085	0.92	0.06	0.003
7.293	0.93	0.06	0.002
7.514	0.93	0.06	0.002
7.749	0.94	0.06	0.002
7.999	0.94	0.06	0.002
8.260	0.94	0.06	0.002
8.551	0.94	0.06	0.002
8.856	0.94	0.05	0.002
9.184	0.94	0.05	0.002
9.537	0.94	0.04	0.001
9.919	0.94	0.04	0.001

Energy (eV)	n	k	$R(\phi = 0)$
10.33	0.94	0.03	0.001
11.0		0.03	
12.0		0.028	

Rhenium, single crystal, $\vec{E} \parallel \hat{c}$[9]

Energy (eV)	n	k	$R(\phi = 0)$
0.10	6.06	51.03	0.991
0.15	4.66	33.96	0.984
0.20	4.16	25.36	0.975
0.25	4.03	20.10	0.962
0.30	4.37	16.69	0.943
0.35	4.50	14.53	0.925
0.40	4.53	12.96	0.909
0.45	4.53	11.78	0.893
0.50	4.53	10.88	0.878
0.55	4.50	10.26	0.867
0.60	4.29	9.75	0.861
0.65	4.07	9.35	0.856
0.70	3.80	8.94	0.853
0.75	3.48	8.55	0.850
0.80	3.21	8.10	0.846
0.85	2.96	7.68	0.841
0.90	2.73	7.24	0.835
0.95	2.56	6.79	0.826
1.00	2.45	6.36	0.813
1.10	2.38	5.61	0.778
1.20	2.35	5.02	0.742
1.30	2.39	4.54	0.702
1.40	2.44	4.13	0.662
1.50	2.50	3.79	0.624
1.60	2.59	3.49	0.587
1.70	2.70	3.27	0.557
1.80	2.82	3.10	0.535
1.90	2.90	3.00	0.520
2.00	2.97	2.91	0.510
2.10	3.03	2.86	0.504
2.20	3.06	2.84	0.501
2.30	3.07	2.82	0.499
2.40	3.06	2.81	0.498
2.50	3.02	2.80	0.497
2.60	2.96	2.77	0.493
2.70	2.89	2.68	0.482
2.80	2.89	2.57	0.468
2.90	2.99	2.47	0.457
3.00	3.11	2.57	0.470
3.20	2.90	2.68	0.482
3.40	2.83	2.50	0.459
3.60	2.93	2.48	0.457
3.80	2.86	2.56	0.467
4.00	2.81	2.51	0.460
4.20	2.86	2.55	0.466
4.40	2.81	2.74	0.489
4.60	2.56	2.83	0.504
4.80	2.41	2.71	0.493
5.00	2.39	2.68	0.488
5.20	2.34	2.75	0.500
5.40	2.20	2.81	0.515
5.60	2.02	2.84	0.530
5.80	1.83	2.80	0.538
6.00	1.65	2.71	0.541
6.20	1.54	2.59	0.532
6.40	1.45	2.50	0.526
6.80	1.32	2.31	0.508
7.00	1.26	2.23	0.500
7.20	1.20	2.15	0.493
7.40	1.16	2.06	0.480
7.60	1.12	1.99	0.470
7.80	1.08	1.89	0.454
8.00	1.05	1.80	0.435
8.20	1.05	1.71	0.411
8.40	1.05	1.62	0.386
8.60	1.06	1.55	0.360
8.80	1.09	1.48	0.336
9.00	1.11	1.43	0.317
9.20	1.13	1.39	0.301
9.40	1.16	1.34	0.281
9.60	1.18	1.32	0.274
9.80	1.20	1.29	0.264
10.00	1.23	1.26	0.252
10.20	1.25	1.25	0.246
10.40	1.28	1.25	0.242
10.60	1.29	1.25	0.242
10.80	1.30	1.26	0.244
11.00	1.30	1.27	0.247
11.20	1.29	1.28	0.249
11.40	1.28	1.28	0.252
11.60	1.26	1.28	0.252
11.80	1.24	1.26	0.249
12.00	1.23	1.24	0.244
12.40	1.22	1.21	0.237
12.80	1.21	1.18	0.230
13.20	1.22	1.16	0.222
13.60	1.22	1.13	0.215
14.00	1.24	1.12	0.209
14.40	1.27	1.11	0.204
14.80	1.29	1.15	0.213
15.20	1.29	1.19	0.225
15.60	1.26	1.22	0.236
16.00	1.23	1.25	0.248
16.40	1.19	1.27	0.259
16.80	1.14	1.29	0.269
17.00	1.12	1.30	0.275
17.40	1.07	1.30	0.286
18.00	0.99	1.30	0.300
18.40	0.93	1.29	0.311
18.80	0.87	1.28	0.321
19.20	0.81	1.25	0.330
19.60	0.77	1.21	0.332
20.00	0.73	1.18	0.333
20.40	0.70	1.14	0.332
20.80	0.67	1.11	0.332
21.20	0.64	1.08	0.334
21.60	0.61	1.04	0.335
22.00	0.58	1.01	0.340
22.40	0.55	0.97	0.341
22.80	0.53	0.93	0.338
23.20	0.51	0.89	0.334
23.60	0.50	0.85	0.329
24.00	0.48	0.80	0.319
24.40	0.48	0.76	0.207
24.80	0.47	0.72	0.296
25.20	0.47	0.68	0.282
25.60	0.47	0.65	0.270
26.00	0.47	0.61	0.255
26.40	0.48	0.57	0.240
26.80	0.48	0.54	0.225
27.20	0.49	0.51	0.208
27.60	0.50	0.48	0.193
28.00	0.51	0.45	0.176
29.00	0.54	0.39	0.145
30.00	0.57	0.33	0.114
31.00	0.62	0.29	0.086
32.00	0.66	0.26	0.065
33.00	0.68	0.24	0.054
34.00	0.72	0.21	0.041
35.00	0.76	0.20	0.031
36.00	0.79	0.20	0.025
37.00	0.82	0.19	0.021
38.00	0.85	0.20	0.018
39.00	0.89	0.21	0.016
40.00	0.88	0.26	0.022
42.00	0.88	0.26	0.022
44.00	0.89	0.29	0.026
46.00	0.85	0.32	0.035
48.00	0.82	0.30	0.036
50.00	0.80	0.30	0.038
52.00	0.78	0.30	0.044
54.00	0.72	0.30	0.055
56.00	0.66	0.24	0.061
58.00	0.65	0.16	0.055

Rhenium, single crystal, $\vec{E} \perp \hat{c}$[9]

Energy (eV)	n	k	$R(\phi = 0)$
0.10	4.25	42.83	0.991
0.15	3.28	28.08	0.984
0.20	3.28	20.66	0.971
0.25	3.47	16.27	0.951
0.30	3.73	13.44	0.926
0.35	3.93	11.54	0.900
0.40	3.99	10.15	0.875
0.45	4.17	9.03	0.846
0.50	4.34	8.26	0.821
0.55	4.45	7.73	0.801
0.60	4.53	7.40	0.788
0.65	4.44	7.26	0.784
0.70	4.13	7.09	0.784
0.75	3.77	6.75	0.779
0.80	3.55	6.32	0.766
0.85	3.39	5.95	0.752
0.90	3.26	5.61	0.737
0.95	3.17	5.27	0.719
1.00	3.09	4.96	0.701
1.10	3.05	4.39	0.658
1.20	3.08	3.89	0.613
1.30	3.20	3.56	0.578
1.40	3.23	3.38	0.559
1.50	3.23	3.12	0.532
1.60	3.29	2.88	0.507
1.70	3.38	2.72	0.491
1.80	3.47	2.59	0.480
1.90	3.54	2.50	0.473
2.00	3.63	2.43	0.469
2.10	3.74	2.40	0.470
2.20	3.83	2.38	0.472
2.30	3.93	2.44	0.481
2.40	4.00	2.55	0.492
2.50	4.01	2.70	0.505
2.60	3.90	2.84	0.514
2.70	3.74	2.92	0.517
2.80	3.57	2.88	0.511
2.90	3.49	2.75	0.497
3.00	3.53	2.71	0.493
3.20	3.55	2.84	0.506
3.40	3.34	2.88	0.508
3.60	3.25	2.83	0.501
3.80	3.24	2.84	0.502
4.00	3.19	2.94	0.513

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
4.20	3.05	3.06	0.526
4.40	2.88	3.15	0.539
4.60	2.67	3.18	0.548
4.80	2.44	3.17	0.554
5.00	2.25	3.12	0.556
5.20	2.10	3.04	0.555
5.40	1.96	2.96	0.553
5.60	1.84	2.88	0.551
5.80	1.73	2.81	0.549
6.00	1.61	2.74	0.549
6.20	1.51	2.64	0.545
6.40	1.42	2.56	0.541
6.80	1.28	2.37	0.526
7.00	1.22	2.28	0.517
7.20	1.16	2.19	0.508
7.40	1.12	2.08	0.493
7.60	1.12	1.98	0.468
7.80	1.08	1.93	0.463
8.00	1.05	1.83	0.443
8.20	1.05	1.74	0.418
8.40	1.05	1.66	0.397
8.60	1.06	1.58	0.372
8.80	1.07	1.52	0.351
9.00	1.09	1.46	0.327
9.20	1.11	1.41	0.309
9.40	1.14	1.36	0.290
9.60	1.17	1.31	0.273
9.80	1.20	1.27	0.258
10.00	1.24	1.24	0.244
10.20	1.29	1.22	0.234
10.40	1.33	1.23	0.233
10.60	1.36	1.25	0.238
10.80	1.38	1.28	0.245
11.00	1.37	1.31	0.253
11.20	1.36	1.33	0.259
11.40	1.33	1.34	0.264
11.60	1.31	1.34	0.266
11.80	1.28	1.33	0.266
12.00	1.26	1.32	0.264
12.40	1.23	1.29	0.257
12.80	1.22	1.26	0.251
13.20	1.20	1.23	0.245
13.60	1.19	1.20	0.236
14.00	1.20	1.16	0.225
14.40	1.22	1.13	0.214
14.80	1.27	1.12	0.207
15.20	1.31	1.17	0.218
15.60	1.31	1.23	0.234
16.00	1.28	1.28	0.251
16.40	1.24	1.33	0.270
16.80	1.17	1.37	0.288
17.00	1.14	1.38	0.297
17.40	1.06	1.39	0.314
18.00	0.95	1.38	0.334
18.40	0.88	1.36	0.346
18.80	0.82	1.33	0.355
19.20	0.76	1.29	0.360
19.60	0.72	1.25	0.363
20.00	0.67	1.21	0.369
20.40	0.64	1.15	0.364
20.80	0.61	1.10	0.357
21.20	0.60	1.06	0.349
21.60	0.58	1.02	0.342
22.00	0.57	0.98	0.336
22.40	0.56	0.95	0.328
22.80	0.55	0.92	0.325
23.20	0.53	0.89	0.322
23.60	0.52	0.85	0.317
24.00	0.50	0.82	0.314
24.40	0.49	0.79	0.309
24.80	0.48	0.75	0.303
25.20	0.47	0.72	0.295
25.60	0.47	0.68	0.286
26.00	0.46	0.64	0.276
26.40	0.46	0.61	0.263
26.80	0.46	0.57	0.249
27.20	0.47	0.53	0.231
27.60	0.48	0.50	0.216
28.00	0.49	0.47	0.198
29.00	0.51	0.41	0.164
30.00	0.55	0.34	0.129
31.00	0.59	0.29	0.097
32.00	0.64	0.26	0.072
33.00	0.67	0.24	0.060
34.00	0.70	0.22	0.047
35.00	0.74	0.20	0.036
36.00	0.77	0.19	0.029
37.00	0.80	0.19	0.023
38.00	0.84	0.19	0.018
39.00	0.88	0.21	0.016
40.00	0.87	0.25	0.023
42.00	0.87	0.25	0.023
44.00	0.88	0.28	0.026
46.00	0.84	0.31	0.035
48.00	0.82	0.30	0.036
50.00	0.80	0.30	0.039
52.00	0.77	0.30	0.044
54.00	0.71	0.29	0.055
56.00	0.66	0.23	0.061
58.00	0.64	0.16	0.055
Rhodium[11]			
0.10	18.48	69.43	0.986
0.20	8.66	37.46	0.977
0.30	5.85	25.94	0.967
0.40	4.74	19.80	0.955
0.50	4.20	16.07	0.941
0.60	3.87	13.51	0.925
0.70	3.67	11.72	0.908
0.80	3.63	10.34	0.887
0.90	3.62	9.36	0.867
1.00	3.71	8.67	0.848
1.10	3.67	8.26	0.837
1.20	3.51	7.94	0.832
1.30	3.26	7.63	0.829
1.40	3.01	7.31	0.827
1.50	2.78	6.97	0.823
1.60	2.60	6.64	0.818
1.70	2.42	6.33	0.813
1.80	2.30	6.02	0.805
1.90	2.20	5.76	0.798
2.00	2.12	5.51	0.789
2.10	2.05	5.30	0.780
2.20	2.00	5.11	0.772
2.30	1.94	4.94	0.765
2.40	1.90	4.78	0.756
2.50	1.88	4.65	0.748
2.60	1.85	4.55	0.743
2.70	1.80	4.49	0.742
2.90	1.63	4.36	0.748
3.00	1.53	4.29	0.753
3.10	1.41	4.20	0.760
3.20	1.30	4.09	0.764
3.30	1.20	3.97	0.767
3.40	1.11	3.84	0.769
3.50	1.04	3.71	0.768
3.60	0.99	3.58	0.764
3.70	0.95	3.45	0.759
3.80	0.91	3.34	0.753
3.90	0.88	3.23	0.747
4.00	0.86	3.12	0.739
4.20	0.83	2.94	0.722
4.40	0.80	2.76	0.706
4.60	0.78	2.60	0.684
4.80	0.79	2.46	0.659
5.00	0.79	2.34	0.635
5.20	0.79	2.23	0.613
5.40	0.80	2.14	0.591
5.60	0.80	2.06	0.573
5.80	0.79	2.00	0.561
6.00	0.76	1.93	0.556
6.20	0.73	1.85	0.544
6.40	0.70	1.77	0.534
6.60	0.68	1.69	0.518
6.80	0.67	1.60	0.498
7.00	0.66	1.52	0.476
7.20	0.66	1.43	0.452
7.40	0.66	1.35	0.423
7.60	0.67	1.27	0.394
7.80	0.68	1.20	0.363
8.00	0.69	1.12	0.329
8.20	0.71	1.04	0.288
8.40	0.74	0.97	0.252
8.60	0.78	0.89	0.212
8.80	0.83	0.83	0.179
9.00	0.88	0.77	0.148
9.20	0.95	0.73	0.125
9.40	1.01	0.71	0.110
9.60	1.07	0.69	0.102
9.80	1.12	0.69	0.098
10.00	1.17	0.69	0.098
10.60	1.26	0.73	0.106
11.00	1.29	0.76	0.113
11.60	1.32	0.80	0.124
12.00	1.32	0.82	0.127
12.60	1.32	0.82	0.129
13.00	1.32	0.83	0.131
13.60	1.32	0.85	0.134
14.00	1.32	0.86	0.138
14.60	1.30	0.89	0.144
15.00	1.28	0.90	0.147
15.60	1.25	0.90	0.147
16.00	1.24	0.89	0.147
16.50	1.23	0.88	0.145
17.00	1.22	0.88	0.144
17.50	1.22	0.87	0.143
18.00	1.23	0.88	0.145
18.50	1.25	0.92	0.155
19.00	1.24	0.98	0.172
19.50	1.18	1.05	0.193
20.00	1.10	1.09	0.213
20.50	1.00	1.09	0.230
21.00	0.91	1.05	0.234
21.50	0.86	1.00	0.228
22.00	0.83	0.95	0.219

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
22.50	0.81	0.92	0.214
23.00	0.79	0.90	0.213
23.50	0.75	0.87	0.214
24.00	0.73	0.84	0.210
24.50	0.70	0.81	0.208
25.00	0.69	0.77	0.202
25.50	0.67	0.74	0.195
26.00	0.66	0.70	0.188
26.50	0.65	0.66	0.176
27.00	0.65	0.64	0.168
27.50	0.65	0.61	0.159
28.00	0.65	0.59	0.152
29.00	0.65	0.54	0.137
30.00	0.66	0.51	0.127
31.00	0.64	0.49	0.127
32.00	0.61	0.44	0.126
33.00	0.60	0.37	0.110
34.00	0.65	0.30	0.074
35.00	0.69	0.28	0.058
36.00	0.73	0.27	0.049
37.00	0.74	0.28	0.047
38.00	0.74	0.27	0.045
39.00	0.75	0.25	0.041

Ruthenium, single crystal, $\vec{E} \parallel \hat{c}$[9]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.10	11.50	51.38	0.984
0.20	5.93	27.14	0.970
0.30	4.33	18.50	0.953
0.40	3.60	13.97	0.933
0.50	3.18	11.04	0.909
0.60	3.28	8.89	0.865
0.70	3.62	7.73	0.822
0.80	3.42	7.02	0.801
0.90	3.25	6.12	0.766
1.00	3.39	5.33	0.715
1.10	3.66	4.83	0.675
1.20	3.84	4.57	0.654
1.30	3.94	4.38	0.638
1.40	4.02	4.19	0.624
1.50	4.16	4.07	0.614
1.60	4.33	4.08	0.615
1.70	4.42	4.21	0.624
1.80	4.40	4.38	0.636
1.90	4.29	4.61	0.651
2.00	4.04	4.81	0.667
2.10	3.69	4.90	0.679
2.20	3.35	4.82	0.683
2.30	3.09	4.70	0.681
2.40	2.89	4.55	0.677
2.50	2.74	4.40	0.671
2.60	2.64	4.25	0.663
2.70	2.58	4.14	0.656
2.80	2.54	4.05	0.650
2.90	2.48	4.03	0.650
3.00	2.38	4.03	0.656
3.10	2.26	4.00	0.661
3.20	2.13	3.96	0.666
3.30	2.00	3.91	0.671
3.40	1.87	3.83	0.673
3.50	1.76	3.74	0.674
3.60	1.66	3.65	0.675
3.70	1.57	3.55	0.673
3.80	1.49	3.45	0.672
3.90	1.42	3.35	0.668
4.00	1.37	3.24	0.661
4.20	1.29	3.08	0.649
4.40	1.22	2.93	0.639
4.60	1.16	2.79	0.628
4.80	1.11	2.67	0.617
5.00	1.06	2.56	0.607
5.20	1.01	2.46	0.600
5.40	0.95	2.35	0.593
5.60	0.92	2.23	0.576
5.80	0.90	2.14	0.559
6.00	0.88	2.05	0.545
6.20	0.87	1.98	0.531
6.40	0.84	1.91	0.521
6.60	0.82	1.84	0.510
6.80	0.79	1.77	0.500
7.00	0.76	1.69	0.489
7.20	0.75	1.61	0.472
7.40	0.73	1.54	0.455
7.60	0.73	1.46	0.433
7.80	0.73	1.39	0.411
8.00	0.72	1.33	0.391
8.20	0.72	1.26	0.366
8.40	0.73	1.20	0.342
8.60	0.74	1.14	0.318
8.80	0.74	1.08	0.295
9.00	0.75	1.02	0.267
9.20	0.77	0.97	0.243
9.40	0.79	0.91	0.217
9.60	0.82	0.86	0.190
9.80	0.85	0.81	0.167
10.00	0.88	0.76	0.144
10.20	0.92	0.72	0.125
10.40	0.96	0.69	0.110
10.60	1.01	0.67	0.100
10.80	1.05	0.66	0.094
11.00	1.09	0.65	0.090
11.20	1.12	0.65	0.088
11.40	1.15	0.65	0.087
11.60	1.18	0.65	0.088
11.80	1.21	0.66	0.090
12.00	1.23	0.67	0.092
12.40	1.26	0.69	0.098
12.80	1.27	0.72	0.104
13.20	1.28	0.74	0.108
13.60	1.28	0.75	0.111
14.00	1.28	0.76	0.114
14.40	1.27	0.76	0.114
14.80	1.27	0.76	0.114
15.00	1.27	0.76	0.114
15.60	1.28	0.77	0.115
16.00	1.30	0.78	0.118
16.50	1.32	0.80	0.123
17.00	1.34	0.85	0.136
17.50	1.32	0.93	0.155
18.00	1.26	0.99	0.173
18.50	1.18	1.02	0.185
19.00	1.11	1.02	0.192
19.50	1.05	1.02	0.199
20.00	0.99	1.02	0.208
20.50	0.92	0.99	0.212
21.00	0.86	0.94	0.209
21.50	0.83	0.90	0.203
22.00	0.81	0.86	0.193
23.00	0.77	0.79	0.182
24.00	0.74	0.74	0.171
25.00	0.71	0.69	0.163
26.00	0.68	0.63	0.154
27.00	0.67	0.57	0.140
28.00	0.66	0.51	0.124
29.00	0.67	0.46	0.107
30.00	0.67	0.43	0.097
31.00	0.67	0.37	0.084
32.00	0.69	0.33	0.070
33.00	0.71	0.30	0.058
34.00	0.73	0.27	0.048
35.00	0.75	0.25	0.039
36.00	0.77	0.24	0.035
37.00	0.79	0.23	0.039
38.00	0.80	0.22	0.027
39.00	0.82	0.22	0.024
40.00	0.83	0.22	0.022

Ruthenium, single crystal, $\vec{E} \perp \hat{c}$[5]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.10	11.85	50.81	0.983
0.20	6.68	27.18	0.966
0.30	4.94	18.92	0.950
0.40	3.90	14.51	0.933
0.50	3.27	11.63	0.915
0.60	2.98	9.54	0.888
0.70	2.82	7.99	0.856
0.80	2.73	6.71	0.815
0.90	2.82	5.54	0.751
1.00	3.17	4.59	0.670
1.10	3.69	3.91	0.604
1.20	4.28	3.66	0.585
1.30	4.66	3.72	0.593
1.40	4.86	3.79	0.601
1.50	4.99	3.89	0.609
1.60	5.08	4.03	0.618
1.70	5.12	4.22	0.629
1.80	5.10	4.45	0.642
1.90	4.96	4.78	0.660
2.00	4.61	5.06	0.677
2.10	4.21	5.09	0.682
2.20	3.94	5.00	0.681
2.30	3.69	4.97	0.684
2.40	3.44	4.88	0.684
2.50	3.27	4.77	0.681
2.60	3.14	4.66	0.677
2.70	3.06	4.59	0.674
2.80	2.99	4.59	0.676
2.90	2.87	4.64	0.686
3.00	2.64	4.69	0.701
3.10	2.40	4.64	0.710
3.20	2.18	4.55	0.717
3.30	2.00	4.43	0.721
3.40	1.84	4.30	0.723
3.50	1.71	4.16	0.723
3.60	1.60	4.03	0.722
3.70	1.50	3.90	0.721
3.80	1.41	3.77	0.718
3.90	1.35	3.64	0.713
4.00	1.29	3.53	0.707
4.20	1.21	3.31	0.694
4.40	1.16	3.13	0.679
4.60	1.13	2.97	0.662
4.80	1.09	2.86	0.652
5.00	1.03	2.75	0.648
5.20	0.97	2.64	0.643
5.40	0.91	2.52	0.635
5.60	0.88	2.40	0.622

Energy (eV)	*n*	*k*	$R(\phi = 0)$
5.80	0.86	2.29	0.605
6.00	0.84	2.20	0.591
6.20	0.82	2.11	0.576
6.40	0.81	2.04	0.564
6.60	0.78	1.97	0.556
6.80	0.76	1.89	0.545
7.00	0.73	1.82	0.538
7.20	0.70	1.75	0.527
7.40	0.68	1.67	0.513
7.60	0.67	1.59	0.496
7.80	0.66	1.51	0.476
8.00	0.66	1.44	0.454
8.20	0.65	1.36	0.430
8.40	0.66	1.29	0.403
8.60	0.66	1.22	0.378
8.80	0.68	1.15	0.346
9.00	0.69	1.09	0.317
9.20	0.70	1.02	0.286
9.40	0.73	0.95	0.251
9.60	0.77	0.89	0.216
9.80	0.82	0.84	0.185
10.00	0.86	0.81	0.163
10.20	0.90	0.77	0.143
10.40	0.94	0.74	0.127
10.60	0.99	0.72	0.115
10.80	1.04	0.71	0.108
11.00	1.08	0.70	0.104
11.20	1.11	0.70	0.102
11.40	1.14	0.70	0.101
11.60	1.17	0.71	0.102
11.80	1.20	0.72	0.104
12.00	1.22	0.73	0.107
12.40	1.25	0.76	0.113
12.80	1.26	0.78	0.118
13.20	1.27	0.81	0.124
13.60	1.27	0.83	0.129
14.00	1.26	0.84	0.132
14.40	1.25	0.84	0.132
14.80	1.25	0.84	0.133
15.00	1.25	0.84	0.133
15.60	1.25	0.85	0.134
16.00	1.27	0.85	0.134
16.50	1.28	0.89	0.145
17.00	1.28	0.94	0.158
17.50	1.25	1.00	0.175
18.00	1.19	1.04	0.190
18.50	1.12	1.05	0.200
19.00	1.07	1.05	0.205
19.50	1.02	1.04	0.212
20.00	0.97	1.04	0.219
20.50	0.91	1.03	0.228
21.00	0.85	1.01	0.234
21.50	0.80	0.97	0.234
22.00	0.77	0.94	0.233
23.00	0.71	0.87	0.229
24.00	0.67	0.79	0.218
25.00	0.64	0.73	0.205
26.00	0.61	0.66	0.194
27.00	0.60	0.59	0.177
28.00	0.60	0.53	0.155
29.00	0.61	0.48	0.134
30.00	0.62	0.45	0.123
31.00	0.61	0.40	0.114
32.00	0.63	0.34	0.093
33.00	0.65	0.31	0.077
34.00	0.67	0.28	0.065
35.00	0.70	0.26	0.054
36.00	0.72	0.25	0.047
37.00	0.73	0.23	0.041
38.00	0.75	0.22	0.035
39.00	0.77	0.22	0.031
40.00	0.79	0.22	0.028

Selenium, single crystal, $\vec{E} \parallel \hat{c}$ [22]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.01364	2.914	0.248	0.242
0.01488	3.175	9.95E-02	0.272
0.01612	3.263	2.13E-03	0.282
0.01736	3.306	3.81E-02	0.287
0.01860	3.330	7.04E-03	0.290
0.01984	3.346	4.23E-02	0.291
0.02108	3.358	3.40E-03	0.293
0.02232	3.366	5.31E-02	0.294
0.02356	3.372	1.96E-03	0.294
0.02480	3.377	2.39E-02	0.295
0.02604	3.380		0.295
0.02728		1.16E-02	
0.02976		7.96E-03	
0.03224		8.57E-03	
0.03472		2.70E-02	
0.03720	3.397	1.72E-02	0.297
0.04463		1.13E-02	
0.04959	3.403	2.79E-03	0.298
0.05703		1.56E-03	
0.06199	3.405	1.35E-03	0.298
0.06819		5.79E-04	
0.07439	3.407	4.44E-04	0.298
0.08059		4.41E-04	
0.08679	3.408	4.32E-04	0.298
0.09299		2.44E-04	
0.09919	3.409	3.23E-04	0.299
0.1116	3.409	2.87E-04	0.299
0.1240	3.410	2.71E-04	0.299
0.2480	3.417	2.67E-04	0.299
0.3720	3.427	1.90E-04	0.301
0.4959	3.442	1.41E-04	0.302
0.6199	3.462	1.12E-04	0.304
0.7439	3.486	9.42E-05	0.307
0.8679	3.516	8.07E-05	0.310
0.9919	3.551	7.11E-05	0.314
1.116	3.592	6.37E-05	0.319
1.240	3.640	5.81E-05	0.324
1.50		1.33E-04	
1.60		1.59E-04	
1.70		6.27E-04	
1.80	4.46	2.20E-02	0.402
2.0	4.79	0.76	0.438
2.2	4.49	1.19	0.431
2.4	4.28	1.21	0.417
2.6	4.40	1.32	0.430
2.8	4.59	1.70	0.462
3.0	4.44	2.29	0.490
3.2	3.92	2.59	0.493
3.4	3.69	2.76	0.502
3.6	3.39	3.01	0.521
3.8	(3.00)		
4.0	(2.65)		
4.2	(2.30)		
4.5	1.92	2.78	0.528
5.0	1.50	2.31	0.482
6.0	1.57	1.49	0.288
7.0	1.84	1.45	0.276
8.0	1.35	1.68	0.353
9.0	1.35	1.64	0.342
10.0	0.92	1.07	0.238
12.0	1.00	1.10	0.232
14.0	0.81	0.91	0.211
16.0	0.65	0.61	0.160
18.0	0.65	0.48	0.120
20.0	0.69	0.36	0.076
22.0	0.81	0.25	0.030
24.0	0.91	0.18	0.011
26.0	0.86	0.15	0.012
28.0	0.85	0.13	0.011
30.0	0.87	0.11	0.008

Selenium, single crystal, $\vec{E} \perp \hat{c}$ [22]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.01364	2.854	0.0239	0.231
0.01488	2.932	0.0325	0.241
0.01612	3.140	0.1750	0.269
0.01736	2.959	1.3300	0.321
0.01860	2.111	0.2550	0.133
0.01984	2.356	0.0746	0.164
0.02108	2.462	0.0276	0.178
0.02232	2.502	0.0442	0.184
0.02356	2.543	0.0097	0.190
0.02480	2.550	0.0239	0.191
0.02604	2.582		0.195
0.02728	2.600	0.0101	0.198
0.02976	2.576	9.95E-03	0.194
0.03224	2.598	1.16E-02	0.197
0.03472	2.607	1.68E-02	0.199
0.03720	2.613	1.54E-02	0.199
0.04463		1.17E-02	
0.04959	2.627	3.58E-03	0.201
0.05703		8.65E-04	
0.06199	2.632	2.07E-03	0.202
0.06819		2.89E-04	
0.07439	2.635	1.59E-04	0.202
0.08059		1.35E-04	
0.08679	2.636	1.42E-04	0.202
0.09299		1.04E-04	
0.09919	2.637	8.95E-05	0.203
0.1116	2.638	8.84E-05	0.203
0.1240	2.639	8.51E-05	0.203
0.2480	2.645	5.97E-05	0.204
0.3720	2.652	5.44E-05	0.205
0.4959	2.654	4.58E-05	0.205
0.6199	2.675	3.82E-05	0.208
0.7439	2.692	3.32E-05	0.210
0.8679	2.713	2.96E-05	0.213
0.9919	2.739	2.69E-05	0.216
1.116	2.772	2.48E-05	0.221
1.240	2.816	2.31E-05	0.226
1.50		7.37E-05	
1.60		8.63E-05	
1.70		3.60E-04	
1.80	3.32	0.11	0.289
2.00	3.38	0.65	0.310
2.20	3.07	0.73	0.282
2.40	2.93	0.61	0.259
2.60	3.00	0.53	0.263
2.80	3.12	0.58	0.279
3.00	3.30	0.70	0.305
3.20	3.35	1.01	0.328
3.40	3.22	1.24	0.334

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
3.60	3.06	1.47	0.344
3.80	2.84	1.66	0.351
4.00	2.51	1.81	0.356
4.20	2.18	1.83	0.352
4.50	1.75	1.94	0.382
5.00	1.25	1.50	0.316
6.00	1.32	0.73	0.107
7.00	1.62	0.61	0.105
8.00	1.81	0.69	0.135
9.00	1.66	1.02	0.182
10.00	1.72	0.95	0.171
12.00	1.25	1.02	0.181
14.00	0.98	0.92	0.178
16.00	0.68	0.96	0.274
18.00	0.61	0.65	0.191
20.00	0.73	0.48	0.094
22.00	0.78	0.39	0.060
24.00	0.78	0.32	0.046
26.00	0.78	0.26	0.036
28.00	0.80	0.19	0.023
30.00	0.79	0.14	0.020
Silicon, single crystal[23]			
0.01240	3.4185	2.90E-04	0.300
0.01488	3.4190	2.30E-04	0.300
0.01736	3.4192	1.90E-04	0.300
0.01984	3.4195	1.70E-04	0.300
0.02480	3.4197		0.300
0.03100	3.4199		0.300
0.04092	3.4200		0.300
0.04463		1.08E-04	
0.04959	3.4201	9.15E-05	0.300
0.05703		1.56E-04	
0.06199	3.4204	2.86E-04	0.300
0.06943		3.84E-04	
0.07439		7.16E-04	
0.08059	(3.4207)	1.52E-04	0.300
0.08679		1.02E-04	
0.09299		2.59E-04	
0.09919		1.77E-04	
0.1054		1.53E-04	
0.1116		2.02E-04	
0.1178		1.22E-04	
0.1240	3.4215	6.76E-05	0.300
0.1364		5.49E-05	
0.1488		2.41E-05	
0.1612		2.49E-05	
0.1736	(3.4230)	1.68E-05	0.300
0.1798		2.45E-05	
0.1860		2.66E-06	
0.1922		1.74E-06	
0.1984		8.46E-07	
0.2046		5.64E-07	
0.2108	(3.4244)	4.17E-07	0.300
0.2170		4.05E-07	
0.2232		3.94E-07	
0.2294		3.26E-07	
0.2356		2.97E-07	
0.2418		2.82E-07	
0.2480	3.4261	1.99E-07	0.300
0.3100	3.4294		0.301
0.3626	3.4327		0.301
0.4568	3.4393	2.50E-09	0.302
0.6199	3.4490		0.303
0.8093	3.4784		0.306

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
1.033	3.5193		0.311
1.1	(3.5341)	1.30E-05	0.312
1.2		1.80E-04	
1.3		2.26E-03	
1.4		7.75E-03	
1.5	3.673	5.00E-03	0.327
1.6	3.714	8.00E-03	0.331
1.7	3.752	1.00E-02	0.335
1.8	3.796	0.013	0.340
1.9	3.847	0.016	0.345
2.0	3.906	0.022	0.351
2.1	3.969	0.030	0.357
2.2	4.042	0.032	0.364
2.3	4.123	0.048	0.372
2.4	4.215	0.060	0.380
2.5	4.320	0.073	0.390
2.6	4.442	0.090	0.400
2.7	4.583	0.130	0.412
2.8	4.753	0.163	0.426
2.9	4.961	0.203	0.442
3.0	5.222	0.269	0.461
3.1	5.570	0.387	0.486
3.2	6.062	0.630	0.518
3.3	6.709	1.321	0.561
3.4	6.522	2.705	0.592
3.5	5.610	3.014	0.575
3.6	5.296	2.987	0.564
3.7	5.156	3.058	0.563
3.8	5.065	3.182	0.568
3.9	5.016	3.346	0.577
4.0	5.010	3.587	0.591
4.1	5.020	3.979	0.614
4.2	4.888	4.639	0.652
4.3	4.086	5.395	0.703
4.4	3.120	5.344	0.726
4.5	2.451	5.082	0.740
4.6	1.988	4.678	0.742
4.7	1.764	4.278	0.728
4.8	1.658	3.979	0.710
4.9	1.597	3.749	0.693
5.0	1.570	3.565	0.675
5.1	1.571	3.429	0.658
5.2	1.589	3.354	0.646
5.3	1.579	3.353	0.647
5.4	1.471	3.366	0.663
5.5	1.340	3.302	0.673
5.6	1.247	3.206	0.675
5.7	1.180	3.112	0.673
5.8	1.133	3.045	0.672
5.9	1.083	2.982	0.673
6.0	1.010	2.909	0.677
6.5	0.847	2.73	0.688
7.0	0.682	2.45	0.691
7.5	0.563	2.21	0.693
8.0	0.478	2.00	0.691
8.5	0.414	1.82	0.688
9.0	0.367	1.66	0.683
9.5	0.332	1.51	0.672
10.0	0.306	1.38	0.661
12.0	0.257	0.963	0.590
14.0	0.275	0.641	0.460
16.0	0.345	0.394	0.297
18.0	0.455	0.219	0.159
20.0	0.567	0.0835	0.079
22.14	0.675	0.0405	0.038

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
24.31	0.752	0.0243	0.020
26.38	0.803	0.0178	0.012
28.18	0.834	0.0152	0.008
30.24	0.860	0.0138	0.006
31.79	0.877	0.0132	0.004
34.44	0.899	0.0121	0.003
36.47	0.913	0.0113	0.002
38.75	0.925	0.0104	0.002
40.00	0.930	0.0100	0.001
Silver[6]			
0.10	9.91	90.27	0.995
0.20	2.84	45.70	0.995
0.30	1.41	30.51	0.994
0.40	0.91	22.89	0.993
0.50	0.67	18.32	0.992
1.00	0.28	9.03	0.987
1.50	0.27	5.79	0.969
2.00	0.27	4.18	0.944
2.50	0.24	3.09	0.914
3.00	0.23	2.27	0.864
3.25	0.23	1.86	0.816
3.50	0.21	1.42	0.756
3.60	0.23	1.13	0.671
3.70	0.30	0.77	0.475
3.77	0.53	0.40	0.154
3.80	0.73	0.30	0.053
3.90	1.30	0.36	0.040
4.00	1.61	0.60	0.103
4.10	1.73	0.85	0.153
4.20	1.75	1.06	0.194
4.30	1.73	1.13	0.208
4.50	1.69	1.28	0.238
4.75	1.61	1.34	0.252
5.00	1.55	1.36	0.257
5.50	1.45	1.34	0.257
6.00	1.34	1.28	0.246
6.50	1.25	1.18	0.225
7.00	1.18	1.06	0.196
7.50	1.14	0.91	0.157
8.00	1.16	0.75	0.114
9.00	1.33	0.56	0.074
10.00	1.46	0.56	0.082
11.00	1.52	0.56	0.088
12.00	1.61	0.59	0.100
13.00	1.66	0.64	0.112
14.00	1.72	0.78	0.141
14.50	1.64	0.88	0.152
15.00	1.56	0.92	0.156
16.00	1.42	0.91	0.151
17.00	1.33	0.86	0.139
18.00	1.28	0.80	0.124
19.00	1.27	0.75	0.111
20.00	1.29	0.71	0.103
21.00	1.35	0.75	0.112
21.50	1.37	0.80	0.124
22.00	1.34	0.87	0.141
22.50	1.26	0.93	0.157
23.00	1.17	0.94	0.163
23.50	1.10	0.93	0.165
24.00	1.04	0.90	0.165
24.50	0.99	0.87	0.160
25.00	0.95	0.83	0.154
25.50	0.91	0.78	0.144
26.00	0.90	0.74	0.133

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
26.50	0.89	0.69	0.121
27.00	0.89	0.65	0.109
27.50	0.89	0.62	0.099
28.00	0.90	0.59	0.090
28.50	0.91	0.57	0.084
29.00	0.92	0.56	0.079
30.00	0.93	0.54	0.074
31.00	0.93	0.53	0.072
32.00	0.92	0.53	0.072
33.00	0.90	0.51	0.071
34.00	0.88	0.49	0.067
35.00	0.86	0.45	0.061
36.00	0.89	0.44	0.055
38.00	0.89	0.39	0.043
40.00	0.90	0.37	0.039
42.00	0.90	0.35	0.036
44.00	0.90	0.33	0.033
46.00	0.90	0.32	0.031
48.00	0.89	0.31	0.030
50.00	0.88	0.29	0.027
52.00	0.89	0.28	0.024
54.00	0.88	0.17	0.024
56.00	0.87	0.26	0.024
58.00	0.87	0.24	0.021
60.00	0.87	0.22	0.018
62.00	0.88	0.21	0.016
64.00	0.88	0.21	0.016
66.00	0.88	0.21	0.016
68.00	0.87	0.21	0.017
70.00	0.83	0.20	0.021
72.00	0.85	0.18	0.016
74.00	0.85	0.17	0.014
76.00	0.85	0.16	0.013
78.00	0.85	0.15	0.013
80.00	0.85	0.14	0.012
85.00	0.85	0.11	0.011
90.00	0.85	0.08	0.009
95.00	0.86	0.06	0.007
100.00	0.87	0.04	0.005

Sodium[24]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.55	0.262	9.97	0.990
0.58	0.241	9.45	0.989
0.63	0.207	8.80	0.990
0.67	0.175	8.09	0.990
0.73	0.147	7.42	0.990
0.81	0.123	6.67	0.989
0.92	0.099	5.82	0.989
1.05	0.078	5.11	0.989
1.23	0.064	4.35	0.987
1.44	0.053	3.72	0.986
1.65	0.050	3.22	0.983
1.87	0.049	2.76	0.978
2.07	0.053	2.48	0.971
2.27	0.059	2.23	0.961
2.45	0.063	2.07	0.953
2.64	0.066	1.88	0.943
2.82	0.068	1.76	0.936
2.95	0.068	1.63	0.928
3.06	0.069	1.54	0.921
3.20	0.065	1.47	0.921
3.40	0.061	1.33	0.916
3.71	0.055	1.13	0.908
3.97	0.049	1.01	0.908
6.199	0.390		0.193
6.358	0.454		0.141
6.526	0.485		0.120
6.702	0.533		0.093
6.888	0.574		0.073
7.130	0.616		0.056
7.328	0.641		0.048
7.583	0.674		0.038
7.847	0.700		0.031
8.015	0.710		0.029
8.634	0.762		0.018
9.143	0.800		0.012
9.709	0.819		0.010
10.20	0.843		0.007
11.08	0.870		0.005
11.83	0.887		0.004
12.73	0.907		0.002
13.05	0.913		0.002
13.42	0.914		0.002
13.73	0.917		0.002
14.07	0.922		0.002
14.83	0.934		0.001
15.05	0.936		0.001
15.46	0.942		0.001
16.21	0.948		0.001
18.10	0.964		0.000
21.12	0.979		0.000
25.51	0.993		0.000
26.95	1.00		0.000
27.68	1.01		0.000
28.37	1.01		0.000
29.52	1.02		0.000

Tantalum[16]

Energy (eV)	*n*	*k*	*R*(ϕ = 0)
0.10	10.14	66.39	0.984
0.15	9.45	46.41	0.9834
0.20	5.77	35.46	0.982
0.26	3.67	27.53	0.981
0.30	2.87	23.90	0.980
0.38	2.03	18.87	0.978
0.50	1.37	14.26	0.974
0.58	1.15	12.19	0.970
0.70	0.96	9.92	0.962
0.78	0.89	8.77	0.956
0.90	0.84	7.38	0.942
1.00	0.89	6.47	0.992
1.10	0.93	5.75	0.899
1.20	0.98	5.14	0.872
1.30	1.00	4.62	0.842
1.40	1.04	4.15	0.805
1.50	1.09	3.73	0.762
1.60	1.15	3.33	0.707
1.70	1.24	2.95	0.640
1.80	1.35	2.60	0.560
1.90	1.57	2.24	0.460
2.00	1.83	1.99	0.388
2.10	2.10	1.84	0.354
2.20	2.36	1.81	0.351
2.30	2.56	1.86	0.365
2.40	2.68	1.92	0.378
2.50	2.75	1.98	0.388
2.60	2.80	2.02	0.395
2.70	2.84	2.08	0.405
2.80	2.85	2.14	0.412
2.90	2.84	2.20	0.420
3.00	2.81	2.24	0.425
3.20	2.73	2.31	0.432
3.40	2.61	2.33	0.435
3.60	2.49	2.30	0.430
3.80	2.40	2.22	0.418
4.00	2.36	2.14	0.406
4.20	2.35	2.06	0.392
4.40	2.39	2.01	0.384
4.60	2.45	2.00	0.384
4.80	2.53	2.06	0.394
5.00	2.58	2.20	0.416
5.20	2.52	2.44	0.450
5.40	2.31	2.61	0.480
5.60	2.06	2.67	0.501
5.80	1.83	2.63	0.510
6.00	1.63	2.56	0.515
6.20	1.48	2.45	0.512
6.40	1.37	2.33	0.504
6.60	1.29	2.22	0.492
6.80	1.23	2.11	0.478
7.00	1.18	2.01	0.462
7.20	1.15	1.91	0.445
7.40	1.13	1.82	0.425
7.60	1.12	1.75	0.406
7.80	1.11	1.68	0.390
8.00	1.11	1.61	0.370
8.20	1.12	1.55	0.350
8.40	1.13	1.50	0.332
8.60	1.14	1.45	0.317
8.80	1.17	1.41	0.301
9.00	1.19	1.40	0.294
9.20	1.21	1.38	0.289
9.40	1.21	1.38	0.287
9.60	1.21	1.38	0.285
9.80	1.21	1.37	0.285
10.00	1.20	1.37	0.286
10.20	1.19	1.37	0.286
10.40	1.18	1.37	0.287
10.60	1.16	1.36	0.288
10.80	1.15	1.36	0.289
11.00	1.13	1.35	0.290
11.20	1.11	1.35	0.292
11.40	1.09	1.34	0.293
11.60	1.07	1.33	0.294
11.80	1.05	1.32	0.295
12.00	1.02	1.31	0.296
12.20	1.00	1.29	0.295
12.40	0.98	1.28	0.294
12.60	0.96	1.26	0.292
12.80	0.94	1.24	0.289
13.00	0.93	1.22	0.286
13.60	0.91	1.16	0.272
14.00	0.90	1.15	0.272
14.60	0.85	1.15	0.285
15.00	0.80	1.13	0.293
15.60	0.72	1.08	0.301
16.00	0.68	1.04	0.304
16.60	0.63	0.97	0.301
17.00	0.60	0.92	0.296
17.60	0.60	0.92	0.296
18.00	0.55	0.79	0.274
18.60	0.53	0.71	0.254
19.00	0.53	0.65	0.236
19.60	0.53	0.57	0.207
20.00	0.54	0.52	0.185
20.60	0.55	0.44	0.153

Energy (eV)	*n*	*k*	$R(\phi = 0)$
21.00	0.57	0.39	0.127
21.60	0.64	0.34	0.089
22.00	0.64	0.32	0.081
22.60	0.69	0.27	0.058
23.00	0.73	0.24	0.043
23.60	0.80	0.26	0.033
24.00	0.80	0.26	0.034
24.60	0.82	0.25	0.029
25.00	0.83	0.25	0.026
25.60	0.86	0.24	0.022
26.00	0.88	0.25	0.022
26.60	0.87	0.26	0.023
27.00	0.87	0.25	0.022
27.60	0.89	0.23	0.019
28.00	0.90	0.23	0.017
28.60	0.91	0.22	0.015
29.00	0.92	0.22	0.014
29.60	0.94	0.22	0.014
30.00	0.95	0.22	0.014
31.00	0.97	0.23	0.014
32.00	0.98	0.24	0.015
33.00	0.98	0.25	0.015
34.00	0.99	0.25	0.016
35.00	0.99	0.26	0.017
36.00	0.99	0.27	0.018
37.00	0.99	0.28	0.019
38.00	0.98	0.28	0.021
39.00	0.97	0.29	0.022
40.00	0.95	0.29	0.023

Tellurium, $\vec{E} \parallel \hat{c}$[25]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.01364	4.82	0.118	0.431
0.01488	5.26	0.0505	0.463
0.01612	5.47	0.0278	0.477
0.01736	5.59	0.0174	0.485
0.01860		0.0796	
0.01984		0.0696	
0.02108		0.0749	
0.02232		0.1900	
0.02356		0.2220	
0.02480		0.0716	
0.02604		0.0682	
0.02728		0.0832	
0.02976		0.0149	
0.03224		2.14E-03	
0.03472		1.71E-02	
0.03720	5.94	3.71E-03	0.507
0.03968		2.44E-03	
0.04339	5.96	1.59E-03	0.508
0.04711		7.85E-04	
0.05083		7.38E-04	
0.05579		3.89E-04	
0.06199	5.98	3.09E-04	0.509
0.07439		2.52E-04	
0.08679		2.96E-04	
0.09919		3.68E-04	
0.12400	6.246	3.34E-04	0.524
0.15500	6.253		0.525
0.20660	6.286		0.526
0.24800	6.316	7.48E-05	0.528
0.31	6.372	1.18E-05	0.531
0.35		4.93E-04	
0.41		6.74E-03	
0.5	6.53	2.30E-02	0.539
0.6	6.71	7.50E-02	0.549
0.7	7.00	0.24	0.563
0.8	7.23	0.48	0.574
0.9	7.48	0.94	0.589
1.0	7.70	1.56	0.606
1.2	6.99	2.22	0.593
1.4	7.11	2.46	0.604
1.6	6.75	2.91	0.606
1.8	6.89	3.70	0.637
2.0	4.67	4.67	0.654
2.2	4.94	5.16	0.681
2.4	3.94	5.08	0.686
2.6	3.25	4.77	0.681
2.8	2.73	4.42	0.674
3.0	2.30	4.16	0.674
3.5	1.69	3.44	0.646
4.0	1.33	2.64	0.571
4.5	1.32	1.96	0.428
5.0	1.63	1.60	0.312
5.5	1.72	1.57	0.302
6.0	1.73	1.45	0.276
6.5	1.78	1.36	0.257
7.0	1.83	1.36	0.257
7.5	1.72	1.51	0.289
8.0	1.54	1.37	0.260
8.5	1.55	1.23	0.226
9.0	0.99	0.93	0.179
9.5	1.47	1.25	0.233
10.0	0.86	0.86	0.181
11.0	0.80	0.77	0.165
12.0	0.79	0.76	0.164
14.0	0.67	0.59	0.146
16.0	0.59	0.49	0.147
18.0	0.48	0.31	0.160
20.0	0.74	0.20	0.035
22.0	0.83	0.18	0.018
24.0	0.85	0.15	0.013
26.0	0.87	0.12	0.009
28.0	0.89	0.090	0.006
30.0	0.90	0.045	0.003

Tellurium, $\vec{E} \perp \hat{c}$[25]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.01364	2.61	0.2980	0.204
0.01488	3.65	0.0894	0.325
0.01612	4.10	0.0535	0.370
0.01736	4.63	0.4990	0.420
0.01860		0.1170	
0.01984		0.0343	
0.02108	(4.42)	0.0421	0.398
0.02232		0.1060	
0.02356		0.0880	
0.02480		0.0458	
0.02604		0.0928	
0.02728		0.0886	
0.02976		0.0232	
0.03224		3.06E-03	
0.03472		1.25E-02	
0.03720	4.71	2.65E-03	0.422
0.03968		1.89E-03	
0.04339	4.74	1.41E-03	0.425
0.04711		8.38E-04	
0.05083		6.79E-04	
0.05579		1.59E-04	
0.06199	4.77	1.16E-04	0.427
0.07439		7.23E-05	
0.08679		5.34E-05	
0.09919		4.28E-05	
0.1240	4.796	3.18E-05	0.429
0.1550	4.809		0.430
0.2066	4.838		0.432
0.2480	4.864	2.19E-05	0.434
0.31	4.929	3.18E-05	0.439
0.35		7.89E-02	
0.41		0.149	
0.5	4.90		0.437
0.6	4.93		0.439
0.7	4.95	0.11	0.441
0.8	5.10	0.13	0.452
0.9	5.22	0.22	0.461
1.0	5.35	0.45	0.472
1.2	5.17	0.63	0.462
1.4	5.56	0.63	0.488
1.6	5.88	1.15	0.517
1.8	6.10	1.80	0.545
2.0	5.94	2.69	0.571
2.2	5.10	3.61	0.594
2.4	4.24	3.77	0.593
2.6	3.57	3.75	0.591
2.8	3.03	3.63	0.588
3.0	2.51	3.39	0.578
3.5	1.72	2.70	0.532
4.0	1.32	2.01	0.440
4.5	1.28	1.28	0.251
5.0	1.47	0.82	0.132
5.5	1.74	0.51	0.104
6.0	1.94	0.39	0.118
6.5	2.19	0.32	0.148
7.0	2.48	0.40	0.192
7.5	2.60	0.69	0.226
8.0	2.59	0.91	0.245
8.5	2.39	1.00	0.235
9.0	1.11	1.24	0.259
9.5	2.08	1.11	0.224
10.0	0.99	1.04	0.215
11.0	0.84	1.01	0.237
12.0	0.87	0.87	0.182
14.0	0.59	0.87	0.282
16.0	0.64	0.55	0.144
18.0	0.52	0.41	0.161
20.0	0.50	0.38	0.165
22.0	0.56	0.29	0.110
24.0	0.54	0.25	0.113
26.0	0.50	0.20	0.127
28.0	0.48	0.17	0.135
30.0	0.46	0.088	0.140

Titanium (Polycrystalline)[14]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.10	5.03	23.38	0.965
0.15	3.00	15.72	0.954
0.20	2.12	11.34	0.939
0.25	2.05	8.10	0.890
0.30	6.39	9.94	0.833
0.35	2.74	6.21	0.792
0.40	2.49	4.68	0.708
0.45	3.35	3.25	0.545
0.50	4.43	3.22	0.555
0.60	4.71	3.77	0.597
0.70	4.38	3.89	0.603
0.80	4.04	3.82	0.596
0.90	3.80	3.65	0.582
1.00	3.62	3.52	0.570

Energy (eV)	n	k	R(ϕ = 0)
1.10	3.47	3.40	0.560
1.20	3.35	3.30	0.550
1.30	3.28	3.25	0.546
1.40	3.17	3.28	0.549
1.50	2.98	3.32	0.557
1.60	2.74	3.30	0.559
1.70	2.54	3.23	0.557
1.80	2.36	3.11	0.550
1.90	2.22	2.99	0.540
2.00	2.11	2.88	0.530
2.10	2.01	2.77	0.520
2.20	1.92	2.67	0.509
2.30	1.86	2.56	0.495
2.40	1.81	2.47	0.483
2.50	1.78	2.39	0.471
2.60	1.75	2.34	0.462
2.70	1.71	2.29	0.456
2.80	1.68	2.25	0.451
2.90	1.63	2.21	0.447
3.00	1.59	2.17	0.444
3.10	1.55	2.15	0.442
3.20	1.50	2.12	0.442
3.30	1.44	2.09	0.442
3.40	1.37	2.06	0.443
3.50	1.30	2.01	0.443
3.60	1.24	1.96	0.441
3.70	1.17	1.90	0.436
3.80	1.11	1.83	0.430
3.85	1.08	1.78	0.423
3.90	1.06	1.73	0.413
4.00	1.04	1.62	0.389
4.20	1.05	1.45	0.333
4.40	1.13	1.33	0.284
4.60	1.17	1.29	0.265
4.80	1.21	1.23	0.244
5.00	1.24	1.21	0.236
5.20	1.27	1.20	0.228
5.40	1.17	1.16	0.228
5.60	1.24	1.21	0.234
5.80	1.21	1.22	0.241
6.00	1.15	1.21	0.244
6.20	1.11	1.18	0.240
6.40	1.08	1.14	0.232
6.60	1.04	1.06	0.212
6.80	1.05	1.02	0.198
7.00	1.06	0.97	0.182
7.20	1.07	0.95	0.175
7.40	1.11	0.94	0.167
7.60	1.09	0.92	0.165
7.80	1.11	0.93	0.165
8.00	1.10	0.94	0.169
8.20	1.10	0.95	0.171
8.40	1.08	0.95	0.175
8.60	1.04	0.96	0.181
8.80	1.02	0.95	0.181
9.00	1.00	0.94	0.182
9.20	0.97	0.93	0.182
9.40	0.95	0.91	0.181
9.60	0.94	0.90	0.179
9.80	0.91	0.88	0.179
10.00	0.89	0.88	0.180
10.20	0.86	0.85	0.178
10.40	0.85	0.83	0.175
10.60	0.81	0.79	0.167
10.80	0.80	0.76	0.162
11.00	0.79	0.72	0.152
11.20	0.81	0.69	0.139
11.40	0.81	0.69	0.139
11.60	0.79	0.68	0.139
11.80	0.78	0.67	0.137
12.00	0.77	0.65	0.132
12.80	0.76	0.55	0.106
13.20	0.76	0.52	0.097
13.60	0.76	0.48	0.087
14.00	0.77	0.45	0.077
14.40	0.77	0.42	0.069
14.80	0.79	0.38	0.058
15.20	0.79	0.36	0.052
15.60	0.79	0.32	0.045
16.00	0.83	0.31	0.037
16.40	0.84	0.28	0.030
16.80	0.87	0.27	0.025
17.20	0.90	0.25	0.020
17.60	0.93	0.25	0.017
18.00	0.94	0.24	0.165
18.40	0.94	0.23	0.017
18.80	0.95	0.24	0.016
19.20	0.96	0.25	0.016
19.60	0.97	0.25	0.017
20.00	0.98	0.27	0.018
20.40	0.98	0.27	0.019
20.60	1.00	0.29	0.020
21.20	0.99	0.31	0.023
21.60	0.99	0.31	0.024
22.00	0.98	0.32	0.025
22.40	0.98	0.33	0.027
22.80	0.97	0.33	0.028
23.20	0.96	0.34	0.030
23.60	0.95	0.35	0.031
24.00	0.92	0.35	0.033
24.5	0.91	0.34	0.032
25.0	0.91	0.33	0.032
25.5	0.89	0.33	0.032
26.0	0.89	0.33	0.032
26.5	0.88	0.32	0.032
27.0	0.86	0.31	0.032
27.5	0.85	0.30	0.033
28.0	0.84	0.29	0.033
28.5	0.82	0.26	0.029
29.0	0.83	0.25	0.027
30.0	0.84	0.22	0.022

Tungsten[27]

Energy (eV)	n	k	R(ϕ = 0)
0.10	14.06	54.71	0.983
0.20	3.87	28.30	0.981
0.25	2.56	22.44	0.980
0.30	1.83	18.32	0.979
0.34	1.71	15.71	0.973
0.38	1.86	13.88	0.963
0.42	1.92	12.63	0.954
0.46	1.69	11.59	0.952
0.50	1.40	10.52	0.952
0.54	1.23	9.45	0.948
0.58	1.17	8.44	0.938
0.62	1.28	7.52	0.917
0.66	1.45	6.78	0.888
0.70	1.59	6.13	0.856
0.74	1.83	5.52	0.810
0.78	2.12	5.00	0.759
0.82	2.36	4.61	0.710
0.86	2.92	4.37	0.661
0.90	3.11	4.44	0.660
0.94	3.15	4.43	0.658
0.98	3.15	4.36	0.653
1.00	3.14	4.32	0.649
1.10	3.05	4.04	0.627
1.20	3.00	3.64	0.590
1.30	3.12	3.24	0.545
1.40	3.29	2.96	0.515
1.50	3.48	2.79	0.500
1.60	3.67	2.68	0.494
1.70	3.84	2.79	0.507
1.80	3.82	2.91	0.518
1.90	3.70	2.94	0.518
2.00	3.60	2.89	0.512
2.10	3.54	2.84	0.506
2.20	3.49	2.76	0.497
2.30	3.49	2.72	0.494
2.40	3.45	2.72	0.493
2.50	3.38	2.68	0.487
2.60	3.34	2.62	0.480
2.70	3.31	2.55	0.472
2.80	3.31	2.49	0.466
2.90	3.32	2.45	0.461
3.00	3.35	2.42	0.459
3.10	3.39	2.41	0.460
3.20	3.43	2.45	0.465
3.30	3.45	2.55	0.476
3.40	3.39	2.66	0.485
3.50	3.24	2.70	0.488
3.60	3.13	2.67	0.482
3.70	3.05	2.62	0.476
3.80	2.99	2.56	0.468
3.90	2.96	2.50	0.460
4.00	2.95	2.43	0.451
4.20	3.02	2.33	0.440
4.40	3.13	2.32	0.442
4.60	3.24	2.41	0.455
4.80	3.33	2.57	0.475
5.00	3.40	2.85	0.505
5.20	3.27	3.27	0.548
5.40	2.92	3.58	0.586
5.60	2.43	3.70	0.618
5.80	2.00	3.61	0.637
6.00	1.70	3.42	0.643
6.20	1.47	3.24	0.646
6.40	1.32	3.04	0.640
6.60	1.21	2.87	0.631
6.80	1.12	2.70	0.619
7.00	1.06	2.56	0.607
7.20	1.01	2.43	0.593
7.40	0.98	2.30	0.573
7.60	0.95	2.18	0.556
7.80	0.93	2.06	0.533
8.00	0.94	1.95	0.505
8.20	0.94	1.86	0.481
8.40	0.96	1.76	0.449
8.60	0.99	1.70	0.422
8.80	1.01	1.65	0.401
9.00	1.01	1.60	0.388
9.20	1.02	1.55	0.369
9.40	1.03	1.50	0.352
9.60	1.05	1.44	0.329
9.80	1.09	1.38	0.307
10.00	1.13	1.34	0.287

Energy (eV)	*n*	*k*	$R(\phi = 0)$
10.20	1.19	1.33	0.274
10.40	1.24	1.34	0.270
10.60	1.27	1.36	0.274
10.80	1.29	1.39	0.282
11.00	1.28	1.42	0.290
11.20	1.27	1.44	0.297
11.40	1.25	1.46	0.305
11.60	1.22	1.48	0.313
11.80	1.20	1.48	0.318
12.00	1.16	1.48	0.323
12.40	1.10	1.47	0.329
12.80	1.04	1.44	0.333
13.20	0.98	1.40	0.332
13.60	0.94	1.35	0.325
14.00	0.91	1.28	0.312
14.40	0.90	1.23	0.296
14.80	0.90	1.17	0.276
15.20	0.93	1.13	0.255
15.60	0.97	1.12	0.246
16.00	0.98	1.14	0.249
16.40	0.97	1.17	0.260
16.80	0.94	1.19	0.273
17.20	0.90	1.21	0.289
17.60	0.85	1.21	0.304
18.00	0.80	1.20	0.317
18.40	0.74	1.18	0.330
18.80	0.69	1.15	0.340
19.20	0.64	1.11	0.347
19.60	0.60	1.07	0.353
20.00	0.56	1.02	0.354
20.40	0.54	0.97	0.350
20.80	0.52	0.92	0.342
21.20	0.50	0.87	0.331
21.60	0.50	0.82	0.318
22.00	0.49	0.77	0.303
22.40	0.49	0.73	0.287
22.80	0.49	0.69	0.272
23.20	0.49	0.66	0.263
23.60	0.48	0.62	0.252
24.00	0.49	0.57	0.234
24.40	0.50	0.53	0.213
24.80	0.51	0.49	0.191
25.20	0.53	0.46	0.171
25.60	0.55	0.43	0.150
26.00	0.57	0.40	0.132
26.40	0.59	0.38	0.117
26.80	0.61	0.37	0.105
27.00	0.62	0.36	0.099
27.50	0.64	0.34	0.085
28.00	0.67	0.32	0.073
28.50	0.69	0.31	0.065
29.00	0.71	0.30	0.057
29.50	0.73	0.30	0.052
30.00	0.75	0.29	0.047
31.00	0.78	0.29	0.042
32.00	0.79	0.29	0.040
33.00	0.82	0.28	0.033
34.00	0.84	0.29	0.032
35.00	0.85	0.31	0.033
36.00	0.85	0.32	0.036
37.00	0.84	0.33	0.039
38.00	0.83	0.33	0.040
39.00	0.81	0.33	0.042
40.00	0.80	0.33	0.045

Energy (eV)	*n*	*k*	$R(\phi = 0)$
Vanadium[9]			
0.10	12.83	45.89	0.978
0.20	3.90	24.30	0.975
0.28	2.13	17.35	0.973
0.36	1.54	13.32	0.966
0.44	1.28	10.74	0.957
0.52	1.16	8.93	0.945
0.60	1.10	7.59	0.929
0.68	1.07	6.54	0.909
0.76	1.08	5.67	0.882
0.80	1.10	5.30	0.864
0.90	1.18	4.50	0.811
1.00	1.34	3.80	0.730
1.10	1.60	3.26	0.632
1.20	1.93	2.88	0.543
1.30	2.25	2.71	0.498
1.40	2.48	2.72	0.491
1.50	2.57	2.79	0.499
1.60	2.57	2.84	0.507
1.70	2.52	2.88	0.512
1.80	2.45	2.88	0.515
1.90	2.36	2.85	0.514
2.00	2.34	2.81	0.509
2.10	2.31	2.78	0.506
2.20	2.28	2.80	0.510
2.30	2.23	2.83	0.516
2.40	2.15	2.88	0.528
2.50	2.02	2.91	0.540
2.60	1.89	2.92	0.552
2.70	1.74	2.89	0.561
2.80	1.61	2.85	0.569
2.90	1.48	2.80	0.577
3.00	1.36	2.73	0.582
3.20	1.16	2.55	0.585
3.40	0.99	2.37	0.586
3.60	0.87	2.17	0.575
3.80	0.80	1.96	0.547
4.00	0.78	1.76	0.503
4.20	0.80	1.60	0.449
4.40	0.83	1.47	0.400
4.60	0.87	1.38	0.355
4.80	0.90	1.31	0.326
5.00	0.91	1.26	0.304
5.25	0.93	1.18	0.271
5.50	0.94	1.14	0.258
5.75	0.96	1.09	0.235
6.00	0.98	1.06	0.223
6.25	0.97	1.02	0.212
6.50	0.97	0.98	0.199
6.75	0.97	0.94	0.185
7.00	0.98	0.91	0.175
7.33	0.97	0.89	0.170
7.66	0.98	0.87	0.162
8.00	0.98	0.85	0.155
8.33	0.98	0.81	0.146
8.66	0.98	0.81	0.145
9.00	0.96	0.79	0.142
9.50	0.94	0.77	0.136
10.00	0.91	0.74	0.133
10.50	0.89	0.71	0.126
11.00	0.87	0.65	0.112
11.50	0.88	0.58	0.091
12.00	0.90	0.58	0.089
12.50	0.89	0.57	0.086
13.00	0.88	0.55	0.082

Energy (eV)	*n*	*k*	$R(\phi = 0)$
13.50	0.87	0.53	0.079
14.00	0.86	0.51	0.075
14.50	0.86	0.49	0.070
15.00	0.86	0.47	0.065
15.50	0.86	0.46	0.062
16.00	0.85	0.45	0.061
16.50	0.84	0.43	0.059
17.00	0.84	0.41	0.056
17.50	0.83	0.40	0.054
18.00	0.82	0.38	0.051
18.50	0.82	0.37	0.048
19.00	0.82	0.35	0.045
19.50	0.82	0.34	0.043
20.00	0.81	0.32	0.041
20.50	0.81	0.31	0.038
21.00	0.81	0.29	0.036
21.50	0.81	0.28	0.033
22.00	0.81	0.27	0.032
22.50	0.81	0.25	0.029
23.00	0.82	0.24	0.027
23.50	0.82	0.23	0.025
24.00	0.82	0.22	0.024
24.50	0.83	0.21	0.022
25.00	0.83	0.20	0.020
25.50	0.83	0.19	0.019
26.00	0.83	0.18	0.018
26.50	0.84	0.17	0.016
27.00	0.84	0.16	0.015
27.50	0.85	0.16	0.014
28.00	0.85	0.15	0.013
28.50	0.86	0.14	0.012
29.00	0.86	0.14	0.011
29.50	0.86	0.13	0.010
30.00	0.87	0.13	0.009
31.00	0.88	0.12	0.008
32.00	0.90	0.11	0.007
33.00	0.90	0.10	0.005
34.00	0.91	0.10	0.005
35.00	0.92	0.09	0.004
36.00	0.94	0.10	0.004
37.00	0.94	0.10	0.004
38.00	0.95	0.11	0.004
39.00	0.95	0.12	0.004
40.00	0.95	0.13	0.005
Zinc, $\vec{E} \parallel \hat{c}$[28]			
0.7514	1.9241	7.5619	0.883
0.827	1.7921	6.9973	0.874
0.866	1.5571	6.7753	0.881
0.952	1.4824	6.2296	0.868
0.992	1.5762	5.8843	0.847
1.033	1.5407	5.3192	0.823
1.078	1.5853	4.9013	0.793
1.127	1.7768	4.5307	0.748
1.181	1.9808	4.2004	0.701
1.240	2.8821	3.4766	0.575
1.305	3.2039	3.0042	0.520
1.377	2.9459	3.5761	0.584
1.459	3.2523	4.2447	0.640
1.550	3.8086	4.6212	0.657
1.653	3.7577	4.6239	0.659
1.722	3.5908	4.4614	0.650
1.823	3.4234	4.3232	0.642
1.937	3.0132	3.9974	0.624
1.984	1.8562	3.9706	0.690

Energy (eV)	*n*	*k*	$R(\phi = 0)$
2.066	1.4856	4.0555	0.737
2.094	1.2525	3.9961	0.762
2.119	1.0017	3.8683	0.789
2.275	0.7737	3.9129	0.832
2.445	0.6395	3.4013	0.821
2.666	0.4430	3.1379	0.851
2.917	0.3589	2.8140	0.853
3.220	0.3069	2.5088	0.847
3.594	0.2737	2.1737	0.828
4.065	0.2510	1.8528	0.799
4.678	0.2354	1.6357	0.776

Zinc, $\vec{E} \perp \hat{c}$ [28]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.751	1.4469	7.4158	0.905
0.827	1.4744	6.9688	0.892
0.866	1.3628	6.6886	0.892
0.952	1.3165	6.2212	0.881
0.992	1.3835	5.8910	0.863
1.033	1.2889	5.4001	0.850
1.078	1.3095	4.9025	0.822
1.127	1.6897	4.4062	0.746
1.181	1.9701	4.0176	0.684
1.240	2.8717	3.2873	0.555
1.305	3.3991	2.7684	0.497
1.377	3.1807	3.4709	0.569
1.459	3.5064	4.1994	0.630
1.550	4.1241	4.7768	0.664
1.653	4.0269	4.8027	0.667
1.722	3.9369	4.6356	0.657
1.823	3.7549	4.3042	0.635
1.937	3.4512	4.1942	0.631
1.984	3.2515	4.2980	0.644
2.066	2.0802	4.7231	0.738
2.094	1.7084	4.7923	0.774
2.119	1.3329	4.4751	0.791
2.275	0.9725	4.2879	0.825
2.455	0.7568	3.7627	0.824
2.666	0.5470	3.4277	0.845
2.917	0.4774	3.0476	0.834
3.220	0.3911	2.7463	0.835
3.594	0.3147	2.3041	0.821
4.065	0.3013	2.0077	0.789
4.678	0.2806	1.7997	0.770

Zirconium (Polycrystalline)[28]

Energy (eV)	*n*	*k*	$R(\phi = 0)$
0.10	6.18	1.76	0.300
0.15	3.37	1.30	0.123
0.20	2.34	1.08	0.058
0.26	2.24	1.06	0.052
0.30	2.59	1.14	0.073
0.36	3.17	1.26	0.110
0.40	3.09	1.24	0.105
0.46	3.36	1.30	0.123
0.50	4.13	1.44	0.175
0.56	5.01	1.58	0.231
0.60	5.18	1.61	0.242
0.70	4.54	1.51	0.202
0.80	4.03	1.42	0.168
0.90	3.74	1.37	0.149
0.96	3.69	1.36	0.145
1.00	3.66	1.35	0.143
1.10	3.65	1.35	0.142
1.20	3.53	1.33	0.134
1.30	3.25	1.27	0.116
1.40	3.10	1.25	0.106
1.50	3.02	1.23	0.100
1.60	2.88	1.20	0.091
1.70	2.68	1.16	0.078
1.80	2.49	1.12	0.067
2.00	2.14	1.03	0.047
2.10	1.99	1.00	0.040
2.20	1.87	0.97	0.034
2.30	1.78	0.94	0.030
2.40	1.71	0.92	0.027
2.50	1.62	0.90	0.024
2.60	1.54	0.88	0.022
2.70	1.46	0.86	0.019
2.80	1.40	0.84	0.018
2.90	1.34	0.82	0.016
3.00	0.30	0.81	0.016
3.10	1.26	0.80	0.015
3.30	1.19	0.77	0.014
3.40	1.16	0.76	0.013
3.50	1.13	0.75	0.013
3.60	1.10	0.74	0.013
3.70	1.07	0.73	0.013
3.80	1.04	0.72	0.012
3.90	1.01	0.71	0.012
4.00	0.98	0.70	0.012
4.20	0.94	0.68	0.013
4.40	0.89	0.67	0.013
4.60	0.85	0.65	0.014
4.80	0.81	0.64	0.014
5.00	0.78	0.63	0.015
5.20	0.77	0.62	0.016
5.40	0.77	0.62	0.016
5.60	0.80	0.63	0.014
5.80	0.87	0.66	0.013
6.00	1.00	0.71	0.012
6.20	1.11	0.75	0.013
6.40	1.23	0.78	0.014
6.60	1.33	0.81	0.016
6.80	1.42	0.84	0.018
7.00	1.49	0.86	0.020
7.20	1.54	0.88	0.022
7.40	1.58	0.89	0.023
7.60	1.61	0.90	0.024
7.80	1.63	0.90	0.025
8.00	1.66	0.91	0.026
8.20	0.67	0.91	0.026
8.40	1.68	0.92	0.026
8.60	1.68	0.92	0.026
8.80	1.66	0.91	0.026
9.00	1.65	0.91	0.025
9.20	1.63	0.90	0.025
9.40	1.60	0.89	0.024
9.60	1.57	0.89	0.023
9.80	1.52	0.87	0.021
10.00	1.47	0.86	0.020
10.20	1.42	0.84	0.018
10.40	1.35	0.82	0.016
10.50	1.32	0.81	0.016
10.60	1.28	0.80	0.015
10.80	1.23	0.78	0.014
11.00	1.19	0.77	0.014
11.20	1.16	0.76	0.013
11.40	1.13	0.75	0.013
11.60	1.11	0.74	0.013
11.80	1.09	0.74	0.013
12.00	1.08	0.73	0.013
12.40	1.05	0.72	0.012
12.80	1.01	0.71	0.012
13.20	0.98	0.70	0.012
13.60	0.95	0.69	0.013
14.00	0.92	0.68	0.013
14.40	0.89	0.67	0.013
14.80	0.90	0.67	0.013
15.20	0.92	0.68	0.013
15.60	0.95	0.69	0.013
16.00	0.98	0.70	0.012
16.40	1.01	0.71	0.012
16.80	1.04	0.72	0.012
17.20	1.09	0.74	0.013
17.60	1.13	0.75	0.013
18.00	1.17	0.76	0.014
18.40	1.21	0.78	0.014
18.80	1.24	0.79	0.014
19.20	1.27	0.80	0.015
19.60	1.29	0.80	0.015
20.00	1.30	0.81	0.015
20.60	1.29	0.80	0.015
21.00	1.27	0.80	0.015
21.60	1.23	0.78	0.014
22.00	1.20	0.77	0.014
22.60	1.15	0.76	0.013
23.00	1.12	0.75	0.013
23.60	1.08	0.73	0.013
24.00	1.05	0.73	0.013
24.60	1.02	0.71	0.012
25.00	1.00	0.71	0.012
25.60	0.97	0.69	0.012
26.00	0.95	0.69	0.013
26.60	0.91	0.67	0.013
27.00	0.88	0.66	0.013
27.60	0.84	0.65	0.014
28.00	0.83	0.64	0.014
28.60	0.82	0.64	0.014
29.00	0.81	0.64	0.014
29.60	0.82	0.64	0.014
30.00	0.82	0.64	0.014

REFERENCES

1. Shiles, E., Sasaki, T., Inokuti, M., and Smith, D. Y., *Phys. Rev. Sect. B*, 22, 1612, 1980.
2. Edwards, D. F., and Philipp, H. R., in *HOC-I*, p.665.
3. Ives, H. E., and Briggs, N. B., *J. Opt. Soc. Am.*, 27, 395, 1937.
4. Bos, L. W., and Lynch, D. W., *Phys. Rev. Sect. B*, 2, 4567, 1970.
5. Weaver, J. H., Colavita, E., Lynch, D. W., and Rosei, R., *Phys. Rev. Sect. B*, 19, 3850, 1979.
6. Hagemann, H. J., Gudat, W., and Kunz, C., *J. Opt. Soc. Am.*, 65, 742, 1975.
7. Schulz, L. G., *J. Opt. Soc. Am.*, 47, 64, 1957.
8. Potter, R. F., in *HOC-I*, p.465.
9. Olson, C. G., Lynch, D. W., and Weaver, J. H., unpublished.
10. Lynch, D. W., Olson, C. G., and Weaver, J. H., unpublished.
11. Weaver, J. H., Olson, C. G., and Lynch, D. W., *Phys. Rev. Sect. B*, 15, 4115, 1977.
12. Lynch, D. W., and Hunter, W. R., in *HOC-II*, p.345.
13. Priol, M. A., Daudé, A., and Robin, S., *Compt. Rend.*, 264, 935, 1967.
14. Johnson, P. B., and Christy, R. W., *Phys. Rev. Sect. B*, 9, 5056, 1974.
15. Arakawn, E. T., and Inagaki, T., in *HOC-II*, p.461.
16. Weaver, J. H., Lynch, D. W., and Olson, D. G., *Phys. Rev. Sect. B*, 10, 501, 1973.
17. Lynch, D. W., Rosei, R., and Weaver, J. H., *Solid State Commun.*, 9, 2195, 1971.
18. Weaver, J. H., Lynch, D. W., and Olson, C. G., *Phys. Rev. Sect. B*, 7, 4311, 1973.
19. Weaver, J. H., and Benbow, R. L., *Phys. Rev. Sect. B*, 12, 3509, 1975.
20. Weaver, J. H., *Phys. Rev.,Sect. B*, 11, 1416, 1975.
21. Lynch, D. W., and Hunter, W. R., in *HOC-II*, p.364.
22. Palik, E. D., in *HOC-II*, p. 691.
23. Edwards, D. F., in *HOC-I*, p. 547.
24. Lynch, D. W., and Hunter, W. R., in *HOC-II*, p.354.
25. Palik, E. D., in *HOC-II*, p. 709.
26. Lynch, D. W., Olson, C. G., and Weaver, J. H., *Phys. Rev. Sect. B*, 11, 3671, 1975.
27. Weaver, J. H., Lynch, D. W., and Olson, C. G., *Phys. Rev. Sect. B*, 12, 1293, 1975.
28. Lanham, A. P., and Terherne, D. M., *Proc. Phys. Soc.*, 83, 1059, 1964.

ELASTO-OPTIC, ELECTRO-OPTIC, AND MAGNETO-OPTIC CONSTANTS

When a crystal is subjected to a stress field, an electric field, or a magnetic field, the resulting optical effects are in general dependent on the orientation of these fields with respect to the crystal axes. It is useful, therefore, to express the optical properties in terms of the refractive index ellipsoid (or indicatrix):

$$\frac{x^2}{n_x^2} + \frac{y^2}{n_y^2} + \frac{z^2}{n_z^2} = 1$$

or

$$\sum_{ij} B_{ij} x_i y_j = 1 \quad (i, j = 1, 2, 3)$$

where

$$B_{ij} = \left[\frac{1}{\varepsilon}\right]_{ij} = \left[\frac{1}{n^2}\right]_{ij}$$

ε is the dielectric constant or permeability; the quantity B_{ij} has the name impermeability.

A crystal exposed to a *stress* **S** will show a change of its impermeability. The photo-elastic (or elasto-optic) constants, P_{ijkl}, are defined by

$$\Delta\left[\frac{1}{\varepsilon}\right]_{ij} = \Delta\left[\frac{1}{n^2}\right]_{ij} = \sum_{kl} P_{ijkl}\, S_{kl}$$

where n is the refractive index and S_{kl} are the strain tensor elements; the P_{ijkl} are the elements of a 4th rank tensor.

When a crystal is subjected to an *electric field* ***E*** two possible changes of the refractive index may occur depending on the symmetry of the crystal.

1. All materials, including isotropic solids and polar liquids, show an electro-optic birefringence (Kerr effect) which is proportional to the square of the electric field, ***E***:

$$\left[\frac{1}{n^2}\right]_{ij} = \sum_{k,l=1,2,3} K_{ijkl} E_k E_l = \sum_{k,l=1,2,3} g_{ijkl} P_k P_l$$

   where E_k and E_l are the components of the electric field and P_k and P_l the electric polarizations. The coefficients, K_{ijkl}, are the quadratic electro-optic coefficients, while the constants g_{ijkl} are known as the Kerr constants.

2. The other electro-optic effect only occurs in the 20 piezo-electric crystal classes (no center of symmetry). This effect is known as the Pockels effect. The optical impermeability changes linearly with the static field

$$\Delta\left[\frac{1}{n^2}\right]_{ij} = \sum_k r_{ij,k} E_k$$

The coefficients $r_{ij,k}$ have the name (linear) electro-optic coefficients.

The values of the electro-optic coefficients depend on the boundary conditions. If the superscripts T and S denote respectively the conditions of zero stress (free) and zero strain (clamped) one finds:

$$r_{ij}^{\mathrm{T}} = r_{ij}^{\mathrm{S}} + q_{ik}^{\mathrm{E}} e_{jk} = r_{ij}^{\mathrm{S}} + P_{ik}^{\mathrm{E}} d_{jk}$$

where $e_{jk} = (\partial T_k/\partial E_j)_S$ and $d_{jk} = (\partial S_k/\partial E_j)_T$ are the appropriate piezo-electric coefficients.

The interaction between a *magnetic field* and a light wave propagating in a solid or in a liquid gives rise to a rotation of the plane of polarization. This effect is known as *Faraday rotation*. It results from a difference in propagation velocity for left and right circular polarized light.

The Faraday rotation, θ_{F}, is linearly proportional to the magnetic field H:

$$\theta_{\mathrm{F}} = VlH$$

where l is the light path length and V is the *Verdet* constant (minutes/oersted·cm).

For ferromagnetic, ferrimagnetic, and antiferromagnetic materials the magnetic field in the above expression is replaced by the magnetization M and the magneto-optic coefficient in this case is known as the Kund constant K:

$$\text{Specific Faraday rotation } F = KM$$

In the tables below the *Faraday rotation* is listed at the saturation magnetization per unit length, together with the absorption coefficient α, the temperature T, the critical temperature T_C (or T_N), and the wavelength of the measurement.

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ELASTO-OPTIC, ELECTRO-OPTIC, AND MAGNETO-OPTIC CONSTANTS (continued)

In the tables which follow, the properties are presented in groups:

- Elasto-optic coefficients (photoelastic constants)
- Linear electro-optic coefficients (Pockels constants)
- Quadratic electro-optic coefficients (Kerr constants)
- Magneto-optic coefficients:
  - Verdet constants
  - Faraday rotation parameters

Within each group, materials are classified by crystal system or physical state. References are given at the end of each group of tables.

ELASTO-OPTIC COEFFICIENTS (PHOTOELASTIC CONSTANTS)

Name Cubic (43m, 432, m3m)	Formula	λ/μm	p_{11}	p_{12}	p_{44}	p_{11}-p_{12}	Ref.
Sodium fluoride	NaF	0.633	0.08	0.20	-0.03	-0.12	1
Sodium chloride	NaCl	0.589	0.115	0.159	-0.011	-0.042	2
Sodium bromide	NaBr	0.589	0.148	0.184	-0.0036	-0.035	1
Sodium iodide	NaI	0.589	—	—	0.0048	-0.0141	3
Potassium fluoride	KF	0.546	0.26	0.20	-0.029	0.06	1
Potassium chloride	KCl	0.633	0.22	0.16	-0.025	0.06	4
Potassium bromide	KBr	0.589	0.212	0.165	-0.022	0.047	5
Potassium iodide	KI	0.590	0.212	0.171	—	0.041	6
Rubidium chloride	RbCl	0.589	0.288	0.172	-0.041	0.116	7,8
Rubidium bromide	RbBr	0.589	0.293	0.185	-0.034	0.108	7,8
Rubidium iodide	RbI	0.589	0.262	0.167	-0.023	0.095	7,8
Lithium fluoride	LiF	0.589	0.02	0.13	-0.045	-0.11	5
Lithium chloride	LiCl	0.589	—	—	-0.0177	-0.0407	3
Ammonium chloride	NH_4Cl	0.589	0.142	0.245	0.042	-0.103	9
Cadmium telluride	CdTe	1.06	-0.152	-0.017	-0.057	-0.135	10
Calcium fluoride	CaF_2	0.55-0.65	0.038	0.226	0.0254	-0.183	11
Copper chloride	CuCl	0.633	0.120	0.250	-0.082	-0.130	12
Copper bromide	CuBr	0.633	0.072	0.195	-0.083	-0.123	12
Copper iodide	CuI	0.633	0.032	0.151	-0.068	-0.119	12
Diamond	C	0.540-0.589	-0.278	0.123	-0.161	-0.385	13
Germanium	Ge	3.39	-0.151	-0.128	-0.072	-0.023	14
Gallium arsenide	GaAs	1.15	-0.165	-0.140	-0.072	-0.025	15
Gallium phosphide	GaP	0.633	-0.151	-0.082	-0.074	-0.069	15
Strontium fluoride	SrF_2	0.633	0.080	0.269	0.0185	-0.189	16
Strontium titanate	$SrTiO_3$	0.633	0.15	0.095	0.072	—	17
KRS-5	Tl(Br,I)	0.633	-0.140	0.149	-0.0725	-0.289	18,20
KRS-6	Tl(Br,Cl)	0.633	-0.451	-0.337	-0.164	-0.114	19,20
Zinc sulfide	Zn	0.633	0.091	-0.01	0.075	0.101	15

Rare Gases	Formula	λ/μm	p_{11}	p_{12}	p_{44}	p_{11}-p_{12}	Ref.
Neon (T = 24.3 K)	Ne	0.488	0.157	0.168	0.004	-0.011	21
Argon (T = 82.3 K)	Ar	0.488	0.256	0.302	0.015	-0.046	22
Krypton (T = 115.6 K)	Kr	0.488	0.34	0.34	0.037	0	21
Xenon (T = 160.5 K)	Xe	0.488	0.284	0.370	0.029	-0.086	22

Garnets	Formula	λ/μm	p_{11}	p_{12}	p_{44}	p_{11}-p_{12}	Ref.
GGG	$Gd_3Ga_5O_{12}$	0.514	-0.086	-0.027	-0.078	-0.059	23
YIG	$Y_3Fe_5O_{12}$	1.15	0.025	0.073	0.041	—	15
YGG	$Y_3Ga_5O_{12}$	0.633	0.091	0.019	0.079	—	17
YAG	$Y_3Al_5O_{12}$	0.633	-0.029	0.0091	-0.0615	-0.038	15

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ELASTO-OPTIC COEFFICIENTS (PHOTOELASTIC CONSTANTS) continued)

Name Cubic (23, m3)	Formula	λ/µm	p_{11}	p_{12}	p_{44}	p_{13}	Ref.
Barium nitrate	Ba(NO3)2	0.589	—	p_{11}-p_{22} = 0.992	-0.0205	p_{11}-p_{13} = 0.713	13
Lead nitrate	$Pb(NO_3)_2$	0.589	0.162	0.24	-0.0198	0.20	24,25
Sodium bromate	$NaBrO_3$	0.589	0.185	0.218	-0.0139	0.213	26
Sodium chlorate	$NaClO_3$	0.589	0.162	0.24	-0.0198	0.20	26
Strontium nitrate	$Sr(NO_3)_2$	0.41	0.178	0.362	-0.014	0.316	27

Hexagonal (mmc,6mm)	Formula	λ/µm	p_{11}	p_{12}	p_{13}	p_{31}	p_{33}	p_{44}	Ref.
Beryl	$Be_3Al_2Si_6O_{18}$	0.589	0.0099	0.175	0.191	0.313	0.023	-0.152	28
Cadmium sulfide	CdS	0.633	-0.142	-0.066	-0.057	-0.041	-0.20	-0.099	15,2
Zinc oxide	ZnO	0.633	±0.222	±0.099	-0.111	±0.088	-0.235	0.0585	30
Zinc sulfide	ZnS	0.633	-0.115	0.017	0.025	0.0271	-0.13	-0.0627	31

Trigonal (3m,32,$\bar{3}$m)	Formula	λ/µm	p_{11}	p_{12}	p_{13}	p_{14}	p_{31}
Sapphire	Al_2O_3	0.644	-0.23	-0.03	0.02	0.00	-0.04
Calcite	$CaCO_3$	0.514	0.062	0.147	0.186	-0.011	0.241
Lithium niobate	$LiNbO_3$	0.633	±0.034	±0.072	±0.139	±0.066	±0.178
Lithium tantalate	$LiTaO_3$	0.633	-0.081	0.081	0.093	-0.026	0.089
Cinnabar	HgS	0.633			±0.445		
Quartz	SiO_2	0.589	0.16	0.27	0.27	-0.030	0.29
Proustite	Ag_3AsS_3	0.633	±0.10	±0.19	±0.22		±0.24
Sodium nitrite	$NaNO_3$	0.633		±0.21	±0.215	±0.027	±0.25
Tellurium	Te	10.6	0.155	0.130	—	—	—

Trigonal (3m,32,$\bar{3}$m) (continued)	p_{33}	p_{41}	p_{44}	Ref.
Sapphire	-0.20	0.01	-0.10	15,32
Calcite	0.139	-0.036	-0.058	33
Lithium niobate	+-0.060	±0.154	±0.300	15,34
Lithium tantalate	-0.044	-0.085	0.028	15,35
Cinnabar	+-0.115	—	—	36
Quartz	0.10	-0.047	-0.079	37
Proustite	+-0.20	—	—	38
Sodium nitrite		0.055	-0.06	39
Tellurium		—	—	15

Tetragonal (4/mmm,$\bar{4}$2m,422)	Formula	λ/µm	p_{11}	p_{12}	p_{13}	p_{31}
Ammonium dihydrogen phosphate	ADP	0.589	0.319	0.277	0.169	0.197
Barium titanate	$BaTiO_3$	0.633	0.425	—	—	—
Cesium dihydrogen arsenate	CDA	0.633	0.267	0.225	0.200	0.195
Magnesium fluoride	MgF_2	0.546	—	—	—	—
Calomel	Hg_2Cl_2	0.633	±0.551	±0.440	±0.256	±0.137
Potassium dihydrogen phosphate	KDP	0.589	0.287	0.282	0.174	0.241
Rubidium dihydrogen arsenate	RDA	0.633	0.227	0.239	0.200	0.205
Rubidium dihydrogen phosphate	RDP	0.633	0.273	0.240	0.218	0.210
Strontium barium niobate	$Sr_{0.75}Ba_{0.25}Nb_2O_6$	0.633	0.16	0.10	0.08	0.11
Strontium barium niobate	$Sr_{0.5}Ba_{0.5}Nb_2O_6$	0.633	0.06	0.08	0.17	0.09
Tellurium oxide	TeO_2	0.633	0.0074	0.187	0.340	0.090
Rutile	TiO_2	0.633	0.017	0.143	-0.139	-0.080

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ELASTO-OPTIC COEFFICIENTS (PHOTOELASTIC CONSTANTS) (continued)

Name Tetragonal (4/mmm,$\bar{4}$2m,422) (continued)	p_{33}	p_{44}	p_{66}	Ref.
Ammonium dihydrogen phosphate	0.167	-0.058	-0.091	40
Barium titanate	—	—	—	41
Cesium dihydrogen arsenate	0.227	—	—	42
Magnesium fluoride	—	±0.0776	±0.0488	43
Calomel	±0.010	—	±0.047	44
Potassium dihydrogen phosphate	0.122	-0.019	-0.064	45
Rubidium dihydrogen arsenate	0.182	—	—	41
Rubidium dihydrogen phosphate	0.208	—	—	41
Strontium barium niobate	0.47	—	—	46
Strontium barium niobate	0.23	—	—	46
Tellurium oxide	0.240	-0.17	-0.046	47
Rutile	-0.057	-0.009	-0.060	48

Tetragonal (4,$\bar{4}$,4/m)	Formula	λ/μm	p_{11}	p_{12}	p_{13}	p_{16}	p_{31}
Cadmium molybdate	$CdMoO_4$	0.633	0.12	0.10	0.13	—	0.11
Lead molybdate	$PbMoO_4$	0.633	0.24	0.24	0.255	0.017	0.175
Sodium bismuth molybdate	$NaBi(MoO_4)_2$	0.633	0.243	0.205	0.25	—	0.21

Tetragonal (4,$\bar{4}$,4/m) (continued)	p_{33}	p_{44}	p_{45}	p_{61}	p_{66}	Ref.
Cadmium molybdate	0.18	—	—	—	—	49
Lead molybdate	0.300	0.067	-0.01	0.013	0.05	52
Sodium bismuth molybdate	0.29	—	—	—	—	—

Orthorhombic (222,m22,mmm)	Formula	λ/μm	p_{11}	p_{12}	p_{13}	p_{21}	p_{22}	p_{23}
Ammonium chlorate	NH_4ClO_4	0.633	—	0.24	0.18	0.23	—	0.20
Ammonium sulfate	$(NH_4)_2SO_4$	0.633	0.26	0.19	±0.260	±0.230	±0.27	±0.254
Rochelle salt	$NaKC_4H_4O_6$	0.589	0.35	0.41	0.42	0.37	0.28	0.34
Iodic acid (α)	HIO_3	0.633	0.302	0.496	0.339	0.263	0.412	0.304
Sulfur (α)	S	0.633	0.324	0.307	0.268	0.272	0.301	0.310
Barite	$BaSO_4$	0.589	0.21	0.25	0.16	0.34	0.24	0.19
Topaz	$Al_2SiO_4(OH,F)_2$	—	-0.085	0.069	0.052	0.095	-0.120	0.065

Orthorhombic (222,m22,mmm) (continued)	p_{31}	p_{32}	p_{33}	p_{44}	p_{55}	p_{66}	Ref.
Ammonium chlorate	0.19	0.18	±0.02	<±0.02	—	±0.04	51
Ammonium sulfate	0.20	±0.26	0.26	0.015	±0.0015	0.012	52
Rochelle salt	0.36	0.35	0.36	-0.030	0.0046	-0.025	53
Iodic Acid (α)	0.251	0.345	0.336	0.084	-0.030	0.098	54
Sulfur (α)	0.203	0.232	0.270	0.143	0.019	0.118	54
Barite	0.28	0.22	0.31	0.002	-0.012	0.037	55
Topaz	0.095	0.085	-0.083	-0.095	-0.031	0.098	28

Monoclinic (2,m,2/m)	Formula	λ/μm			
Taurine	$C_2H_7NO_3S$	0.589	p_{11} = 0.313	p_{25} = -0.0025	p_{51} = -0.014
			p_{12} = 0.251	p_{31} = 0.362	p_{52} = 0.006
			p_{13} = 0.270	p_{32} = 0.275	p_{53} = 0.0048
			p_{15} = -0.10	p_{33} = 0.308	p_{55} = 0.047

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ELASTO-OPTIC COEFFICIENTS (PHOTOELASTIC CONSTANTS) (continued)

Name Monoclinic (2,m,2/m)	Formula	λ/μm			
Taurine (continued)			p_{21} = 0.281	p_{35} = -0.003	p_{64} = 0.0024
			p_{22} = 0.252	p_{44} = 0.0025	p_{66} = 0.0028
			p_{23} = 0.272	p_{46} = -0.0056	

Isotropic	Formula	λ/μm	p_{11}	p_{12}	p_{44}	Ref.
Fused silica	SiO_2	0.633	0.121	0.270	-0.075	15
Water	H_2O	0.633	±0.31	±0.31		15
Polystyrene		0.633	±0.30	±0.31		25
Lucite		0.633	±0.30	0.28		25
Orpiment	As_2S_3-glass	1.15	0.308	0.299	0.0045	15
Tellurium oxide	TeO_2-glass	0.633	0.257	0.241	0.0079	56
Laser glasses	LGS-247-2	0.488	±0.168	±0.230		57
	LGS-250-3		±0.135	±0.198		
	LGS-1		±0.214	±0.250		
	KGSS-1621		±0.205	±0.239		
Dense flint glasses	LaSF	0.633	0.088	0.147	-0.030	58
(examples)	SF_4		0.215	0.243	-0.014	
	U10502		0.172	0.179	-0.004	
	$TaFd_7$		0.099	0.138	-0.020	

REFERENCES

A. Narasimhamurty, T. S., *Photoelastic and Electro-Optic Properties of Crystals*, Plenum Press, New York, 1981; pp. 290-293.
B. Weber, M. J., Ed., *CRC Handbook of Laser Science and Technology*, Volume IV, Part 2, CRC Press, Boca Raton, FL, 1986; pp. 324-331.
1. Petterson, H. E., *J. Opt. Soc. Am.*, 63, 1243, 1973.
2. Burstein, E. and Smith, P. L., *Phys. Rev.*, 74, 229, 1948.
3. Pakhnev, A. V., et al., *Sov. Phys. J. (transl.)*, 18, 1662, 1975.
4. Feldman, A., Horovitz, D., and Waxler, R. M., *Appl. Opt.*, 16, 2925, 1977.
5. Iyengar, K. S., *Nature (London)*, 176, 1119, 1955.
6. Bansigir, K. G. and Iyengar, K. S., *Acta Crystallogr.*, 14, 727, 1961.
7. Pakhev, A. V., et al., *Sov. Phys. J. (transl.)*, 20, 648, 1975.
8. Bansigir, K. G., *Acta Crystallogr.*, 23, 505, 1967.
9. Krishna Rao, K. V. and Krishna Murty, V. G., *Ind. J. Phys.*, 41, 150, 1967.
10. Weil, R. and Sun, M. J., *Proc. Int. Symp. CdTe (Detectors)*, Strasbourg Centre de Rech. Nucl., 1971, XIX-1 to 6, 1972.
11. Schmidt, E. D. D. and Vedam, K., *J. Phys. Chem. Solids*, 27, 1563, 1966.
12. Biegelsen, D. K., et al., *Phys. Rev. B*, 14, 3578, 1976.
13. Helwege, K. H., *Landolt-Börnstein, New Series Group III*, Vol. II, Springer-Verlag Berlin, 1979.
14. Feldman, A., Waxler, R. M., and Horovitz, D., *J. Appl. Phys.*, 49, 2589, 1978.
15. Dixon, R. W., *J. Appl. Phys.*, 38, 5149, 1967.
16. Shabin, O. V., et al., *Sov. Phys. Sol. State (transl.)*, 13, 3141, 1972.
17. Reintjes, J. and Schultz, M. B., *J. Appl. Phys.*, 39, 5254, 1968.
18. Rivoallan, L. and Favre, F., *Opt. Commun.*, 8, 404, 1973.
19. Rivoallan, L. and Favre, F., *Opt. Commun.*, 11, 296, 1974.
20. Afanasev, I. I., et al., *Sov. J. Opt. Technol.*, 46, 663, 1979.
21. Rand, S. C., et al., *Phys. Rev. B*, 19, 4205, 1979.
22. Sipe, J. E., *Can J. Phys.*, 56, 199, 1978.
23. Christyi, I. L., et al., *Sov. Phys. Sol. State (transl.)*, 17, 922, 1975.
24. Narasimhamurty, T. S., *Curr. Sci. (India)*, 23, 149, 1954.
25. Smith, T. M. and Korpel, A., *IEEE J. Quant. Electron.*, QE-1, 283, 1965.
26. Narasimhamurty, T. S., *Proc. Ind. Acad. Sci.*, A40, 164, 1954.
27. Rabman, A., *Bhagarantam Commem. Vol.*, Bangalore Print. and Publ., 173, 1969.
28. Eppendahl, R., *Ann. Phys. (IV)*, 61, 591, 1920.
29. Laurenti, J. P. and Rouzeyre, M., *J. Appl. Phys.*, 52, 6484, 1981.
30. Sasaki, H., et al., *J. Appl. Phys.*, 47, 2046, 1976.
31. Uchida, N. and Saito, S., *J. Appl. Phys.*, 43, 971, 1972.

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ELASTO-OPTIC COEFFICIENTS (PHOTOELASTIC CONSTANTS) (continued)

32. Waxler, R. M. and Farabaugh, E. M., *J. Res. Natl. Bur. Stand.*, A74, 215, 1970.
33. Nelson, D. F., Lazay, P. D., and Lax, M., *Phys. Rev.*, B6, 3109, 1972.
34. O'Brien, R. J., Rosasco, G. J., and Weber, A., *J. Opt. Soc. Am.*, 60, 716, 1970.
35. Avakyants, L. P., et al., *Sov. Phys.*, 18, 1242, 1976.
36. Sapriel, J., *Appl. Phys. Litt.*, 19, 533, 1971.
37. Narasimhamurty, T. S., *J. Opt. Soc. Am.*, 59, 682, 1969.
38. Zubrinov, I. I., et al., *Sov. Phys. Sol. State (transl.)*, 15, 1921, 1974.
39. Kachalov, O. V. and Shpilko, I. O., *Sov. Phys. JETP (transl.)*, 35, 957, 1972.
40. Narasimhamurty, T. S., et al., *J. Mater. Sci.*, 8, 577, 1973.
41. Tada, K. and Kikuchi, K., *Jpn. J. Appl. Phys.*, 19, 1311, 1980.
42. Aleksandrov, K. S., et al., *Sov. Phys. Sol. State (transl.)*, 19, 1090, 1977.
43. Afanasev, I. I., et al., *Sov. Phys. Sol. State (transl.)*, 17, 2006, 1975.
44. Silvestrova, I. M., et al., *Sov. Phys. Cryst. (transl.)*, 20, 649, 1975.
45. Veerabhadra Rao, K. and Narasimhamurty, T. S., *J. Mater. Sci.*, 10, 1019, 1975.
46. Venturini, E. L., et al., *J. Appl. Phys.*, 40, 1622, 1969.
47. Vehida, N. and Ohmachi, Y., *J. Appl. Phys.*, 40, 4692, 1969.
48. Grimsditch, M. H. and Ramdus, A. K., *Phys. Rev. B*, 22, 4094, 1980.
49. Schinke, D. P. and Viehman,W., unpublished Data.
50. Coquin, G. A., et al., *J. Appl. Phys.*, 42, 2162, 1971.
51. Vasquez, F., et al., *J. Phys. Chem. Solids*, 37, 451, 1976.
52. Luspin, Y. and Hauret, G., *C.R.Ac. Sci. Paris*, B274, 995 1972.
53. Narasimhamurty, T. S., *Phys. Rev.*, 186, 945, 1969.
54. Haussühl, S. and Weber, H. J., *Z. Kristall.*, 132, 266, 1970.
55. Vedam, K., *Proc. Ind. Ac. Sci.*, A34, 161, 1951.
56. Yano, T., Fukumoto, A., and Watanabe, A., *J. Appl. Phys.*, 42, 3674, 1971.
57. Manenkov, A. A. and Ritus, A. I., *Sov. J. Quant. Electr.*, 8, 78, 1978.
58. Eschler, H. and Weidinger, F., *J. Appl. Phys.*, 46, 65, 1975.

LINEAR ELECTRO-OPTIC COEFFICIENTS

Name

Cubic ($\bar{4}3m$)	Formula	λ/μm	r_{41} pm/V
Cuprous bromide	CuBr	0.525	0.85
Cuprous chloride	CuCl	0.633	3.6
Cuprous iodide	CuI	0.55	-5.0
Eulytite (BSO)	$Bi_4Si_3O_{12}$	0.63	0.54
Germanium eulytite (BGO)	$Bi_4Ge_3O_{12}$	0.63	1.0
Gallium arsenide	GaAs	10.6	1.6
Gallium phosphide	GaP	0.56	-1.07
Hexamethylenetetramine	$C_6H_{12}N_4$	0.633	0.78
Sphalerite	ZnS	0.65	2.1
Zinc selenide	ZnSe	0.546	2.0
Zinc telluride	ZnTe	3.41	4.2
Cadmium telluride	CdTe	3.39	6.8

Cubic (23)	Formula	λ/μm	r_{41} pm/V
Ammonium chloride (77 K)	NH_4Cl	—	1.5
Ammonium cadmium langbeinite	$(NH_4)_2Cd_2(SO_4)_3$	0.546	0.70
Ammonium manganese langbeinite	$(NH_4)_2Mn_2(SO_4)_3$	0.546	0.53
Thallium cadmium langbeinite	$Tl_2Cd_2(SO_4)_3$	0.546	0.37
Potassium magnesium langbeinite	$K_2Mg_2(SO_4)_3$	0.546	0.40
Bismuth monogermanate	$Bi_{12}GeO_{20}$	—	3.3
Bismuth monosilicate	$Bi_{12}SiO_{20}$	—	3.3
Sodium chlorate	$NaClO_3$	0.589	0.4
Sodium uranyl acetate	$NaUO_2(CH_3COO)_3$	0.546	0.87

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ELASTO-OPTIC, ELECTRO-OPTIC, AND MAGNETO-OPTIC CONSTANTS (continued)

LINEAR ELECTRO-OPTIC COEFFICIENTS (continued)

Name

Cubic (23)	Formula	λ/μm	r_{41} pm/V
Trenhydrobromide	$N(CH_2CH_2NH_2)_3$ 3HBr	—	1.5
Trenhydrochloride	$N(CH_2CH_2NH_2)_3$ 3HCl	—	1.7

Tetragonal ($\bar{4}$2m)	Formula	T_{tran} K	r_{41} pm/V	r_{63} pm/V
Ammonium dihydrogen phosphate (ADP)	$NH_4H_2PO_4$	148	24.5	-8.5
Ammonium dideuterium phosphate (AD*P)	$NH_4D_2PO_4$	242	—	11.9
Ammonium dihydrogen arsenate (ADA)	$NH_4H_2AsO_4$	—	—	9.2
Cesium dihydrogen arsenate (CsDA)	CsH_2AsO_4	143	—	18.6
Cesium dideuterium arsenate (CsD*A)	CsD_2AsO_4	212	—	36.6
Potassium dihydrogen phosphate (KDP)	KH_2PO_4	123	8.6	-10.5
Potassium dideuterium phosphate (KD*P)	KD_2PO_4	222	8.8	23.8
Potassium dihydrogen arsenate (KDA)	KH_2AsO_4	97	12.5	10.9
Potassium dideuterium arsenate (KD*A)	KD_2AsO_4	162	—	18.2
Rubidium dihydrogen phosphate (RDP)	RbH_2PO_4	147	—	15.5
Rubidium dihydrogen arsenate (RDA)	RbH_2AsO_4	110	—	13.0
Rubidium dideuterium arsenate (RD*A)	RbD_2AsO_4	178	—	21.4

Tetragonal (4mm)	Formula	T_{tran} K	r_{13} pm/V	r_{33} pm/V	r_{51} pm/V
Barium titanate	$BaTiO_3$	406	8	28	—
Potassium lithium niobate	$K_3Li_2Nb_5O_{15}$	693	8.9	5.9	—
Lead titanate	$PbTiO_3$	765	13.8	5.9	—
Strontium barium niobate (SBN75)	$Sr_{0.75}Ba_{0.25}Nb_2O_6$	330	6.7	1340	42
Strontium barium niobate (SBN46)	$Sr_{0.46}Ba_{0.54}Nb_2O_6$	602	~180	35	—

Hexagonal (6mm)	Formula	r_{13} pm/V	r_{33} pm/V	r_{42} pm/V	r_{51} pm/V
Greenockite	CdS	3.1	2.9	2.0	3.7
Greenockite (const. strain)	CdS	1.1	2.4	—	—
Wurzite	ZnS	0.9	1.8	—	—
Zincite	ZnO	-1.4	+2.6	—	—

Hexagonal (6)	Formula	r_{13} pm/V	r_{33} pm/V	r_{42} pm/V	r_{51} pm/V
Lithium iodate	$LiIO_3$	4.1	6.4	1.4	3.3
Lithium potassium sulfate	$LiKSO_4$	r_{13}-r_{33} = 1.6	—	—	—

Trigonal (3m)	Formula	T_{tran} K	r_{13} pm/V	r_{22} pm/V	r_{33} pm/V	r_{42} pm/V
Cesium nitrate	$CsNO_3$	425	—	0.43	—	—
Lithium niobate	$LiNbO_3$	1483	8.6	7.0	30.8	28
Lithium tantalate	$LiTaO_3$	890	8.4	—	30.5	—
Lithium sodium sulfate	$LiNaSO_4$	—	—	<0.02	—	—
Tourmaline	—	—	—	0.3	—	—

Trigonal (32)	Formula	T_{tran} K	r_{11} pm/V	r_{41} pm/V
Cesium tartrate	$Cs_2C_4H_4O_6$	—	1.0	—
Cinnabar	HgS	659	3.1	1.5

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LINEAR ELECTRO-OPTIC COEFFICIENTS (continued)

Name Trigonal (32)	Formula	T_{tran} K	r_{11} pm/V	r_{41} pm/V
Potassium dithionate	$K_2S_2O_6$	—	0.26	—
Strontium dithionate	$SrS_2O_6 \cdot 4H_2O$	—	0.1	—
Quartz	SiO_2	1140	-0.47	0.2
Selenium	Se	398	2.5	

Orthorhombic (222)	Formula	T_{tran} K	r_{41} pm/V	r_{52} pm/V	r_{63} pm/V
Ammonium oxalate	$(NH_4)_2C_2O_4 \cdot 4H_2O$	—	230	330	250
Rochelle salt	$KNaC_4H_4O_6 \cdot 4H_2O$	T_u = 297 T_l = 255	-2.0	-1.7	+0.32

Orthorhombic (mm2)	Formula	*T*trans K	r_{13} pm/V	r_{23} pm/V	r_{33} pm/V	r_{42} pm/V	r_{51} pm/V
Barium sodium niobate (BSN)	Ba_2NaNbO_{15}	833	15	13	48	92	90
Potassium niobate	$KNbO_3$	476	28	1.3	64	380	105

Monoclinic (2)	Formula	T_{trans} K	r_{22} pm/V	r_{32} pm/V
Calcium pyroniobate	$Ca_2Nb_2O_7$	—	0.33	13.7
Triglycine sulfate (TGS)	$(NH_2CH_2COOH)_3 \cdot H_2SO_4$	322	7.2	13.6

REFERENCES

1. Narasimhamurty, T. S., *Photoelastic and Electro-Optic Properties of Crystals*, Plenum Press, New York, 1981, pp. 405-407.
2. Weber, M. J., Ed., *CRC Handbook of Laser Science and Technology*, Vol. IV, CRC Press, Boca Raton, FL, 1986, pp. 258-278.

QUADRATIC ELECTRO-OPTIC COEFFICIENTS

Kerr Constants of Ferroelectric Crystals[1,2]

Name	Formula	T_{tran} K	λ μm	g_{11} 10^{10} esu	g_{12} 10^{10} esu	g_{11}-g_{12} 10^{10} esu	g_{44} 10^{10} esu
Barium titanate	$BaTiO_3$	406	0.633	1.33	-0.11	1.44	
Strontium titanate	$SrTiO_3$	—	0.633	—	—	1.56	—
Potassium tantalate niobate	$KTa_{0.65}Nb_{0.35}O_3$	330	0.633	1.50	-0.42	1.92	1.63
Potassium tantalate	$KTaO_3$	13	0.633	—	—	1.77	1.33
Lithium niobate	$LiNbO_3$	1483	—	0.94	0.25	0.7	0.6
Lithium tantalate	$LiTaO_3$	938	—	1.0	0.17	0.8	0.7
Barium sodium niobate (BSN)	$Ba_{0.8}Na_{0.4}Nb_{2O6}$	833	—	1.55	0.44	1.11	

Kerr Constants of Selected Liquids[2]

K is the Kerr constant at a wavelength of 589 nm and at room temperature; ε is the static dielectric constant; T_m is the melting point; and T_b is the normal boiling point

Name	Molecular formula	*K* 10^{-7} esu	ε	T_m °C	T_b °C
Carbon disulfide	CS_2	+3.23	2.63	-111.5	+46.3
Acetone	C_3H_6O	+16.3	21.0	-94.8	+56.1
Methyl ethyl ketone	C_4H_8O	+13.6	18.56	-86.67	+79.6

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QUADRATIC ELECTRO-OPTIC COEFFICIENTS (continued)

Kerr Constants of Selected Liquids (continued)[2]

Name	Molecular formula	K 10^{-7} esu	ε	T_m °C	T_b °C
Pyridine	C_5H_5N	+20.4	13.26	-42	+115.23
Ethyl cyanoacetate	$C_5H_7NO_2$	+38.8	31.6	-22.5	205
o-Dichlorobenzene	$C_6H_4Cl_2$	+42.6	10.12	-16.7	180
Benzenesulfonyl chloride	$C_6H_5ClO_2S$	+89.9	28.90	+14.5	247
Nitrobenzene	$C_6H_5NO_2$	+326	35.6	+5.7	210.8
Ethyl 3-aminocrotonate	$C_6H_{11}NO_2$	+31.0	—	+33.9	210
Paraldehyde	$C_6H_{12}O_3$	-23.0	14.7	+12.6	124
			12.0[a]		
Benzaldehyde	C_7H_6O	+80.8	17.85	-26	179.05
			14.1[a]		
p-Chlorotoluene	C_7H_7Cl	+23.0	6.25	+7.5	162.4
o-Nitrotoluene	$C_7H_7NO_2$	+174	26.26	-10	222.3
m-Nitrotoluene	$C_7H_7NO_2$	+177	24.95	+15.5	232
p-Nitrotoluene	$C_7H_7NO_2$	+222	22.2	+51.6	238.3
Benzyl alcohol	C_7H_8O	-15.4	11.92	-15.3	205.8
			10.8[a]		
m-Cresol	C_7H_8O	+21.2	12.44	+11.8	202.27
			5.0[a]		
m-Chloroacetophenone	C_8H_7ClO	+69.1			
Acetophenone	C_8H_8O	+66.6	17.44	+19.7	202.3
			15.8[a]		
Quinoline	C_9H_7N	+15.0	9.16	-14.78	237.16
Ethyl salicylate	$C_9H_{10}O_3$	+19.6	8.48	+1.3	231.5
Carvone	$C_{10}H_{14}O$	+23.6	11.2	<0	230
Ethyl benzoylacetate	$C_{11}H_{12}O_3$	+16.0	13.50	<0	270
Water	H_2O	+4.0	80.10	0.00	100.0

[a] Dielectric constant at radiofrequencies (10^8-10^9 Hz).

REFERENCES

1. Narasimhamurty, T. S., *Photoelastic and Electro-Optic Properties of Crystals*, Plenum Press, New York, 1981, p. 408.
2. Gray, D. E., Ed., *AIP Handbook of Physics*, McGraw Hill, New York, 1972, p. 6-241.

MAGNETO-OPTIC CONSTANTS

Verdet Constants of Non-Magnetic Crystals[1]

V is the Verdet constant; *n* is the refractive index; and λ is the wavelength

Material	T K	λ nm	n	V min/Oe cm
Al_2O_3	300	546.1	1.771	0.0240
	300	589.3	1.768	0.0210
$BaTaO_3$	403	427		0.95
	403	496		0.38
	403	620		0.18
	403	826		0.072
$Bi_4Ge_3O_{12}$	300	442	2.077	0.289
	300	632.8	2.048	0.099
	300	1064	2.031	0.026
C (diamond)	300	589.3	2.417	0.0233
$CaCO_3$	300	589.3	1.658	0.019
CaF_2	300	589.3	1.434	0.0088
$Cd_{0.55}Mn_{0.45}Te$	300	632.8		6.87

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MAGNETO-OPTIC CONSTANTS (continued)

Verdet Constants of Non-Magnetic Crystals (continued)[1]

Material	*T* K	λ nm	*n*	*V* min/Oe cm
CuCl	300	546.1	1.93	0.20
GaSe	298	632.8		0.80
$KAl(SO_4)_2 \cdot 12H_2O$	300	589.3	1.456	0.0124
KBr	300	546.1	1.564	0.0500
	300	589.3	1.560	0.0425
KCl	300	589.3	1.490	0.0275
KI	300	546.1	1.673	0.083
	300	589.3	1.666	0.070
$KTaO_3$	296	352		0.44
	296	413		0.19
	296	496		0.096
	296	620		0.051
	296	826		0.022
LaF_3	300	325	1.639	0.054
(H‖c)	300	442	1.615	0.028
	300	632.8	1.601	0.012
	300	1064	1.592	0.006
$MgAl_2O_4$	300	589.3	1.718	0.021
$NH_4AlSO_4 \cdot 12H_2O$	300	589.3	1.459	0.0128
NH_4Br	300	589.3	1.711	0.0504
NH_4Cl	300	546.1		0.0410
	300	589.3	1.643	0.0362
NaBr	300	546.1		0.0621
NaCl	300	546.1		0.0410
	300	589.3	1.544	0.0345
$NaClO_3$	300	546.1		0.0105
	300	589.3	1.515	0.0081
$NiSO_4 \cdot 6H_2O$	297	546.1		0.0256
	297	589.3	1.511	0.0221
SiO_2	300	546.1	1.546	0.0195
	300	589.3	1.544	0.0166
$SrTiO_3$	298	413	2.627	0.78
	298	496		0.31
	298	620		0.14
	298	826		0.066
ZnS	300	546.1		0.287
	300	589.3	2.368	0.226
ZnSe	300	476	2.826	1.50
	300	496	2.759	1.04
	300	514	2.721	0.839
	300	587	2.627	0.529
	300	632.8	2.592	0.406

Verdet Constants of Rare-Earth Aluminum Garnets at Various Wavelengths[1]

The absorption coefficient α for these materials ranges from 0.2 to 0.6 cm^{-1} at 300 K

		V in min/Oe cm							
Material	**T/K**	**λ = 405 nm**	**450 nm**	**480 nm**	**520 nm**	**546 nm**	**578 nm**	**635 nm**	**670 nm**
$Tb_2Al_5O_{12}$	300	-2.266	-1.565	-1.290	-1.039	-0.912	-0.787	-0.620	-0.542
	77		-102.16	-83.45	-3.425	-3.051	-2.603	-2.008	-1.815
	4.2				-64.80	-58.35	-53.77	48.39	-45.15
	1.45		-200.95	-172.52	-139.28	-125.07	-111.27	97.47	-93.42
$Dy_3Al_5O_{12}$	300	-1.241	-0.942	-0.803	-0.667	-0.592	-0.518	-0.411	-0.359
$Ho_3Al_5O_{12}$	300	-0.709	-0.320	-0.260	-0.335	-0.304	-0.299		-0.206

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MAGNETO-OPTIC CONSTANTS (continued)

Verdet Constants of Rare-Earth Aluminum Garnets at Various Wavelengths (continued)[1]

Material	T/K	V in min/Oe cm							
		λ = 405 nm	450 nm	480 nm	520 nm	546 nm	578 nm	635 nm	670 nm
$Er_3Al_5O_{12}$	300	-0.189	-0.240	-0.154	-0.162	-0.157	-0.145	-0.105	-0.089
$Tm_3Al_5O_{12}$	300	+0.151	+0.103	+0.093	0.076	0.069	+0.059	+0.048	
$Yb_3Al_5O_{12}$	298	0.287	0.215	0.186	0.140	0.133	0.116	0.094	
	77	0.718	0.540	0.481	0.393	0.342	0.302	0.239	

Verdet Constants for KDP-Type Crystals[1]

Measurements refer to T = 298 K and
λ = 632.8 nm, with ***k*** ∥ [001]

Material	*V* min/Oe cm
KH_2PO_4 (KDP)	0.0124
$KH_{0.3}D_{1.7}PO_4$ (KD*P)	0.145
$NH_4H_2PO_4$ (ADP)	0.138
KH_2AsO_4 (KDA)	0.238
$KH_{0.1}D_{1.9}AsO_4$ (KD*A)	0.245
$NH_4H_2AsO_4$ (ADH)	0.244

Verdet Constants of Gases[2]

Values refer to *T* = 0°C and P = 101.325 kPa (760 mmHg); n_D is the refractive index at a wavelength of 589 nm

Gas	$(n_D - 1) \times 10^3$	$10^6 \times V$ min/Oe cm
He	0.036	+0.40
Ar	2.81	+9.36
H_2		+6.29
N_2	0.297	+6.46
O_2	0.272	+5.69
Air	0.293	+6.27
Cl_2	0.773	+31.9
HCl	0.447	+21.5
H_2S	0.63	+41.5
NH_3	0.376	+19.0
CO	0.34	+11.0
CO_2	0.45	+9.39
NO	0.297	-58
CH4	0.444	+17.4
n-C4H10		+44.0

Verdet Constants of Liquids[2]

n_D is the refractive index at a wavelength of 589 nm and a temperature of 20°C, unless otherwise indicated. *V* is the Verdet constant

Liquid	λ/nm	*T*/°C	$10^2 \times V$ min/Oe cm	n_D
P	589	33	+13.3	
S	589	114	+8.1	1.929 (110°C)
H_2O	589	20	+1.309	1.3328
D_2O	589	19.7	+1.257	1.3384
H_3PO_4	578	97.4	+1.35	
CS_2	589	20	+4.255	1.6255
CCl_4	578-589	25.1	+1.60	1.463 (15°C)
$SbCl_5$	578	18	+7.45	1.601 (14°C)
$TiCl_4$	578	17	-1.65	1.61
$TiBr_4$	578	46	-5.3	
Methanol	589	18.7	+0.958	1.3289
Acetone	578-589	20.0	+1.116	1.3585
Toluene	578-589	15.0	+2.71	1.4950
Benzene	578-589	15.0	+3.00	1.5005
Chlorobenzene	589	15	+2.92	1.5246
Nitrobenzene	589	15	+2.17	1.5523
Bromoform	589	17.9	+3.13	1.5960

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MAGNETO-OPTIC CONSTANTS (continued)

Verdet Constants of Rare Earth Paramagnetic Crystals[1]

n is the refractive index, and *V* is the Verdet constant at the wavelength and temperature indicated

Rare Earth	Host	*T*/K	λ/nm	*n*	*V* min/Oe cm
Ce^{3+}(30%)	CaF_2	300	325	1.516	-0.956
		300	442	1.502	-0.297
		300	633	1.494	-0.111
		300	1064	1.489	-0.035
Ce^{3+}	CeF_3	300	442	1.613	-1.05
		300	633	1.598	-0.406
		77	633		-1.418
		300	1064	1.589	-0.113
Pr^{3+}(5%)	CaF_2	300	266	1.471	-0.172
		300	325	1.461	-0.0818
		300	442	1.451	-0.0089
		300	633	1.445	-0.0168
		300	1064	1.441	-0.0045
Nd^{3+}(2.9%)	CaF_2	4.2	426		-0.19
Nd^{3+}	NdF_3	300	442	1.60	-0.553
		290	633	1.59	-0.209
		77	633		-0.755
		300	1064	1.58	-0.097
Eu^{3+}(3%)	CaF_2	4.2	430		29
		4.2	440		22
Eu^{2+}	EuF_2	300	450		-4.5
		300	500		-2.6
		300	550		-1.6
		300	600		-1.1
		300	650		-0.8
		300	1064		-0.19
Tb^{3+}	KTb_3F_{10}	300	325	1.531	-2.174
		300	442	1.518	-0.933
		300	633	1.510	-0.386
		77	633		-1.94
		300	1064	1.505	-0.114
Tb^{3+}	$LiTbF_4$	300	325	1.493	-1.9
		300	442	1.481	-0.98
		300	633	1.473	-0.44
		300	1064	1.469	-0.13
Tb^{3+}	$Tb_3Ga_5O_{12}$	300	500	1.989	-0.749
		300	570	1.981	-0.581
		300	633	1.976	-0.461
		300	830	1.967	-0.21
		300	1060	1.954	-0.12

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MAGNETO-OPTIC CONSTANTS (continued)

Verdet Constants of Paramagnetic Glasses[1]

The Verdet constant *V* is given at room temperature for the wavelengths indicated

Rare earth phosphate glasses of composition $R_2O_3 \cdot xP_2O_5$, where *x* is given in the second column

		Verdet constant *V* in min/Oe cm									
R	***x***	**λ = 405 nm**	**λ = 436 nm**	**λ = 480 nm**	**λ = 500 nm**	**λ = 520 nm**	**λ= 546 nm**	**λ= 578 nm**	**λ= 600 nm**	**λ= 635 nm**	**λ= 670 nm**
La		0.037	0.030	0.024	0.022	0.020	0.018	0.015	-0.014	0.013	—
Ce	2.67	-0.672	0.510	-0.366	-0.326	-0.287	-0.253	-0.217	-0.197	-0.173	-0.150
Pr	3.09	-0.447	-0.332	-0.283	-0.261	-0.236	-0.208	-0.182	-0.170	-0.150	-0.132
Nd	2.92	-0.250	-0.209	-0.167	-0.155	-0.136	-0.134	-0.094	-0.080	-0.080	-0.071
Sm	2.87	0.026	0.024	0.020	0.020	0.017	0.015	0.014	0.012	0.011	0.010
Eu	2.93	-0.025	-0.017	-0.010	-0.006	-0.006	-0.005	-0.004	-0.003	-0.002	-0.002
Gd	3.01	0.018	0.015	0.014	0.012	0.012	0.011	0.011	0.010	0.009	0.009
Tb	2.94	-0.560	-0.458	-0.357	-0.323	-0.295	-0.261	-0.226	-0.206	-0.190	-0.164
Dy	2.51	-0.540	-0.453	-0.359	-0.331	-0.301	0.268	-0.237	-0.217	-0.197	-0.173
Ho	2.94	-0.299	-0.313	-0.156	-0.153	-0.138	-0.138	-0.119	-0.110	-0.098	-0.084
Er	3.01	-0.139	-0.121	-0.100	-0.111	-0.095	-0.062	-0.060	-0.057	-0.051	-0.044
Tm	2.79	0.019	0.013	0.012	0.009	0.008	0.006	0.005	0.004	0.004	0.007
Yb	3.01	0.087	0.072	0.056	0.050	0.045	0.041	0.036	0.032	0.029	0.024
The following are rare earth borate glasses with composition: for La and Pr: $R_2O_3 \cdot xP_2O_5$; for Tb-Pr and Dy-Pr: $R_2O_3 \cdot xB_2O_3$; and for other elements: $R_2O_3 \cdot 0.85La_3O_3 \cdot xB_2O_3$.											
La	3.04	0.043	0.036	0.029	0.026	0.023	0.022	0.019	0.018	0.016	0.014
Pr-La	5.44	-0.380	-0.307	-0.230	-0.220	-0.201	-0.178	-0.153	-0.146	-0.128	-0.110
Nd-La	5.41	-0.180	-0.147	-0.120	-0.111	-0.096	-0.094	-0.100	-0.059	-0.056	-0.046
Sm-La	4.97	0.032	0.030	0.025	0.024	0.022	0.019	0.017	0.016	0.014	0.012
Eu-La	4.69	-0.081	-0.060	-0.038	-0.033	-0.029	-0.024	0.019	-0.016	0.014	-0.012
Gd-La	4.71	0.032	0.026	0.024	0.022	0.021	0.020	0.018	0.017	0.015	0.013
Tb-La	4.73	-0.512	-0.419	-0.319	-0.288	-0.262	-0.234	-0.205	-0.186	-0.167	-0.142
Dy-La	4.88	-0.436	-0.361	-0.299	-0.273	-0.246	-0.220	-0.193	-0.177	-0.159	-0.138
Ho-La	4.36	-0.269	-0.252	-0.123	-0.131	-0.112	-0.128	-0.104	-0.096	—	-0.074
Er-La	4.50	-0.093	-0.078	-0.068	-0.082	—	-0.045	-0.042	-0.040	-0.035	-0.034
Tm-La	4.75	0.060	0.046	0.039	0.034	0.031	0.026	0.023	0.021	0.018	0.016
Yb-La	8.58	0.115	0.094	0.073	0.066	0.060	0.054	0.046	0.043	0.037	0.033
Tb-Pr	4.99	-0.940	-0.786	-0.560	-0.536	-0.489	-0.436	-0.380	-0.348	-0.306	-0.265
Dy-Pr	4.63	-0.850	—	—	-0.497	-0.465	-0.413	-0.358	-0.332	-0.290	-0.252
Pr	2.56	-0.843	-0.646	-0.471	-0.480	-0.432	-0.390	-0.334	-0.317	-0.271	-0.243

MAGNETO-OPTIC CONSTANTS (continued)

Verdet Constants of Diamagnetic Glasses[1]

The Verdet constant *V* is given at room temperature for the wavelengths indicated

Glass type	Composition (wt. %)	Verdet constant *V* in min/Oe cm: λ = 325 nm	λ = 442 nm	λ = 633 nm	λ = 1064 nm
SiO_2	100% SiO_2			0.013	
B_2O_3	100% B_2O_3			0.010	
CdO	47.5% CdO, 52.5% P_2O_5	0.079	0.033	0.022	
ZnO	36.4% ZnO, 63.6% P_2O_5	0.072	0.044	0.020	
TeO_2	88.9% TeO_2, 11.1% P_2O_5		0.196	0.076	0.022
ZrF_4	63.1% ZrF_4, 14.9% BaF_2, 7.2% LaF_3, 1.9% AlF_3, 9.1% PbF_2, 3.8% LiF			0.011	

Glass type	Composition (wt. %)	λ = 700 nm	λ = 853 nm	λ = 1060 nm
Bi_2O_3	95% Bi_2O_3, 5% B_2O_3	0.086	0.051	0.033
PbO	95% PbO, 5% B_2O_3	0.093	0.061	0.031
	82% PbO, 18% SiO_2	0.077	0.045	0.027
	50% PbO, 15% K_2O, 35% SiO_2	0.032	0.020	0.011
Tl_2O	95% Tl_2O, 5% B_2O_3	0.092	0.061	0.032
	82% Tl_2O, 18% SiO_2	0.100	0.067	0.043
	50% Tl_2O, 15% K_2O, 35% SiO_2	0.036	0.022	0.012
SnO	76% SnO, 13% B_2O_3, 11% SiO_2	0.071	0.046	0.026
TeO_3	75% TeO_2, 25% Sb_2O_3	0.076	0.052	0.032
	80% TeO_2, 20% $ZnCl_2$	0.073	0.046	0.025
	84% TeO_2, 16% BaO	0.056	0.041	0.029
	70% TeO_2, 30% WO_3	0.052	0.035	0.022
	20% TeO_2, 80% PbO	0.128	0.075	0.048
Sb_2O_3	25% Sb_2O_3, 75% TeO_2	0.076	0.050	0.032
	75% Sb_2O_3, 75% Cs_2O, 5% Al_2O_3	0.074	0.044	0.025
	75% Sb_2O_3, 10% Cs_2O, 10% Rb_2O, 5% Al_2O_3	0.078	0.052	0.030

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MAGNETO-OPTIC CONSTANTS (continued)

Verdet Constants of Commercial Glasses[1]

This table gives the density, ρ, refractive index at 589 nm, n_D, and Verdet constant, V, for the wavelengths indicated; the data refer to room temperature

Glass type	ρ g/cm³	n_D	V in min/Oe cm λ = 365.0 nm	λ = 404.7 nm	λ = 435.8 nm	λ = 546.1 nm	λ = 578.0 nm
BSC	2.49	1.5096	0.0499	0.0392	0.0333	0.02034	0.01798
HC	2.53	1.5189	0.0561	0.0440	0.0372	0.0225	0.01995
LBC	2.87	1.5406	0.0609	0.0477	0.0403	0.0245	0.0216
LF	3.23	1.5785	0.1143	0.0850	0.0693	0.0394	0.0344
BLF	3.48	1.6047	0.1112	0.0832	0.0685	0.0393	0.0344
DBC	3.56	1.6122	0.0662	0.0517	0.0435	0.0261	0.0231
DF	3.63	1.6203	0.1473	0.1076	0.0872	0.0485	0.0423
EDF	3.9	1.6533	0.1725	0.1248	0.1007	0.0556	0.0483

The composition of the glasses in weight percent is:

Glass type	SiO_2	B_2O_3	K_2O	CaO	Al_2O_3	As_2O_3	Na_2O	BaO	ZnO	PbO
BSC	69.6	6.7	20.5	2.9	0.3	0.1	—	—	—	—
HC	72.0	—	10.1	11.4	0.3	0.2	6.1	—	—	—
LBC	57.1	1.8	13.7	0.3	0.2	0.1	—	26.9	—	—
LF	52.5	—	9.5	0.3	0.2	0.1	—	—	—	37.6
BLF	45.2	—	7.8	—	—	0.4	—	16.0	8.3	22.2
DBC	36.2	7.7	0.2	0.2	3.5	0.7	—	44.6	6.7	—
DF	46.3	—	1.1	0.3	0.2	0.1	5.0	—	—	47.0
EDF	40.6	—	7.5	0.2	0.2	0.2	0.1	—	—	51.5

REFERENCES

1. Weber, M. J., *CRC Handbook of Laser Science and Technology*, Vol. IV, Part 2, CRC Press, Boca Raton, FL, 1988, p. 299-310.
2. Gray, D. E., Ed., *American Institute of Physics Handbook*, Third Edition, McGraw Hill, New York, 1972, p. 6-230.

FARADAY ROTATION

Ferro-, Ferri-, and Antiferromagnetic Solids

Material	T_c K	$4\pi M_s$ gauss	F deg/cm	α cm⁻¹	$2F/\alpha$	T K	λ nm
Fe	1043	21,800	4.4×10^5	6.5×10^5	1.4	300	500
			6.5×10^5	5.0×10^5	2.6	300	1000
			7×10^5	4.2×10^5	3.3	300	1500
			7×10^5	3.5×10^5	4.0	300	2000
Co	1390	18,200	2.9×10^5	—	—	300	500
			5.5×10^5	6.1×10^5	1.8	300	1000
			5.5×10^5	4.5×10^5	2.4	300	1500
			5.5×10^5	3.6×10^5	2.7	300	2000
Ni	633	6,400	0.8×10^5	—	—	300	500
			2.6×10^5	5.8×10^5	0.9	300	1000
			1.5×10^5	4.8×10^5	0.6	300	1500
			1×10^5	4.1×10^5	0.25	300	2000
Permalloy (Ni/Fe = 82/18)	803	10,700	1.2×10^5	6×10^5	0.4	300	500

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FARADAY ROTATION (continued)
Ferro-, Ferri-, and Antiferromagnetic Solids (continued)

Material	T_c K	$4\pi M_s$ gauss	F deg/cm	α cm^{-1}	$2F/\alpha$	T K	λ nm
Ni/Fe = 100/0		6,000	1.2×10^5	7.05×10^5	0.34	300	632.8
Ni/Fe = 80/20		10,800	2.2×10^5	7.10×10^5	0.62	300	632.8
Ni/Fe = 60/40		14,900	2.9×10^5	7.54×10^5	0.77	300	632.8
Ni/Fe = 40/60		14,400	2.2×10^5	8.17×10^5	0.54	300	632.8
Ni/Fe = 20/80		19,400	3.3×10^5	8.10×10^5	0.81	300	632.8
Ni/Fe = 0/100	639	21,600	3.5×10^5	8.13×10^5	0.86	300	632.8
MnBi		7,700	4.2×10^5	6.1×10^5	1.4	300	450
			7.5×10^5	4.2×10^5	3.6	300	900
MnAs	313	—	0.44×10^5	5.0×10^5	0.174	300	500
			0.62×10^5	4.4×10^5	0.28	300	900
CrTe	334	1015	0.5×10^5	2.0×10^5	0.5	300	550
			0.4×10^5	1.2×10^5	0.7	300	900
FeRh	333	—	0.9×10^5	3.3×10^5	0.56	348	700
$Y_3Fe_5O_{12}$ (YIG)	560	2500	2400	1500	3.2	300	555
			1250	1400	1.8	300	625
			750	450	3.3	300	770
			175	<0.06	$>3 \times 10^3$	300	5000 to 1500
$Gd_3Fe_5O_{12}$ (GdIG)	Tn = 564	7300	-2000	6000	0.6	300	500
	T = 286		-1050	900	2.3	300	600
			-300	100	6.0	300	800
			-80	70	2.3	300	1000
$NiFe_2O_4$	858	3350	2.0×10^4	5.9×10^4	0.7	300	286
			-1.0×10^4	10×10^4	0.2	300	500
			-120	38	6	300	1500
			+75	15	10	300	3000
			+110	32	7	300	5000
$CoFe_2O_4$	793	4930	2.75×10^4	12×10^4	0.5	300	286
			3.6×10^4	17×10^4	0.4	300	400
			-2.5×10^4	6×10^4	0.8	300	660
$MgFe_2O_4$	593-713[e]	1450[e]	-60	100	1	300	2500
			0	12	0	300	4000
			+35	6	11	300	6000
$Li_{0.5}Fe_{2.5}O_4$	863-953[e]	3240[e]	-440	150	6	300	1500
		to 3900	+10	85	0.2	300	3000
			+110	44	5	300	5000
			+135	80	3	300	7000
$BaFe_{12}O_{19}$	723	—	-50	-38	3	300	2000
			+75	20	7.5	300	3000
			+150	20	15	300	5000
			+165	22	15	300	7000
$Ba_2Zn_2Fe_{12}O_{19}$	—	—	90	120	1.5	300	5000
			75	65	2.0	300	7000
$RbNiF_3$	220	1250	360	35	20	77	450[a]
			70	10	14	77	600[a]
			310	70	9	77	800[a]
			75	25	6	77	1000[a]
$RbNi_{0.75}Co_{0.25}F_3$	109	—	180	9	40	77	600[b]
$RbFeF_3$	102	—	3400	7	900	82	300[c]
			1600	3	1100	82	400[c]
			620	1.5	830	82	600[c]
			300	2.5	240	82	800[c]
FeF_3	365	40	670	14	95	300	349[d]
		at 300 K	180	4.4	82	300	522.5[d]
$CrCl_3$	16.8	3880	2000	200	20	1.5	410

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FARADAY ROTATION (continued)

Ferro-, Ferri-, and Antiferromagnetic Solids (continued)

Material	T_c K	$4\pi M_s$ gauss	F deg/cm	α cm^{-1}	$2F/\alpha$	T K	λ nm
			-500	300	3	1.5	450
			-1000	70	30	1.5	590
$CrBr_3$	32.5	3390	3×10^5	3×10^3	200	1.5	478
			1.6×10^5	1.4×10^4	23	1.5	500
CrI_3	68	2690	1.1×10^5	6.3×10^3	35	1.5	970
			0.8×10^5	3×10^3	53	1.5	1000
$FeBO_3$	348	115	3200	140	45	300	500
		at 300 K	450	38	24	300	700
EuO	69	23700	-1.0×10^5	0.5×10^4	40	5	1100
			5×10^5	9.7×10^4	10	5	700
			0.5×10^5	7.8×10^4	1.3	5	500
			3×10^4	>0.5	~105	20	2500
			660	>1.0	1300	20	10600
EuS	16.3	—	-1.6×10^5	0	—	6	825
			-9.6×10^5	3.3×10^4	58	6	690
			$+5.5 \times 10^5$	1.2×10^5	9.2	6	563
EuSe	7.0	13,200	1.45×10^5	80	3600	4.2	750
			0.95×10^5	60	3170	4.2	800

[a] Measured along the C-axis (magnetic hard axis).
[b] Measured along the C-axis (magnetic easy axis).
[c] Measured along the C-axis ([100]-direction at room temperature).
[d] Strong natural birefringence interferes with the Faraday effect.
[e] Depends on heat treatment.

REFERENCE

1. Weber, M. J., Ed., *CRC Handbook of Laser Science and Technology*, Vol. IV, Part 2, CRC Press, Boca Raton, FL, 1988, pp. 288-296.

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NONLINEAR OPTICAL CONSTANTS
H. P. R. Frederikse

The relation between the polarization density P of a dielectric medium and the electric field E is linear when E is small, but becomes nonlinear as E acquires values comparable with interatomic electric fields (10^5 to 10^8 V/cm). Under these conditions the relation between P and E can be expanded in a Taylor's series

$$P = \varepsilon_0 \chi^{(1)} E + 2\chi^{(2)} E^2 + 4\chi^{(3)} E^3 + \cdots \tag{1}$$

where ε_o is the permittivity of free space, while $\chi^{(1)}$ is the linear and $\chi^{(2)}$, $\chi^{(3)}$ etc. the nonlinear optical susceptibilities.

If we consider two optical fields, the first $E_j^{\omega_1}$ (along the j-direction at frequency ω_1) and the second $E_k^{\omega_2}$ (along the k-direction at frequency ω_2) one can write the second term of the Taylor's series as follows

$$P_i(\omega_1\omega_2) = 2\chi_{ijk}^{\omega_3=\omega_1\pm\omega_2} E_j^{\omega_1} E_k^{\omega_2}$$

When $\omega_1 \neq \omega_2$ the (parametric) mixing of the two fields gives rise to two new polarizations at the frequencies $\omega_3 = \omega_1 + \omega_2$ and $\omega_3' = \omega_1 - \omega_2$. When the two frequencies are equal, $\omega_1 = \omega_2 = \omega$, the result is Second Harmonic Generation (SHG) $\chi_{ijk}(2\omega, \omega, \omega)$, while equal and opposite frequencies, $\omega_1 = \omega$ and $\omega_2 = -\omega$ leads to Optical Rectification (OR): $\chi_{ijk}(0,\omega,-\omega)$. In the SHG case the following convention is adopted: the second order nonlinear coefficient d is equal to one half of the second order nonlinear susceptibility

$$d_{ijk} = 1/2\chi^{(2)}$$

Because of the symmetry of the indices j and k one can replace these two by a single index (subscript) m. Consequently the notation for the SHG nonlinear coefficient in reduced form is d_{im} where m takes the values 1 to 6. Only noncentrosymmetric crystals can possess a nonvanishing d_{ijk} tensor (third rank). The unit of the SHG coefficients is m/V (in the MKSQ/SI system).

In centrosymmetric media the dominant nonlinearity is of the third order. This effect is represented by the third term in the Taylor's series (Equation 1); it is the result of the interaction of a number of optical fields (one to three) producing a new frequency $\omega_4 = \omega_1 + \omega_2 + \omega_3$. The third order polarization is given by

$$P_j(\omega_1\omega_2\omega_3) = g_4 \chi_{jklm} E_k^{\omega_1} E_l^{\omega_2} E_m^{\omega_3}$$

Third Harmonic Generation (THG) is achieved when $\omega_1 = \omega_2 = \omega_3 = \omega$. In this case the constant $g_4 = 1/4$. The third order nonlinear coefficient C is related to the third order susceptibility as follows

$$C_{jklm} = 1/4\chi_{jklm}$$

This coefficient is a fourth rank tensor. In the THG case the matrices must be invariant under permutation of the indices k, l, and m; as a result the notation for the third order nonlinear coefficient can be simplified to C_{jn}. The unit of C_{jn} is $m^2 \cdot V^{-2}$ (in the MKSQ/SI system).

Applications of second order nonlinear optical materials include the generation of higher (up to sixth) optical harmonics, the mixing of monochromatic waves to generate sum or difference frequencies (frequency conversion), the use of two monochromatic waves to amplify a third wave (parametric amplification) and the addition of feedback to such an amplifier to create an oscillation (parametric oscillation).

Third order nonlinear optical materials are used for THG, self-focusing, four wave mixing, optical amplification, and optical conjugation. Many of these effects — as well as the variation and modulation of optical propagation caused by mechanical, electric, and magnetic fields (see the preceeding table on "Elasto-Optic, Electro-Optic, and Magneto-Optic Constants") are used in the areas of optical communication, optical computing, and optical imaging.

REFERENCES (NONLINEAR OPTICS)

1. *Handbook of Laser Science and Technology*, Vol. 111, Part 1; Ed.: Marvin J. Weber, Publ.: CRC Press, Inc., Boca Raton, FL, 1986.
2. Dmitriev, V.G., Gurzadyan, G.G., and Nikogosyan, D., *Handbook of Nonlinear Optical Crystals*, Springer-Verlag, Berlin, 1991.
3. Shen, Y.R., *The Principles of Nonlinear Optics*, John Wiley, New York, 1984.
4. Yariv, A., *Quantum Electronics*, 3rd edition, John Wiley, New York, 1988.
5. Bloembergen, N., *Nonlinear Optics*, W.A. Benjamin, New York, 1965.
6. Zernike F. and Midwinter, J.E., *Applied Nonlinear Optics*, John Wiley, New York, 1973.
7. Hopf, F.A. and Stegeman, G.I., *Applied Classical Electrodynamics*, Volume 2: Nonlinear Optics, John Wiley, New York, 1986.
8. *Nonlinear Optical Properties of Organic Molecules and Crystals*, Eds.: D.S. Chemla and J. Zyss, Publ.: Academic Press, Orlando, FL, 1987.
9. *Optical Phase Conjugation*, Ed.: R.A. Fisher, Publ.: Academic Press, New York, 1983.
10. Zyss, J., *Molecular Nonlinear Optics: Materials, Devices and Physics*, Academic Press, Boston, 1994.
11. Nonlinear Optics, 5 articles in *Physics Today, (Am. Inst. of Phys.)*, Vol. 47, No. 5, May, 1994.

Selected SHG Coefficients of NLO Crystals*

Material	Symmetry class	$d_{im} \times 10^{12}$ m/V	λ μm
GaAs	$\bar{4}3$ m	$d_{14} = 134.1 \pm 42$	10.6
GaP	$\bar{4}3$ m	$d_{14} = 71.8 \pm 12.3$	1.058
InAs	$\bar{4}3$ m	$d_{14} = 364 \pm 47$	1.058
		$d_{14} = 210$	10.6
ZnSe	$\bar{4}3$ m	$d_{14} = 78.4 \pm 29.3$	10.6
		$d_{36} = 26.6 \pm 1.7$	1.058
β-ZnS	$\bar{4}3$ m	$d_{14} = 30.6 \pm 8.4$	10.6
		$d_{36} = 20.7 \pm 1.3$	1.058
ZnTe	$\bar{4}3$ m	$d_{14} = 92.2 \pm 33.5$	10.6
		$d_{14} = 83.2 \pm 8.4$	1.058
		$d_{36} = 89.6 \pm 5.7$	1.058
CdTe	$\bar{4}3$ m	$d_{14} = 167.6 \pm 63$	10.6
Bi_4GeO_{12}	$\bar{4}3$ m	$d_{14} = 1.28$	1.064
$N_4(CH_2)_6$ (hexamine)	$\bar{4}3$ m	$d_{14} = 4.1$	1.06
$LiIO_3$	6	$d_{33} = -7.02$	1.06
		$d_{31} = -5.53 \pm 0.3$	1.064
ZnO	6 mm	$d_{33} = -5.86 \pm 0.16$	1.058
		$d_{31} = 1.76 \pm 0.16$	1.058
		$d_{15} = 1.93 \pm 0.16$	1.058
α-ZnS	6 mm	$d_{33} = 11.37 \pm 0.07$	1.058
		$d_{33} = 37.3 \pm 12.6$	10.6
		$d_{31} = -18.9 \pm 6.3$	10.6
		$d_{15} = 21.37 \pm 8.4$	10.6
CdS	6 mm	$d_{33} = 25.8 \pm 1.6$	1.058
		$d_{31} = -13.1 \pm 0.8$	1.058
		$d_{15} = 14.4 \pm 0.8$	1.058
CdSe	6 mm	$d_{33} = 54.5 \pm 12.6$	10.6
		$d_{31} = -26.8 \pm 2.7$	10.6
$BaTiO_3$	4 mm	$d_{33} = 6.8 \pm 1.0$	1.064
		$d_{31} = 15.7 \pm 1.8$	1.064
		$d_{15} = 17.0 \pm 1.8$	1.064
$PbTiO_3$	4 mm	$d_{33} = 7.5 \pm 1.2$	1.064
		$d_{31} = 37.6 \pm 5.6$	1.064
		$d_{15} = 33.3 \pm 5$	1.064
$K_3Li_2Nb_5O_{15}$	4 mm	$d_{33} = 11.2 \pm 1.6$	1.064
		$d_{31} = 6.18 \pm 1.28$	1.064
		$d_{15} = 5.45 \pm 0.54$	1.064
$K_{0.8}Na_{0.2}Ba_2Nb_5O_{15}$	4 mm	$d_{31} = 13.6 \pm 1.6$	1.064
$SrBaNb_5O_{15}$	4 mm	$d_{33} = 11.3 \pm 3.3$	1.064
		$d_{31} = 4.31 \pm 1.32$	1.064
		$d_{15} = 5.98 \pm 2$	1.064
$NH_4H_2PO_4$ (ADP)	$\bar{4}2$ m	$d_{36} = 0.53$	1.064
		$d_{36} = 0.85$	0.694
KH_2PO_4 (KDP)	$\bar{4}2$ m	$d_{36} = 0.44$	1.064
		$d_{36} = 0.47 \pm 0.07$	0.694
KD_2PO_4 (KD*P)	$\bar{4}2$ m	$d_{36} = 0.38 \pm 0.016$	1.058
		$d_{36} = 0.34 \pm 0.06$	0.694
		$d_{14} = 0.37$	1.058
KH_2AsO_4 (KDA)	$\bar{4}2$ m	$d_{36} = 0.43 \pm 0.025$	1.06
		$d_{36} = 0.39 \pm 0.4$	0.694
$CdGeAs_2$	$\bar{4}2$ m	$d_{36} = 351 \pm 105$	10.6
$AgGaS_2$	$\bar{4}2$ m	$d_{36} = 18 \pm 2.7$	10.6
$AgGaSe_2$	$\bar{4}2$ m	$d_{36} = 37.4 \pm 6.0$	10.6
$(NH_2)_2CO$ (urea)	$\bar{4}2$ m	$d_{36} = 1.3$	1.06
$AlPO_4$	32	$d_{11} = 0.35 \pm 0.03$	1.058
Se	32	$d_{11} = 97 \pm 25$	10.6

Selected SHG Coefficients of NLO Crystals (continued)*

Material	Symmetry class	$d_{im} \times 10^{12}$ m/V	λ µm
Te	32	$d_{11} = 650 \pm 30$	10.6
SiO_2 (quartz)	32	$d_{11} = 0.335$	1.064
HgS	32	$d_{11} = 50.3 \pm 17$	10.6
$(C_6H_5CO)_2$ [benzil]	32	$d_{11} = 3.6 \pm 0.5$	1.064
β-BaB_2O_4 [BBO]	3 m	$d_{22} = 2.22 \pm 0.09$	1.06
		$d_{31} = 0.16 \pm 0.08$	1.06
$LiNbO_3$	3 m	$d_{33} = 34.4$	1.06
		$d_{31} = -5.95$	1.06
		$d_{22} = 2.76$	1.06
$LiTaO_3$	3 m	$d_{33} = -16.4 \pm 2$	1.058
		$d_{31} = -1.07 \pm 0.2$	1.058
		$d_{22} = +1.76 \pm 0.2$	1.058
Ag_3AsS_3 [proustite]	3 m	$d_{31} = 11.3 \pm 2.5$	10.6
		$d_{22} = 18.0 \pm 2.5$	10.6
Ag_3SbS_3 [pyrargerite]	3m	$d_{31} = 12.6 \pm 4$	10.6
		$d_{22} = 13.4 \pm 4$	10.6
α-HIO_3	222	$d_{36} = 5.15 \pm 0.16$	1.064
$NO_2 \cdot CH_3NOC_5H_4 \cdot$ (POM)	222	$d_{36} = 6.4 \pm 1.0$	1.064
$Ba_2NaNb_5O_{15}$ [Banana]	mm 2	$d_{33} = -17.6 \pm 1.28$	1.064
		$d_{31} = -12.8 \pm 1.28$	1.064
$C_6H_4(NO_2)_2$ [MDB]	mm 2	$d_{33} = 0.74$	1.064
		$d_{32} = 2.7$	1.064
		$d_{31} = 1.78$	1.064
$Gd_2(MoO_4)_3$	mm 2	$d_{33} = -0.044 \pm 0.008$	1.064
		$d_{32} = +2.42 \pm 0.36$	1.064
		$d_{31} = -2.49 \pm 0.37$	1.064
$KNbO_3$	mm 2	$d_{33} = -19.58 \pm 1.03$	1.064
		$d_{32} = +11.34 \pm 1.03$	1.064
		$d_{31} = -12.88 \pm 1.03$	1.064
$KTiOPO_4$ [KTP]	mm 2	$d_{33} = 13.7$	1.06
		$d_{32} = \pm 5.0$	1.06
		$d_{31} = \pm 6.5$	1.06
$NO_2C_6H_4 \cdot NH_2$ [mNA]	mm 2	$d_{33} = 13.12 \pm 1.28$	1.064
		$d_{32} = 1.02 \pm 0.22$	1.064
		$d_{31} = 12.48 \pm 1.28$	1.064
$C_{10}H_{12}N_3O_6$ [MAP]	2	$d_{23} = 10.67 \pm 1.3$	1.064
		$d_{22} = 11.7 \pm 1.3$	1.064
		$d_{21} = 2.35 \pm 0.5$	1.064
		$d_{25} = -0.35 \pm 0.3$	1.064
$(NH_2CH_2COOH)_3H_2SO_4$ [TGS]	2	$d_{23} = 0.32$	0.694

* These data are taken from References 1 and 2.

NONLINEAR OPTICAL CONSTANTS (continued)

Selected THG Coefficients of Some NLO Materials*

Material	NLO process	$C_{jn} \times 10^{20}$ m^2/V^{-2}	λ μm
$NH_4H_2PO_4$ [ADP]	(–3ω,ω,ω,ω)	C_{11} = 0.0104	1.06
		C_{18} = 0.0098	1.06
C_6H_6 [benzene]	(–3ω,ω,ω,ω)	C_{11} = 0.0184 ± 0.0042	1.89
$CdGeAs_2$	(–3ω,ω,ω,ω)	C_{11} = 182 ± 84	10.6
p-type: 5×10^{16} cm^{-3}		C_{16} = 175	10.6
		C_{18} = –35	10.6
$C_{40}H_{56}$ [β-carotene]	(–3ω,ω,ω,ω)	C_{11} 0.263 ± 0.08	1.89
GaAs high-resistivity	(–3ω,ω,ω,–ω)	C_{11} = 62 ± 31	1.06
Ge	(–3ω,ω,ω,–ω)	C_{11} = 23.5 ± 12	1.06
$LiIO_3$	(–3ω,ω,ω,–ω)	C_{12} = 0.2285	1.06
		C_{35} = 6.66 ± 1	1.06
KBr	(–3ω,ω,ω,–ω)	C_{11} = 0.0392	1.06
		C_{18}/C_{11} = 0.3667	1.06
KCl	(–3ω,ω,ω,–ω)	C_{11} = 0.0168	1.06
		C_{18}/C_{11} = 0.28	1.06
KH_2PO_4 [KDP]	(–3ω,ω,ω,–ω)	C_{11}–3C_{18} = 0.04	1.06
Si p-type: 10^{14} cm^{-3}	(–3ω,ω,ω,–ω)	C_{11} = 82.8 ± 25	1.06
NaCl	(–3,ω,ω,ω,–ω)	C_{11} = 0.0168	1.06
		C_{18}/C_{11} = 0.4133	1.06
NaF	(–3ω,ω,ω,–ω)	C_{11} = 0.0035	1.06

* These data are taken from Reference 1.

PHASE DIAGRAMS
H. P. R. Frederikse

A phase is a structurally homogeneous portion of matter. Regardless of the number of chemical constituents of a gas, there is only one vapor phase. This is true also for the liquid form of a pure substance, although a mixture of several liquid substances may exist as one or several phases, depending on the interactions among the substances. On the other hand a pure solid may exist in several phases at different temperatures and pressures because of differences in crystal structure (Reference 1). At the phase transition temperature, T_{tr}, the chemical composition of the solid remains the same, but often a change in the physical properties will take place. Such changes are found in ferroelectric crystals (example $BaTiO_3$) which develop a spontaneous polarization below T_{tr}, in superconductors (example Pb) which loose all electrical resistance below the transition point, and in many other classes of solids.

In quite a few cases it is difficult to bring about the phase transition, and the high- (or low-) temperature phase persists in its metastable form. Many liquids remain in the liquid state for shorter or longer periods of time when cooled below the melting point (supercooling). However, often the slightest disturbance will cause solidification. Persistence of the high temperature phase in solid-solid transitions is usually of much longer duration. An example of this behavior is found in white tin; although gray tin is the thermodynamically stable form below T_{tr} (286.4 K), the metal remains in its undercooled, white tin state all the way to $T = 0$ K, and crystals of gray tin are very difficult to produce.

A *phase diagram* is a map which indicates the areas of stability of the various phases as a function of external conditions (temperature and pressure). Pure materials, such as mercury, helium, water, and methyl alcohol are considered one-component systems and they have *unary* phase diagrams. The equilibrium phases in two-component systems are presented in *binary* phase diagrams. Because many important materials consist of three, four, and more components, many attempts have been made to deduce their multicomponent phase diagrams. However, the vast majority of systems with three or more components are very complex, and no overall maps of the phase relationships have been worked out.

It has been shown during the last 20 to 25 years that very useful partial phase diagrams of complex systems can be obtained by means of thermodynamic modeling (References 2, 3). Especially for complicated, multicomponent alloy systems the CALPHAD method has proved to be a successful approach for producing valuable portions of very intricate phase diagrams (Reference 4). With this method thermodynamic descriptions of the free energy functions of various phases are obtained which are consistent with existing (binary) phase diagram information and other thermodynamic data. Extrapolation methods are then used to extend the thermodynamic functions into a ternary system. Comparison of the results of this procedure with available experimental data is then used to fine-tune the phase diagram and add ternary interaction functions if necessary. In principle this approximation strategy can be extended to four, five, and more component systems.

The nearly two dozen phase diagrams shown below present the reader with examples of some important types of single and multicomponent systems, especially for ceramics and metal alloys. This makes it possible to draw attention to certain features like the kinetic aspects of phase transitions (see Figure 22, which presents a time-temperature-transformation, or TTT, diagram for the precipitation of α-phase particles from the β-phase in a Ti-Mo alloy; Reference 1, pp.358-360). The general references listed below and the references to individual figures contain phase diagrams for many additional systems.

GENERAL REFERENCES

1. Ralls, K.M., Courtney, T.H., and Wulff, J., *Introduction to Materials Science and Engineering*, Chapters 16 and 17, John Wiley & Sons, New York, 1976.
2. Kaufman, L., and Bernstein, H., *Computer Calculation of Phase Diagrams*, Academic Press, New York, 1970.
3. Kattner, U.R., Boettinger, W.J.B., and Coriell, S.R., *Z. Metallkd*., 87, 9, 1996.
4. Dinsdale, A.T., Editor, *CALPHAD*, Vol. 1–20, Pergamon Press, Oxford, 1977–1996 and continuing.
5. Baker, H., Editor, *ASM Handbook, Volume 3: Alloy Phase Diagrams*, ASM International, Materials Park, OH, 1992.
6. Massalski, T.B., Editor, *Binary Alloy Phase Diagrams, Second Edition*, ASM International, Materials Park, OH, 1990.
7. Roth. R.S., Editor, *Phase Diagrams for Ceramists*, Vol. I (1964) to Volume XI (1995), American Ceramic Society, Waterville, OH.

REFERENCES TO INDIVIDUAL PHASE DIAGRAMS

Figure 1. Carbon: Reference 7, Vol. X (1994), Figure 8930. Reprinted with permission.
Figure 2. Si-Ge : Ref.5, p. 2.231. Reprinted with permission.
Figure 3. H_2O (ice): See figure.
Figure 4. SiO_2: Reference 7, Vol. XI (1995), Figure 9174. Reprinted with permission.
Figure 5. Fe-O: Darken, L.S., and Gurry, R.W., *J. Am. Chem. Soc*., 68, 798, 1946. Reprinted with permission.
Figure 6. Ti-O: Reference 5, p. 2.324. Reprinted with permission.
Figure 7. $BaO-TiO_2$: Reference 7, Vol. III (1975), Figure 4302. Reprinted with permission.
Figure 8. $MgO-Al_2O_3$: Reference 7, Vol. XI (1995), Figure 9239. Reprinted with permission.
Figure 9. $Y_2O_3-ZrO_2$: Reference 7, Vol. XI (1995), Figure 9348. Reprinted with permission.
Figure 10. Si-N-Al-O (Sialon): Reference 7, Vol. X (1994), Figure 8759. Reprinted with permission.
Figure 11. $PbO-ZrO_2-TiO_2$ (PZT): Reference 7, Vol. III (1975), Figure 4587. Reprinted with permission.
Figure 12. Al-Si-Ca-O: Reference 7 (1964), Vol. I, Figure 630. Reprinted with permission.
Figure 13. Y-Ba-Cu-O: Whitler, J.D., and Roth, R.S., *Phase Diagrams for High T_c Superconductors*, Figure S-082, American Ceramic Society, Waterville, OH, 1990. Reprinted with permission.
Figure 14. Al-Cu: Reference 5, p. 2.44. Reprinted with permission.
Figure 15. Fe-C: Ralls, K.M., Courtney, T.H., and Wulff, J., *Introduction to Materials Science and Engineering*, Figure 16.13 , John Wiley & Sons, New York, 1976. Reprinted with permission.
Figure 16. Fe-Cr: Reference 5, p. 2.152. Reprinted with permission.

Figure 17. Cu-Sn: Reference 5, p. 2.178. Reprinted with permission.
Figure 18. Cu-Ni: Reference 5, p. 2.173. Reprinted with permission.
Figure 19. Pb-Sn (solder): Reference 5, p. 2.335. Reprinted with permission.
Figure 20. Cu-Zn (brass): Subramanian, P.R., Chakrabarti, D.J., and Laughlin, D.E., Editors, *Phase Diagrams of Binary Copper Alloys*, p. 487, ASM International, Materials Park, OH, 1994. Reprinted with permission.
Figure 21. Co-Sm: Reference 5, p. 2.148. Reprinted with permission.
Figure 22. Ti-Mo: Reference 5, p. 2.296; Reference 1, p. 359. Reprinted with permission.
Figure 23: Fe-Cr-Ni: Reference 5, Figure 48. Reprinted with permission.

Figure 1

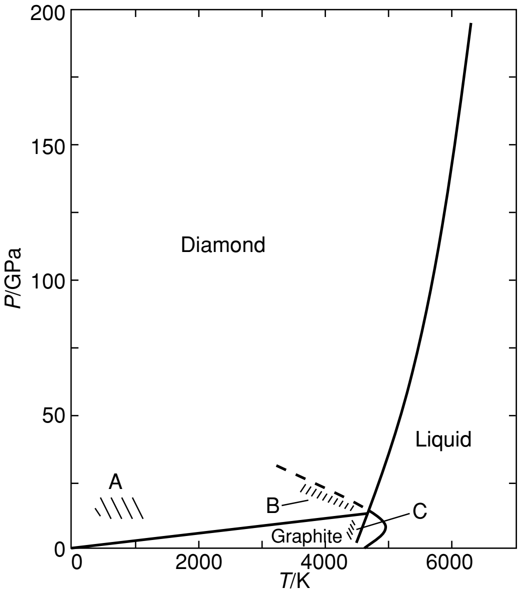


Figure 1. Phase diagram of carbon. (A) Martensitic transition: hex graphite → hex diamond. (B) Fast graphite-to-diamond transition. (C) Fast diamond-to-graphite transition.

Figure 2

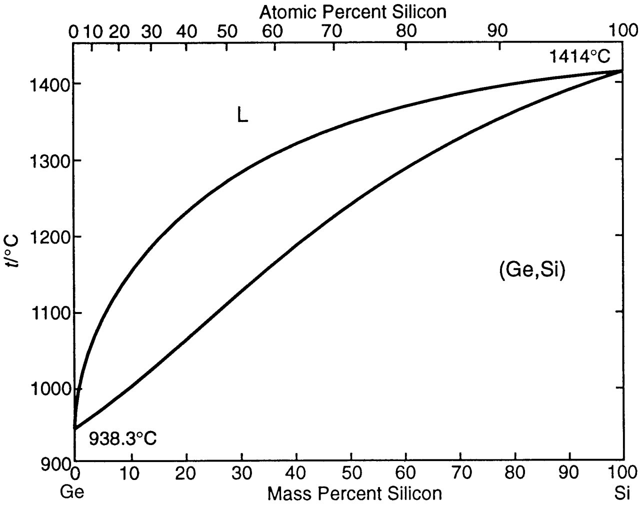


Figure 2. Si-Ge system.

Phase	Composition, mass % Si	Pearson symbol	Space group
(Ge,Si)	0 to 100	*cF*8	$Fd\bar{3}m$
High-pressure phases			
GeII	—	*tI*4	$I4_1/amd$
SiII	—	*tI*4	$I4_1/amd$

FIGURE 3

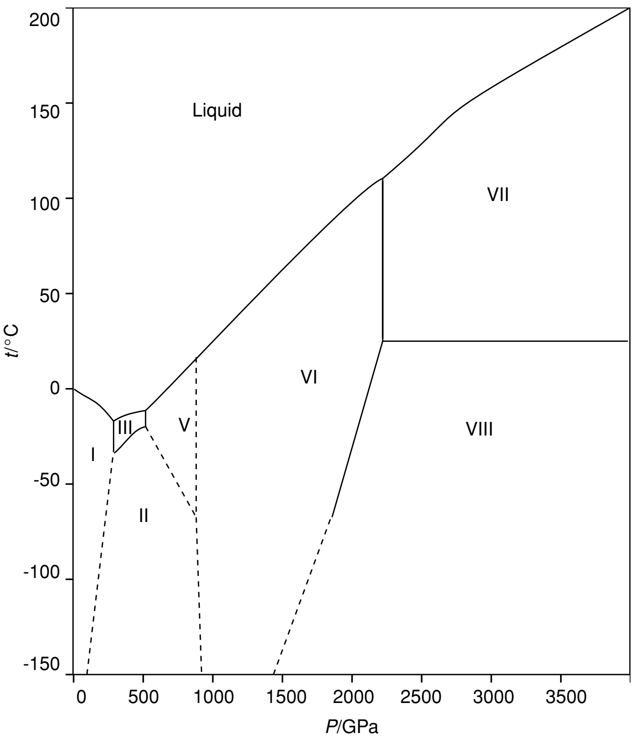


Figure 3. Diagram of the principal phases of ice. Solid lines are measured boundaries between stable phases; dotted lines are extrapolated. Ice IV is a metastable phase which exists in the region of ice V. Ice IX exists in the region below -100°C and pressures in the range 200–400 MPa. Ice X exists at pressures above 44 GPa. See Table 1 for the coordinates of the triple points, where liquid water is in equilibrium with two adjacent solid phases.

Table 1. Crystal Structure, Density, and Transition Temperatures for the Phases of Ice

Phase	Crystal system	Cell parameters	Z	n	ρ/g cm^{-3}	Triple ponts
Ih	Hexagonal	a = 4.513; c = 7352	4	4	0.93	I-III: -21.99°C, 209.9 MPa
Ic	Cubic	a = 6.35	8	4	0.94	
II	Rhombohedral	a = 7.78; α = 113.1°	12	4	1.18	
III	Tetragonal	a = 6.73; c = 6.83	12	4	1.15	III-V: -16.99°C, 350.1 MPa
IV	Rhombohedral	a = 7.60; α = 70.1°	16	4	1.27	
V	Monoclinic	a = 9.22; b = 7.54, c = 10.35; β = 109.2°	28	4	1.24	V-VI: 0.16°C, 632.4 MPa
VI	Tetragonal	a = 6.27; c = 5.79	10	4	1.31	VI-VII: 82°C, 2216 MPa
VII	Cubic	a = 3.41	2	8	1.56	
VIII	Tetragonal	a = 4.80; c = 6.99	8	8	1.56	
IX	Tetragonal	a = 6.73; c = 6.83	12	4	1.16	
X	Cubic	a = 2.83	2	8	2.51	

REFERENCES

1. Wagner, W., Saul, A., and Pruss, A., *J. Phys. Chem. Ref. Data*, 23, 515, 1994.
2. Lerner, R.G. and Trigg, G.L., Editors, *Encyclopedia of Physics,* VCH Publishers, New York, 1990.
3. Donnay, J.D.H. and Ondik, H.M, *Crystal Data Determinative Tables, Third Edition, Volume 2, Inorganic Compounds,* Joint Committee on Powder Diffraction Standards, Swarthmore, PA, 1973.
4. Hobbs, P.V., *Ice Physics,*Oxford University Press, Oxford, 1974.

Figure 4

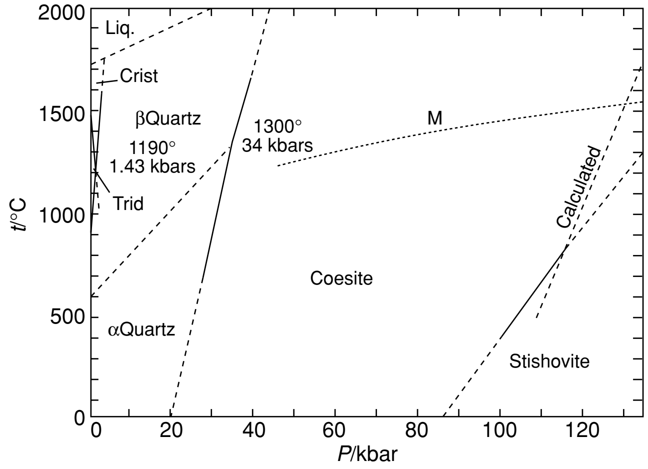


Figure 4. SiO_2 system. Crist = cristobalite; Trid = tridymite.

Figure 5

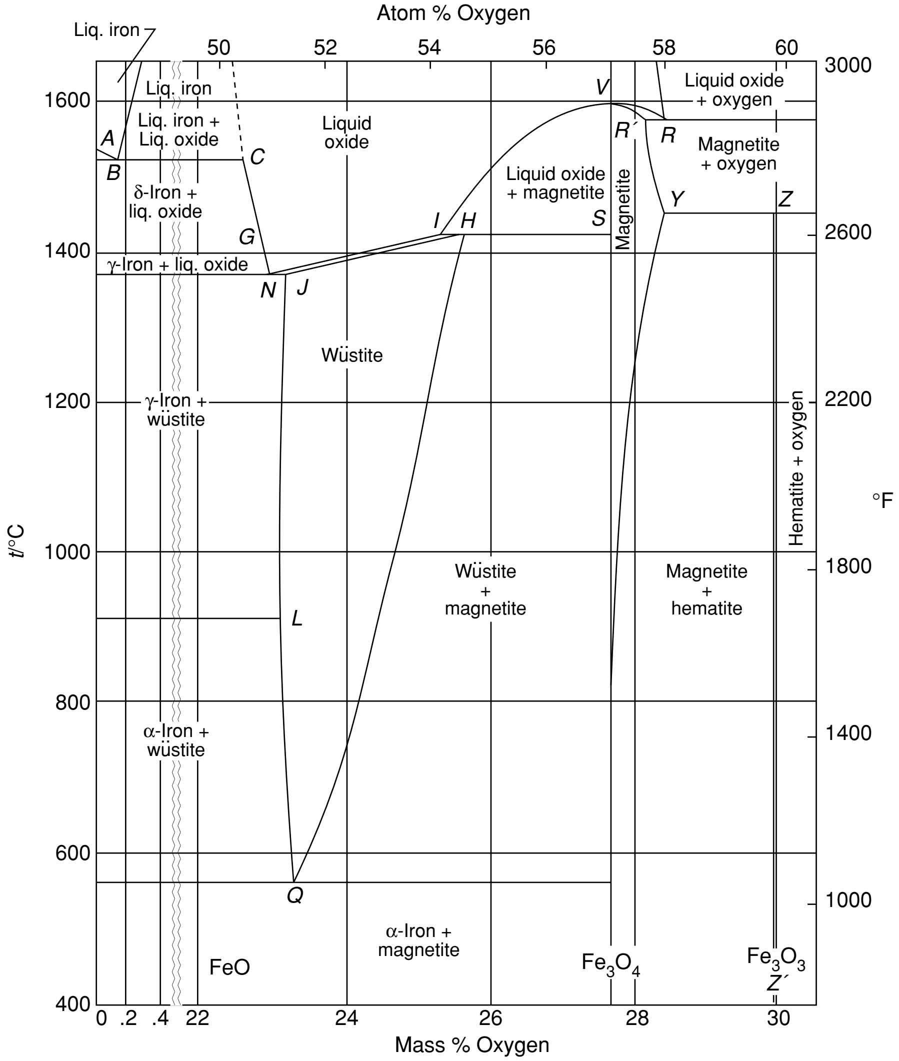


Figure 5. Fe-O system.

Figure 5 (continued)

Point	t/°C	% O	p_{CO_2}/p_{CO}	Point	t/°C	% O	p_{CO_2}/p_{CO}	p_{O_2}/atm
A	1539			*Q*	560	23.26	1.05	
B	1528	0.16	0.209	*R*	1583	28.30		1
C	1528	22.60	0.209	*R′*	1583	28.07		1
G	1400[a]	22.84	0.263	*S*	1424	27.64	16.2	
H	1424	25.60	16.2	*V*	1597	27.64		0.0575
I	1424	25.31	16.2	*Y*	1457	28.36		1
J	1371	23.16	0.282	*Z*	1457	30.04		1
L	911[a]	23.10	0.447	*Z′*		30.6		
N	1371	22.91	0.282					

[a] Values for pure iron.

Figure 6

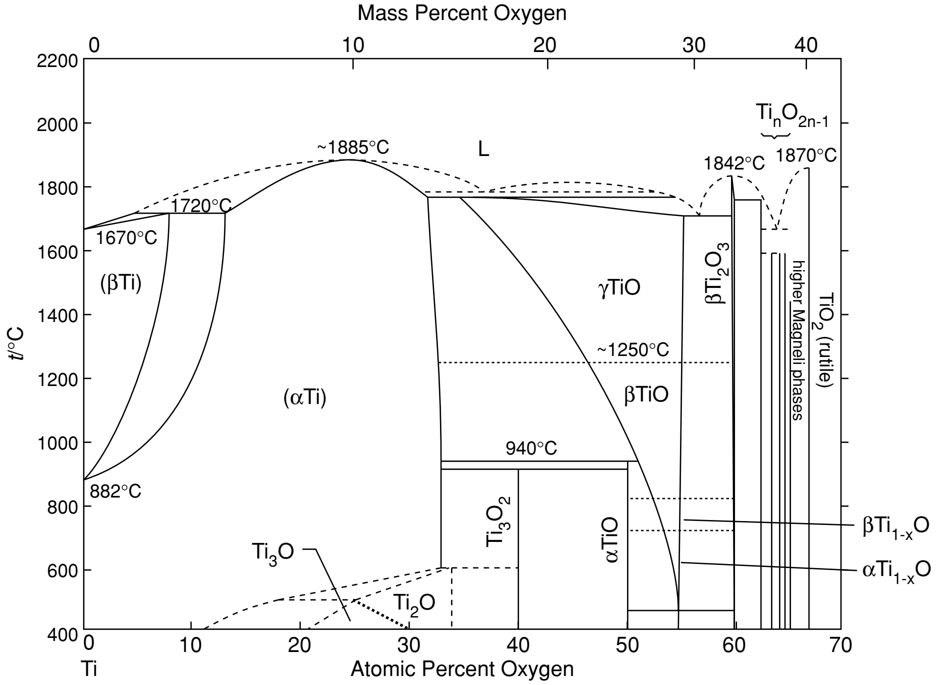


Figure 6. Ti-O system.

Phase	Composition, mass % O	Pearson symbol	Space group
(βTi)	0 to 3	$cI2$	$Im\bar{3}m$
(αTi)	0 to 13.5	$hP2$	$P63/mmc$
Ti_3O	~8 to ~13	hP~16	$P\bar{3}c$
Ti_2O	~10 to 14.4	$hP3$	$P\bar{3}m1$
γTiO	15.2 to 29.4	$cF8$	$Fm\bar{3}m$
Ti_3O_2	~18	hP~5	$P6/mmm$
βTiO	~24 to ~29.4	c**	—
αTiO	~25.0	$mC16$	$A2/m$ or $B*/*$
$\beta Ti_{1-x}O$	~29.5	$oI12$	$I222$
$\alpha Ti_{1-x}O$	~29.5	$tI18$	$I4/m$
βTi_2O_3	33.2 to 33.6	$hR30$	$R\bar{3}c$
αTi_2O_3	33.2 to 33.6	$hR30$	$R\bar{3}c$
βTi_3O_5	35.8	m**	—
αTi_3O_5	35.8	$mC32$	$C2/m$
$\alpha' Ti_3O_5$	35.8	$mC32$	Cc

Figure 6 (continued)

Phase	Composition, mass % O	Pearson symbol	Space group
γTi_4O_7	36.9	*aP*44	$P\bar{1}$
βTi_4O_7	36.9	*aP*44	$P\bar{1}$
αTi4O_7	36.9	*aP*44	$P\bar{1}$
γTi_5O_9	37.6	*aP*28	$P\bar{1}$
βTi_6O_{11}	38.0	*aC*68	$A\bar{1}$
Ti_7O_{13}	38.3	*aP*40	$P\bar{1}$
Ti_8O_{15}	38.5	*aC*92	$A\bar{1}$
Ti_9O_{17}	38.7	*aP*52	$P\bar{1}$
Rutile TiO_2	40.1	*tP*6	$P4_2/mnm$
Metastable phases			
Anatase	—	*tI*12	$I4_1/amd$
Brookite	—	*oP*24	*Pbca*
High-pressure phases			
TiO_2-II	—	*oP*12	*Pbcn*
TiO_2-III	—	*hP*~48	—

FIGURE 7

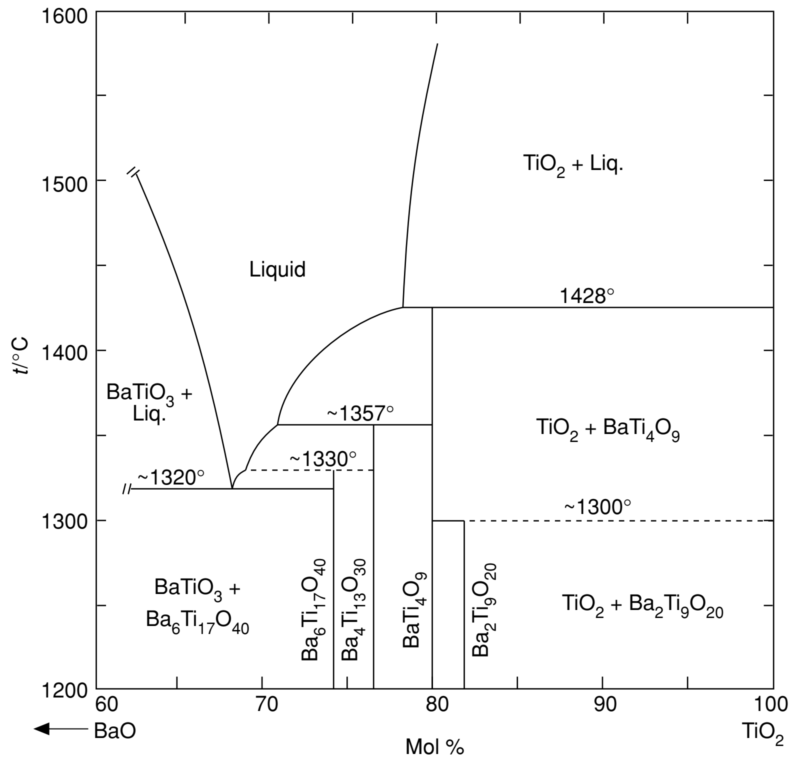


Figure 7. BaO-TiO_2 system.

Figure 8

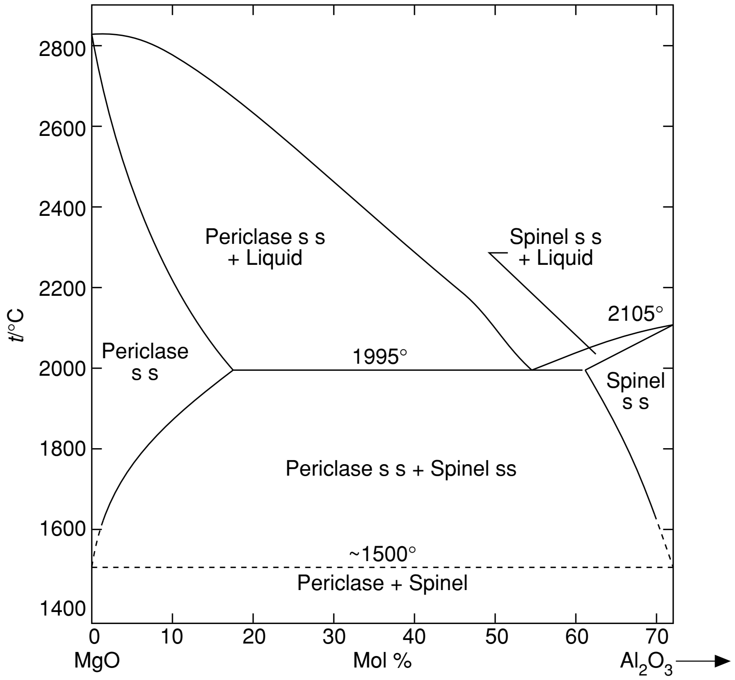


Figure 8. $MgO-Al_2O_3$ system.

Figure 9

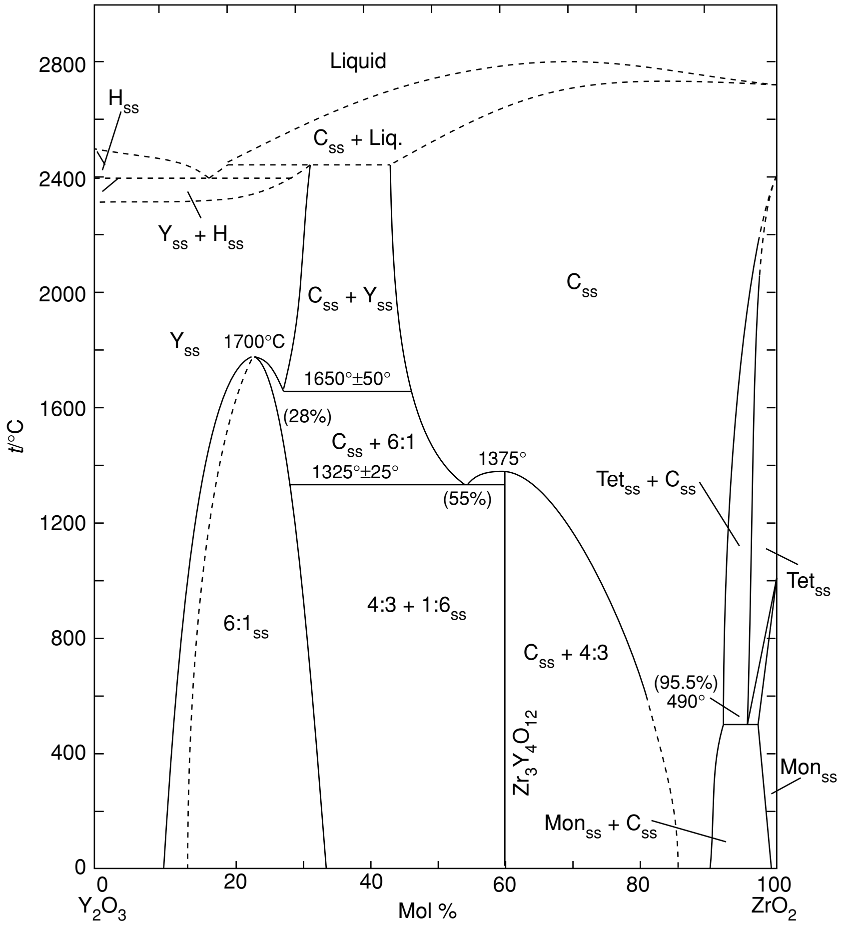


Figure 9. Y_2O_3-ZrO_2 system. C_{ss} = cubic ZrO_2 ss (fluorite-type ss); Y_{ss} = cubic Y_2O_3 ss; Tet_{ss} = tetragonal ZrO_2 ss; Mon_{ss} = monoclinic ZrO_2 ss; H_{ss} = hexagonal Y_2O_3 ss; 3:4 = $Zr_3Y_4O_{12}$; 1:6 = ZrY_6O_{11} ss.

Figure 10

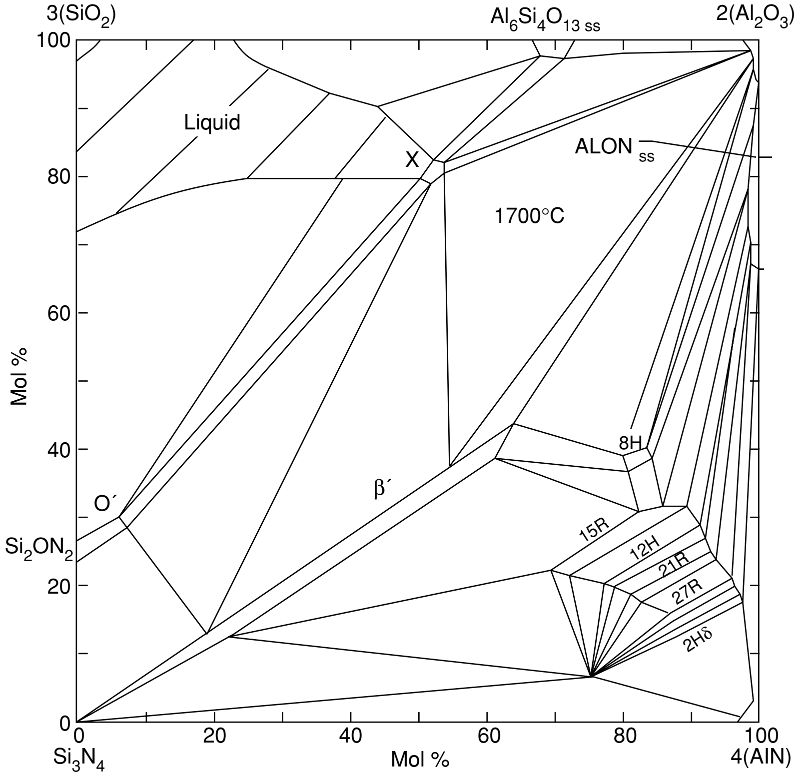


Figure 10. 3(SiO_2)-Si_3N_4-4(AlN)-2(Al_2O_3) system. "Behavior" diagram at 1700°C. The labels 8H, 15R, 12H, 21R, 27R, $2H^{\delta}$ indicate defect AlN polytypes. β′ = 3-sialon ($Si_{6-x}Al_xO_xN_{8-x}$); O′ = sialon of Si_2ON_2 type; X = $SiAlO_2N$ ("nitrogen mullite"). ALON ss = aluminum oxynitride ss extending from approximately Al_7O_9N to Al_3O_3N.

Figure 11

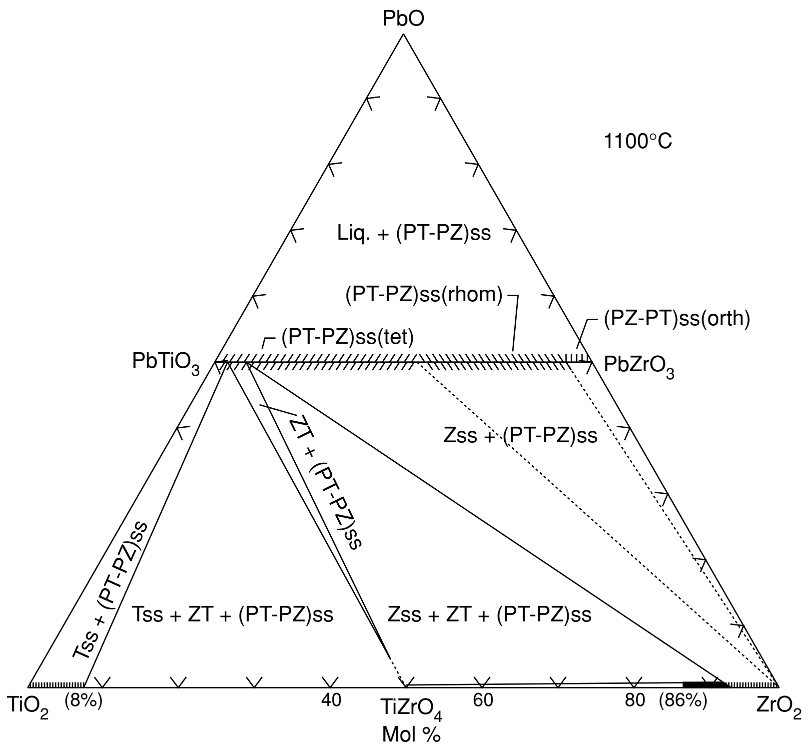


Figure 11. PbO-ZrO_2-TiO_2 (PZT) system, subsolidus at 1100°C. P = PbO; T = TiO_2; Z = ZrO_2.

Figure 12

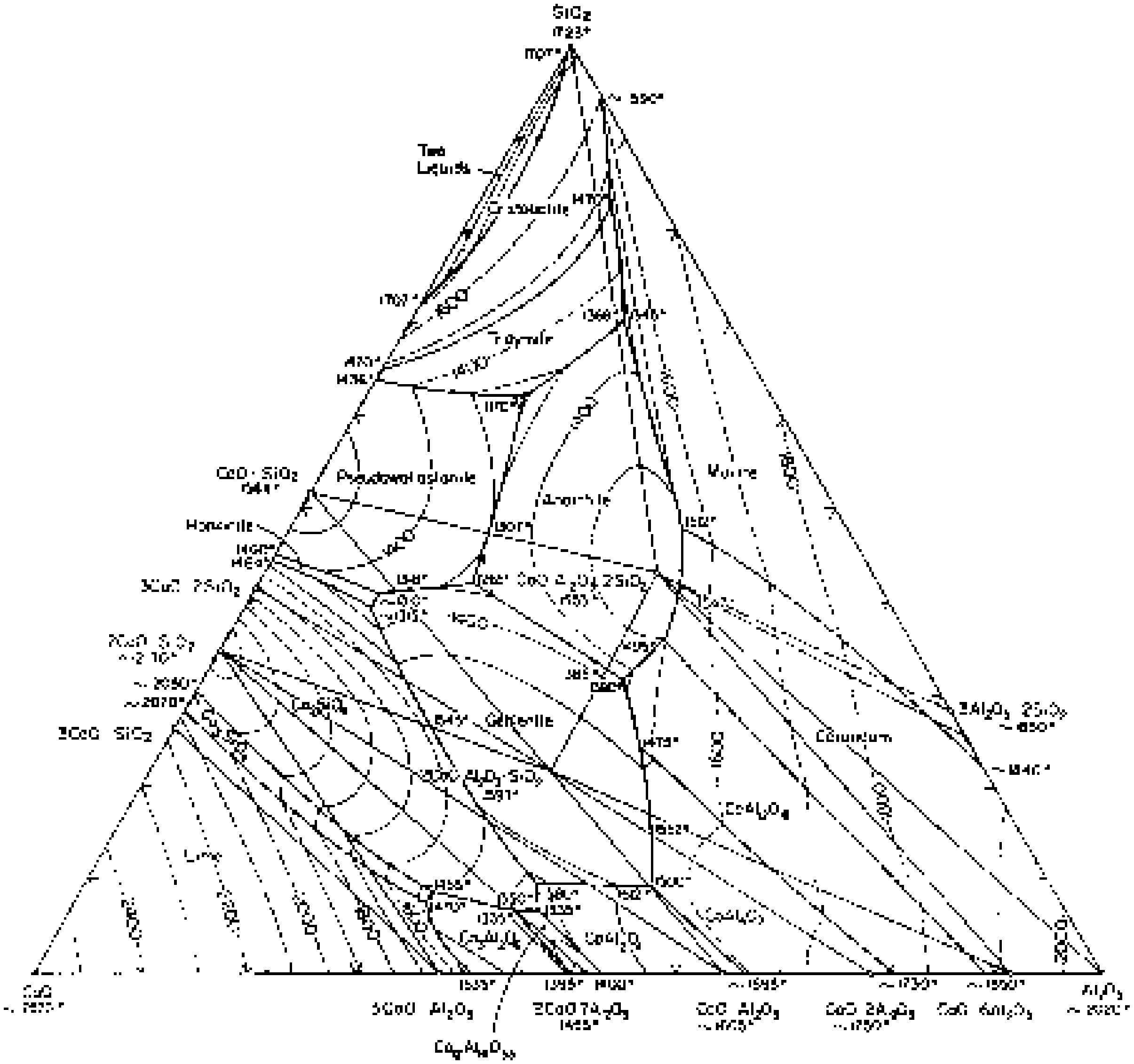


Figure 12. CaO-Al_2O_3-SiO_2 system (temperatures in °C).

Crystalline Phases

Notation	Oxide formula
Cristobalite } Tridymite	SiO_2
Pseudowollastonite	$CaO{\cdot}SiO_2$
Rankinite	$3CaO{\cdot}2SiO_2$
Lime	CaO
Corundum	Al_2O_3
Mullite	$3Al_2O_3{\cdot}2SiO_2$
Anorthite	$CaO{\cdot}Al_2O_3{\cdot}2SiO_2$
Gehlenite	$2CaO{\cdot}Al_2O_3{\cdot}SiO_2$

Temperatures up to approximately 1550°C are on the Geophysical Laboratory Scale; those above 1550°C are on the 1948 International Scale.

Figure 13

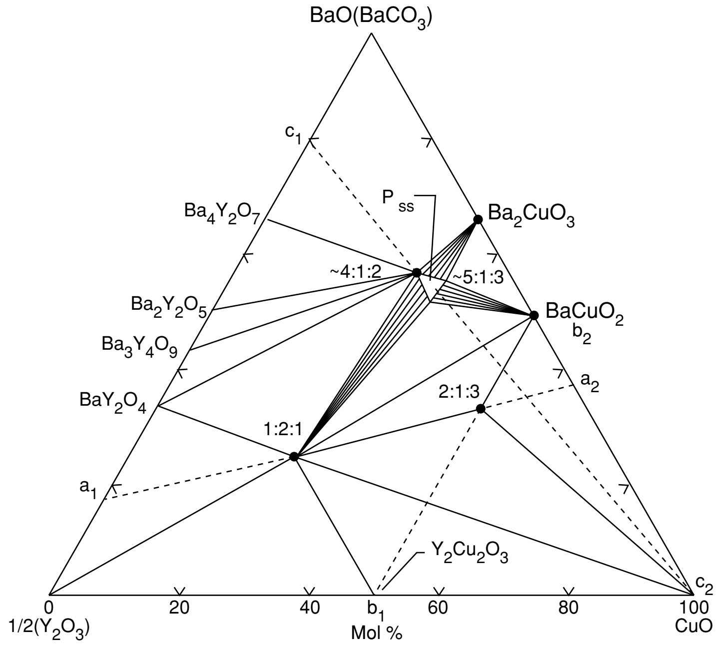


Figure 13. BaO-Y_2O_3-CuO system. 2:1:3 = $Ba_2YCu_3O_{7-x}$; 1:2:1 = BaY_2CuO_5; 4:1:2 = $Ba_4YCu_2O_{7.5+x}$; and 5:1:3 = $Ba_5YCu_3O_{9.5+x}$. The superconducting 2:1:3 phase was prepared using barium peroxide.

Figure 14

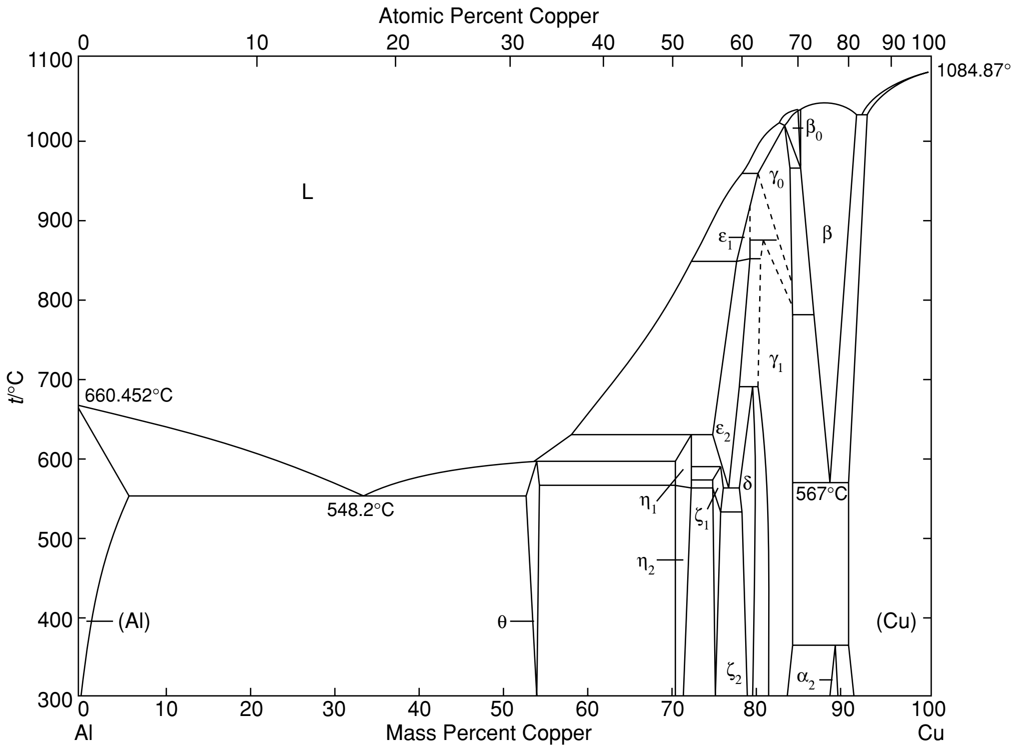


Figure 14. Al-Cu system.

Figure 14 (continued)

Phase	Composition, wt % Cu	Pearson symbol	Space group
(Al)	0 to 5.65	*cF*4	$Fm\bar{3}m$
θ	52.5 to 53.7	*tI*12	*I*4/*mcm*
η_1	70.0 to 72.2	*oP*16 or *oC*16	*Pban* or *Cmmm*
η_2	70.0 to 72.1	*mC*20	*C*2/*m*
ζ_1	74.4 to 77.8	*hP*42	*P*6/*mmm*
ζ_2	74.4 to 75.2	(a)	—
ε_1	77.5 to 79.4	(b)	—
ε_2	72.2 to 78.7	*hP*4	*P*63/*mmc*
δ	77.4 to 78.3	(c)	$R\bar{3}m$
γ_0	77.8 to 84	(d)	—
γ_1	79.7 to 84	*cP*52	$P\bar{4}3m$
β_0	83.1 to 84.7	(d)	—
β	85.0 to 91.5	*cI*2	$Im\bar{3}m$
α_2	88.5 to 89	(e)	—
(Cu)	90.6 to 100	*cF*4	$Fm\bar{3}m$
Metastable phases			
θ′	—	*tP*6	—
β′	—	*cF*16	$Fm\bar{3}m$
Al_3Cu_2	61 to 70	*hp*5	$P\bar{3}m1$

(a) Monoclinic? (b) Cubic? (c) Rhombohedral. (d) Unknown. (e) $D0_{22}$-type long-period superlattice.

Figure 15

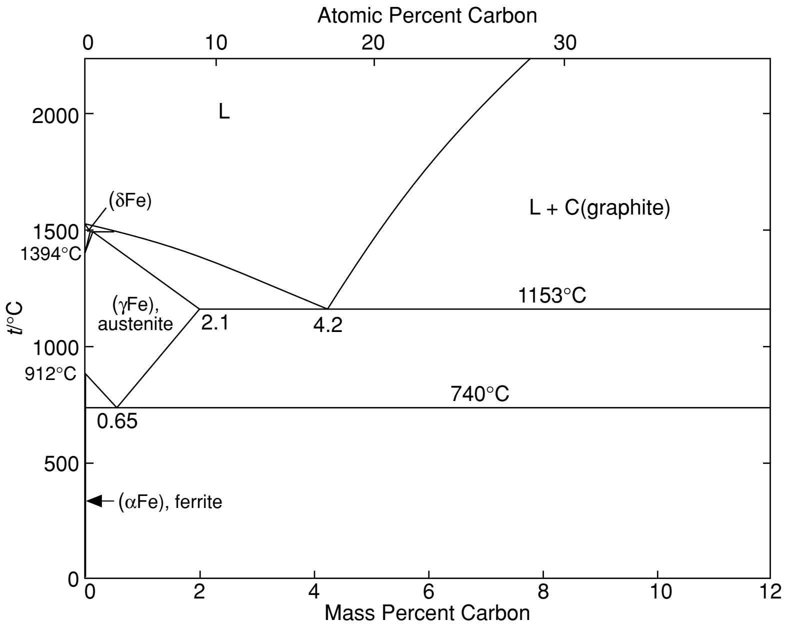


Figure 15. Fe-C system.

Phase	Composition, mass % C	Pearson symbol	Space group
(δFe)	0 to 0.09	*cI*2	$Im\bar{3}m$
(γFe)	0 to 2.1	*cF*4	$Fm\bar{3}m$
(αFe)	0 to 0.021	*cI*2	$Im\bar{3}m$
(C)	100	*hP*4	$P6_3/mmc$
Metastable/high-pressure phases			
(εFe)	0	*hP*2	$P6_3/mmc$
Martensite	< 2.1	*tI*4	*I*4/*mmm*

Figure 15 (continued)

Phase	Composition, mass % C	Pearson symbol	Space group
Fe_4C	5.1	*cP*5	$P\bar{4}3m$
Fe_3C (θ)	6.7	*oP*16	*Pnma*
Fe_5C_2 (χ)	7.9	*mC*28	*C*2/*c*
Fe_7C_3	8.4	*hP*20	$P6_3mc$
Fe_7C_3	8.4	*oP*40	*Pnma*
Fe_2C (η)	9.7	*oP*6	*Pnnm*
Fe_2C (ε)	9.7	*hP**	$P6_322$
Fe_2C	9.7	*hP**	$P\bar{3}m1$
(C)	100	*cF*8	$Fd\bar{3}m$

Figure 16

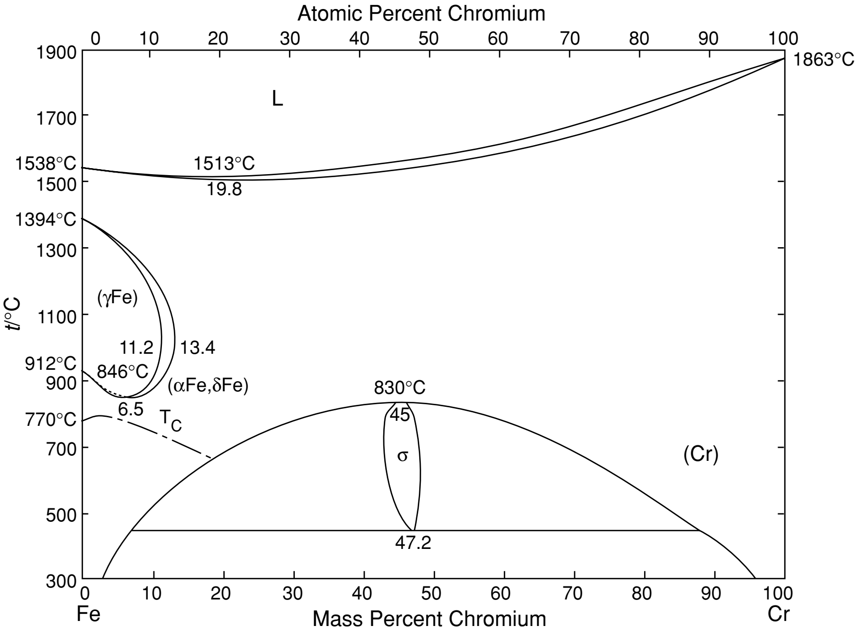


Figure 16. Fe-Cr system.

Phase	Composition, mass % Cr	Pearson symbol	Space group
(aFe, Cr)	0 to 100	*cI*2	$Im\bar{3}m$
(γFe)	0 to 11.2	*cF*4	$Fm\bar{3}m$
σ	42.7 to 48.2	*tP*30	$P4_2/mnm$

Figure 17

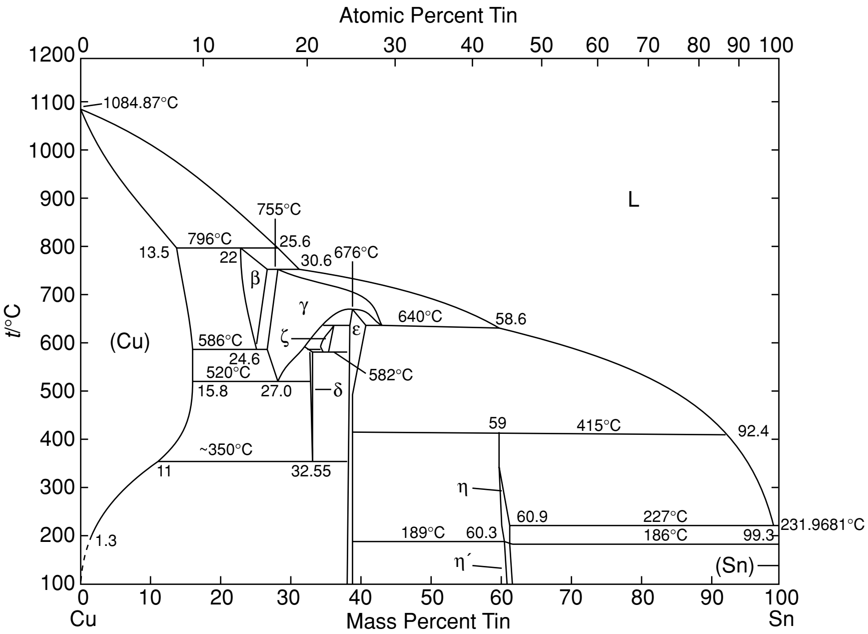


Figure 17. Cu-Sn system.

Phase	Composition, mass % Sn	Pearson symbol	Space group
α	0 to 15.8	*cF*4	$Fm\bar{3}m$
β	22.0 to 27.0	*cI*2	$Im\bar{3}m$
γ	25.5 to 41.5	*cF*16	$Fm\bar{3}m$
δ	32 to 33	*cF*416	$F\bar{4}3m$
ζ	32.2 to 35.2	*hP*26	$P6_3$
ε	27.7 to 39.5	*oC*80	*Cmcm*
η	59.0 to 60.9	*hP*4	$P6_3/mmc$
η′	44.8 to 60.9	(a)	—
(βSn)	~100	*tI*4	$I4_1/amd$
(αSn)	100	*cF*8	$Fd\bar{3}m$

(a) Hexagonal; superlattice based on NiAs-type structure.

Figure 18

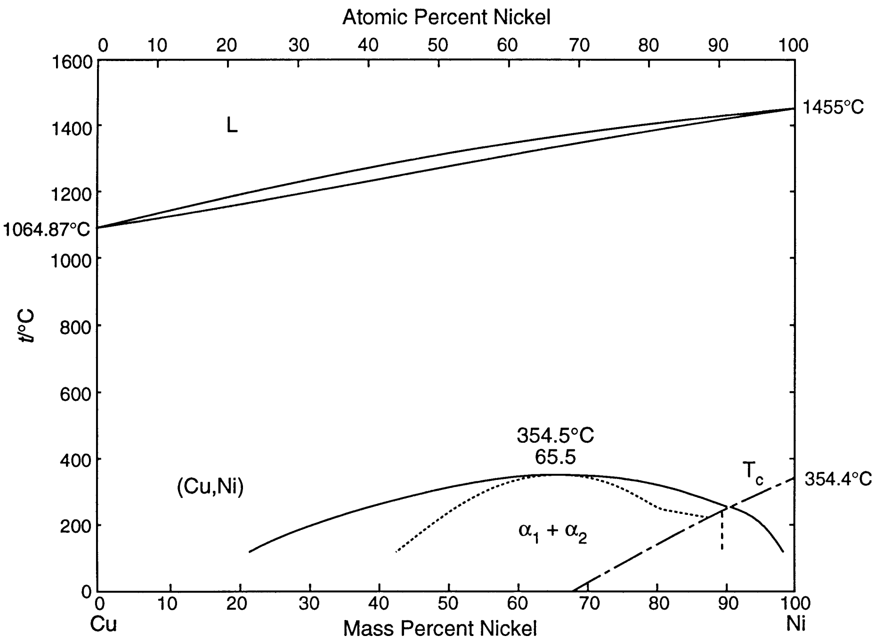


Figure 18. Cu-Ni system.

Phase	Composition, mass % Ni	Pearson symbol	Space group
(Cu, Ni) (above 354.5°C)	0 to 100	*cF*4	$Fm\bar{3}m$

Figure 19

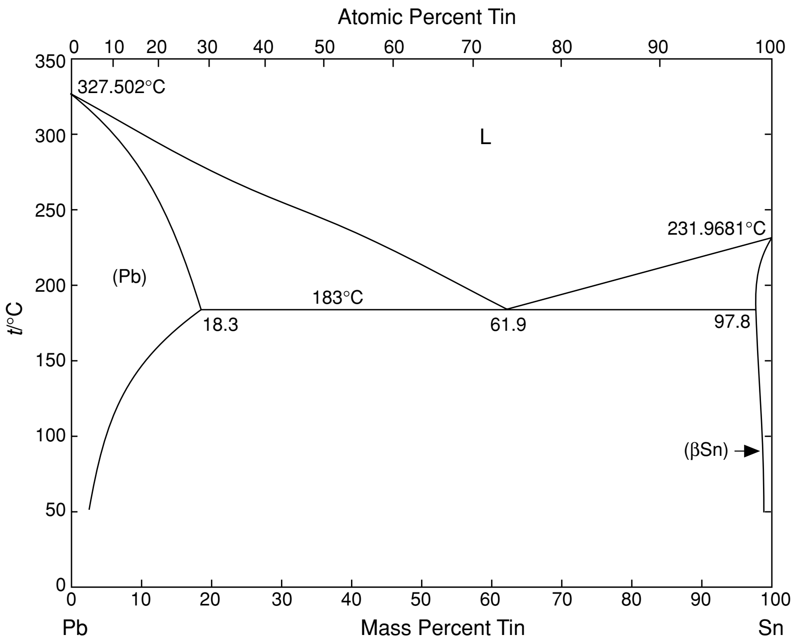


Figure 19. Pb-Sn system.

Figure 19 (continued)

Phase	Composition, mass % Sn	Pearson symbol	Space group
(Pb)	0 to 18.3	*cF*4	$Fm\bar{3}m$
(βSn)	97.8 to 100	*tI*4	$I4_1/amd$
(αSn)	100	*cF*8	$Fd\bar{3}m$
High-pressure phases			
ε(a)	52 to 74	*hP*1	*P*6/*mmm*
ε′(b)	52	*hP*2	$P6_3/mmc$

(a) From phase diagram calculated at 2500 MPa. (b) This phase was claimed for alloys at 350°C and 5500 MPa.

Figure 20

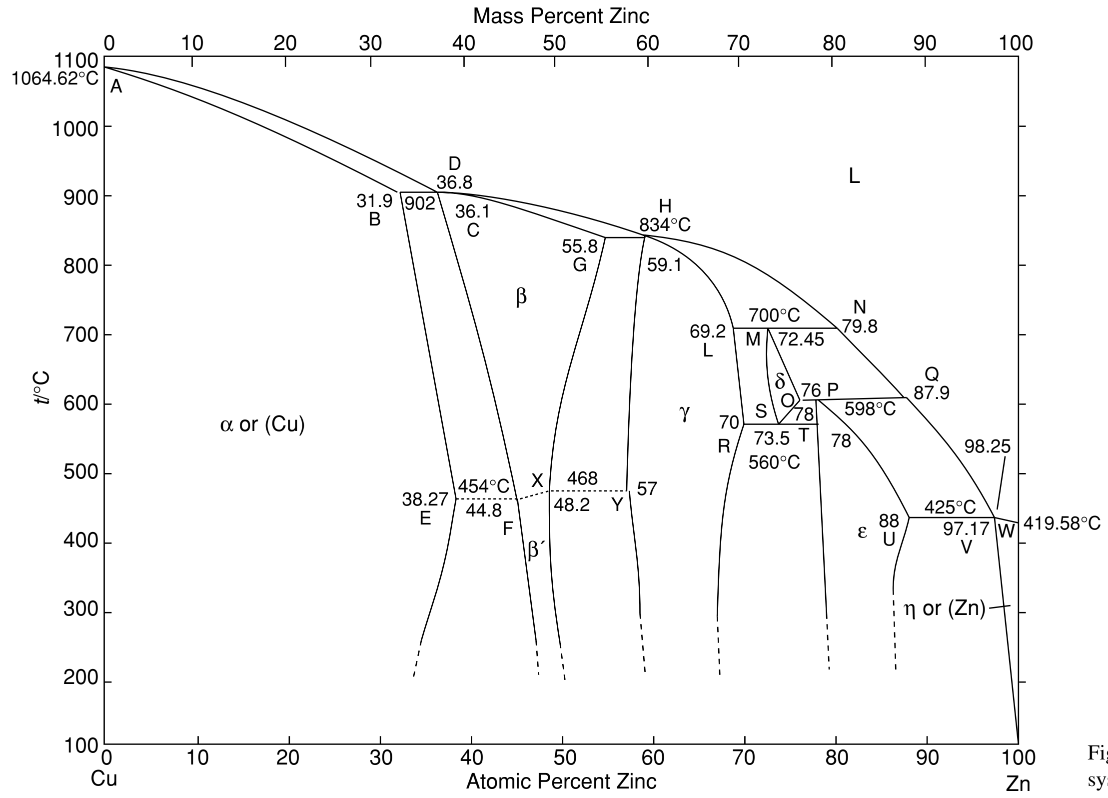


Figure 20. Cu-Zn system.

Phase	Composition, mass % Zn	Pearson symbol	Space group
α or (Cu)	0 to 38.95	*cF*4	$Fm\bar{3}m$
β	36.8 to 56.5	*cI*2	$Im\bar{3}m$
β′	45.5 to 50.7	*cP*2	$Pm\bar{3}m$
γ	57.7 to 70.6	*cI*52	$I\bar{4}3m$
δ	73.02 to 76.5	*hP*3	$P\bar{6}$
ε	78.5 to 88.3	*hP*2	$P6_3/mmc$
η or (Zn)	97.25 to 100	*hP*2	$P6_3/mmc$

Figure 21

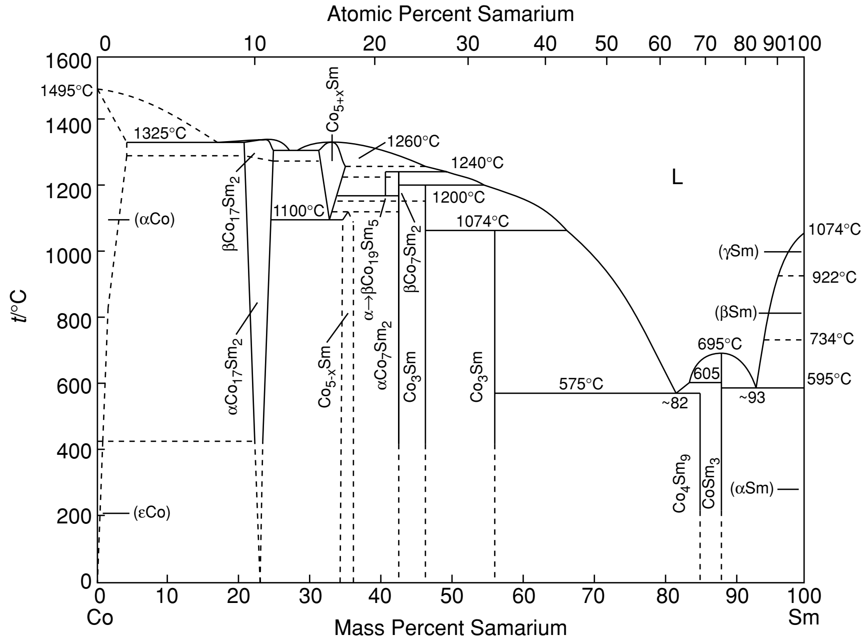


Figure 21. Co-Sm system.

Phase	Composition, mass % Sm	Pearson symbol	Space group
(αCo)	0 to ~3.7	*cF*4	$Fm\bar{3}m$
(εCo)	~0	*hP*2	$P6_3/mmc$
$\beta Co_{17}Sm_2$	~23.0	*hP*38	$P6_3/mmc$
$\alpha Co_{17}Sm_2$	~23.0	*hR*19	$R\bar{3}m$
		*hP*8	$P6/mmm$
$Co_{5+x}Sm$	~33 to 34	—	—
$Co_{5-x}Sm$	~34 to 35	—	—
$Co_{19}Sm_5$	~40.1	*hR*24	$R\bar{3}m$
		*hP*48	$P6_3/mmc$
αCo_7Sm_2	~42.1	*hR*18	$R\bar{3}m$
βCo_7Sm_2	~42.1	*hP*36	$P6_3/mmc$
Co_3Sm	46	*hR*12	$R\bar{3}m$
Co_2Sm	56.0	*hR*4	$R\bar{3}m$
		*cF*24	$Fd\bar{3}m$
Co_4Sm_9	~85.1	*o***	—
$CoSm_3$	88	*oP*16	$Pnma$
(γSm)	~100	*cI*2	$Im\bar{3}m$
(βSm)	~100	*hP*2	$P6_3/mmc$
(αSm)	~100	*hR*3	$R\bar{3}m$
Other reported phases			
Co_5Sm	~33.8	*hP*6	$P6/mmm$
Co_2Sm_5	~86.4	*mC*28	$C2/c$

Figure 22

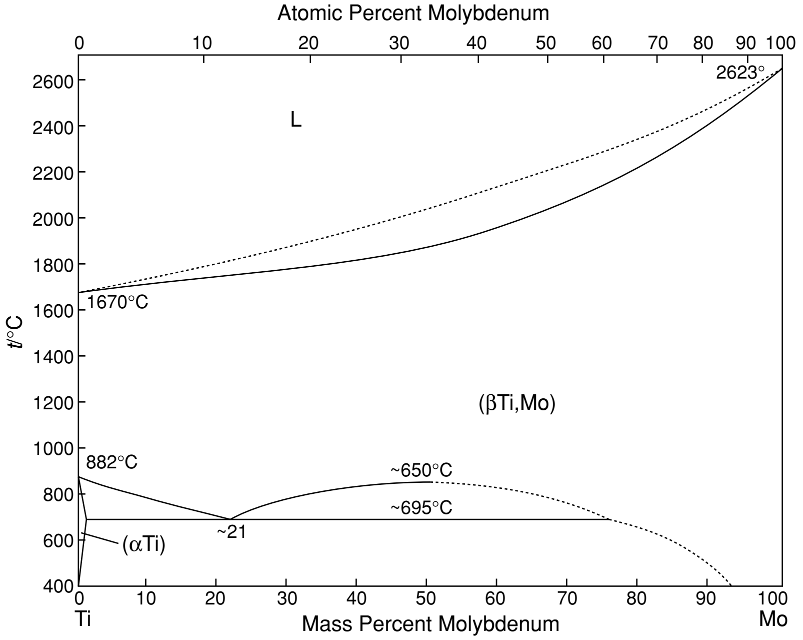
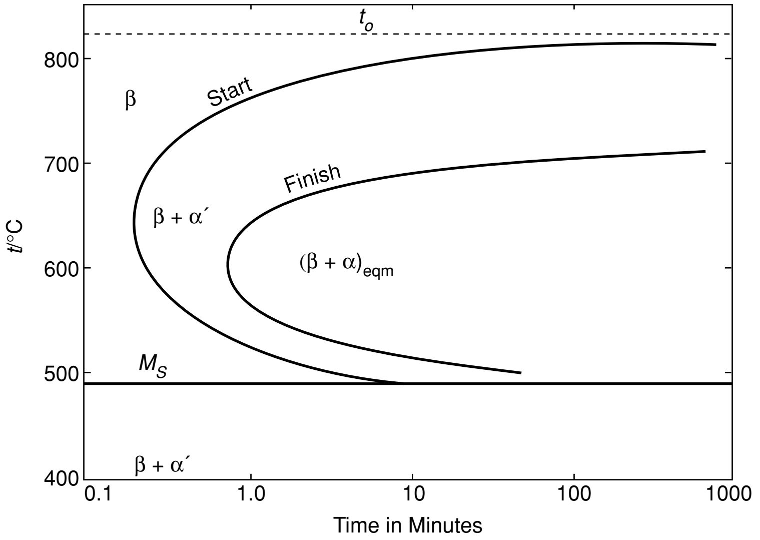


Figure 22. Ti-Mo system.

Phase	Composition, mass % Mo	Pearson symbol	Space group
(βTi, Mo)	0 to 100	*cI*2	$Im\bar{3}m$
(αTi)	0 to 0.8	*hP*2	$P6_3/mmc$
α′	(a)	*hP*2	$P6_3/mmc$
α″	(a)	*oC*4	*Cmcm*
ω	(a)	*hP*3	*P*6/*mmm*

(a) Metastable.



Experimental time-temperature-transformation (TTT) diagram for Ti-Mo. The start and finish times of the isothermal precipitation reaction vary with temperature as a result of the temperature dependence of the nucleation and growth processes. Precipitation is complete, at any temperature, when the equilibrium fraction of α is established in accordance with the lever rule. The solid horizontal line represents the athermal (or nonthermally activated) martensitic transformation that occurs when the β phase is quenched.

Figure 23

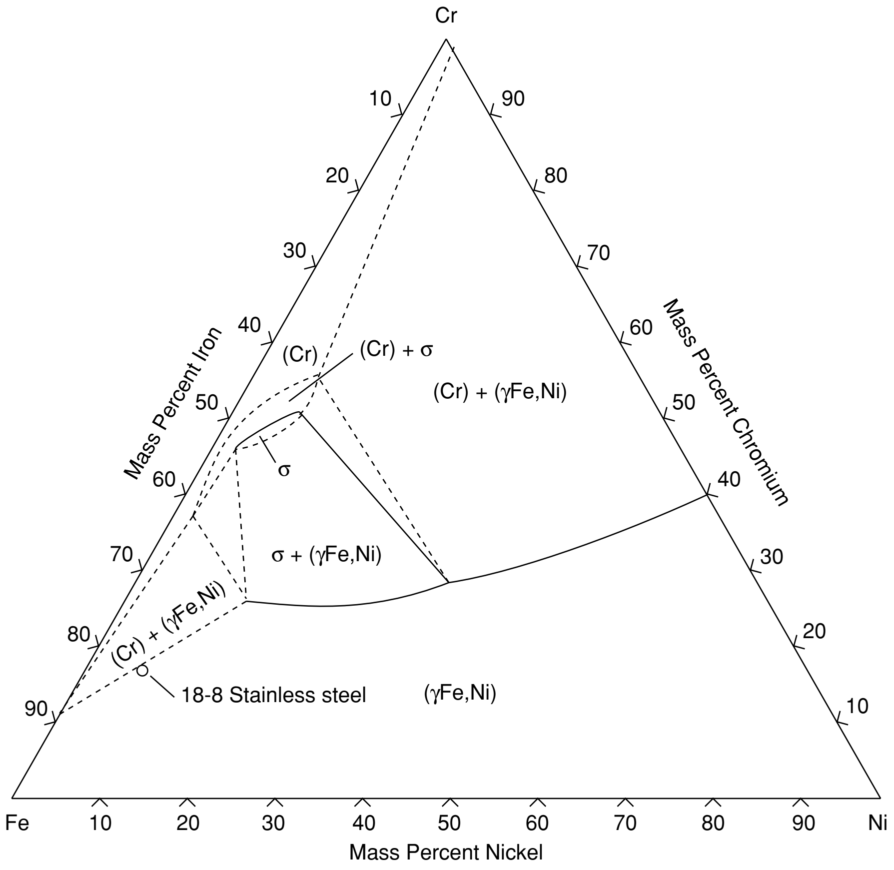


Figure 23. The isothermal section at 900°C (1652°F) of the iron-chromium-nickel ternary phase diagram, showing the nominal composition of 18-8 stainless steel.

Figure 13

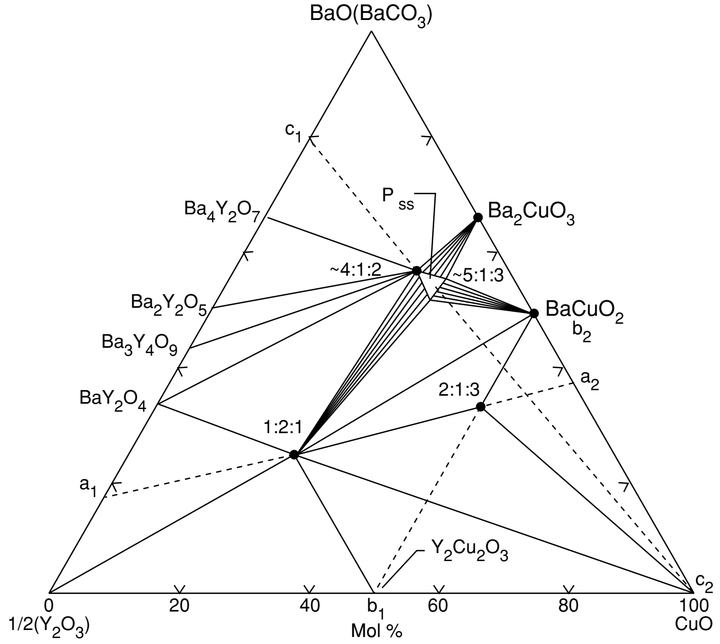


Figure 13. BaO-Y_2O_3-CuO system. 2:1:3 = $Ba_2YCu_3O_{7-x}$; 1:2:1 = BaY_2CuO_5; 4:1:2 = $Ba_4YCu_2O_{7.5+x}$; and 5:1:3 = $Ba_5YCu_3O_{9.5+x}$. The superconducting 2:1:3 phase was prepared using barium peroxide.

Figure 14

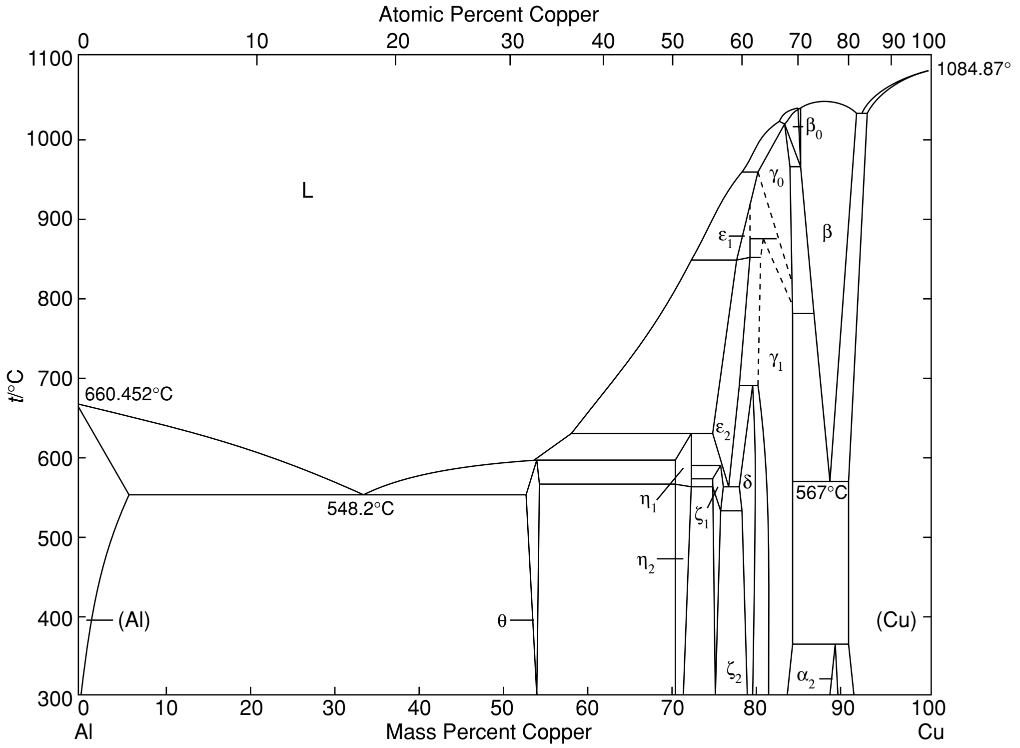


Figure 14. Al-Cu system.

Figure 14 (continued)

Phase	Composition, wt % Cu	Pearson symbol	Space group
(Al)	0 to 5.65	*cF*4	$Fm\bar{3}m$
θ	52.5 to 53.7	*tI*12	*I*4/*mcm*
η_1	70.0 to 72.2	*oP*16 or *oC*16	*Pban* or *Cmmm*
η_2	70.0 to 72.1	*mC*20	*C*2/*m*
ζ_1	74.4 to 77.8	*hP*42	*P*6/*mmm*
ζ_2	74.4 to 75.2	(a)	—
ε_1	77.5 to 79.4	(b)	—
ε_2	72.2 to 78.7	*hP*4	*P*63/*mmc*
δ	77.4 to 78.3	(c)	$R\bar{3}m$
γ_0	77.8 to 84	(d)	—
γ_1	79.7 to 84	*cP*52	$P\bar{4}3m$
β_0	83.1 to 84.7	(d)	—
β	85.0 to 91.5	*cI*2	$Im\bar{3}m$
α_2	88.5 to 89	(e)	—
(Cu)	90.6 to 100	*cF*4	$Fm\bar{3}m$
Metastable phases			
θ′	—	*tP*6	—
β′	—	*cF*16	$Fm\bar{3}m$
Al_3Cu_2	61 to 70	*hp*5	$P\bar{3}m1$

(a) Monoclinic? (b) Cubic? (c) Rhombohedral. (d) Unknown. (e) $D0_{22}$-type long-period superlattice.

Figure 15

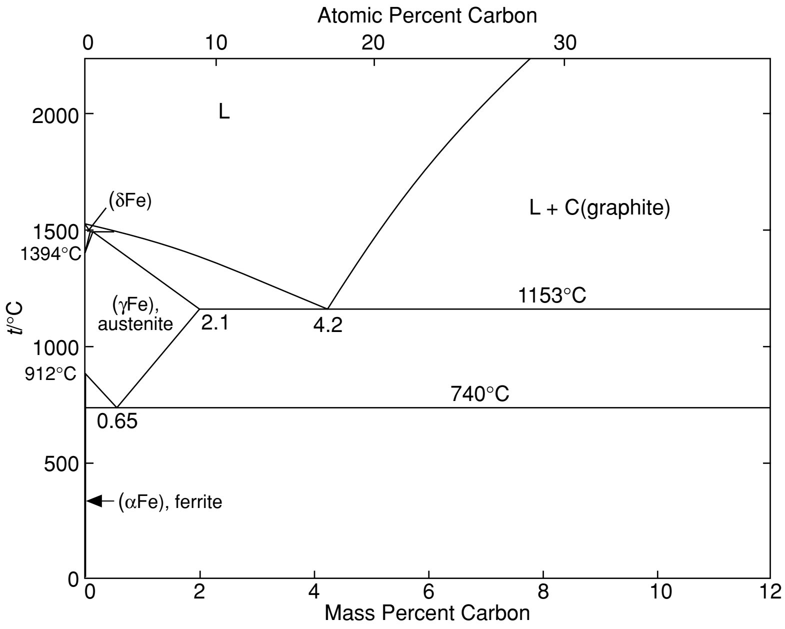


Figure 15. Fe-C system.

Phase	Composition, mass % C	Pearson symbol	Space group
(δFe)	0 to 0.09	*cI*2	$Im\bar{3}m$
(γFe)	0 to 2.1	*cF*4	$Fm\bar{3}m$
(αFe)	0 to 0.021	*cI*2	$Im\bar{3}m$
(C)	100	*hP*4	$P6_3/mmc$
Metastable/high-pressure phases			
(εFe)	0	*hP*2	$P6_3/mmc$
Martensite	< 2.1	*tI*4	*I*4/*mmm*

Figure 15 (continued)

Phase	Composition, mass % C	Pearson symbol	Space group
Fe_4C	5.1	*cP*5	$P\bar{4}3m$
Fe_3C (θ)	6.7	*oP*16	*Pnma*
Fe_5C_2 (χ)	7.9	*mC*28	*C*2/*c*
Fe_7C_3	8.4	*hP*20	$P6_3mc$
Fe_7C_3	8.4	*oP*40	*Pnma*
Fe_2C (η)	9.7	*oP*6	*Pnnm*
Fe_2C (ε)	9.7	*hP**	$P6_322$
Fe_2C	9.7	*hP**	$P\bar{3}m1$
(C)	100	*cF*8	$Fd\bar{3}m$

Figure 16

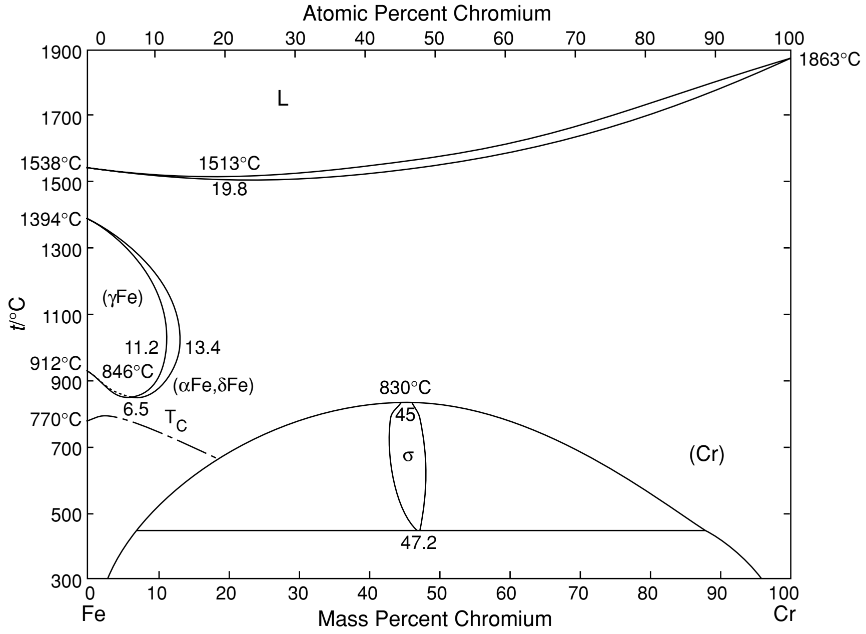


Figure 16. Fe-Cr system.

Phase	Composition, mass % Cr	Pearson symbol	Space group
(aFe, Cr)	0 to 100	*cI*2	$Im\bar{3}m$
(γFe)	0 to 11.2	*cF*4	$Fm\bar{3}m$
σ	42.7 to 48.2	*tP*30	$P4_2/mnm$

Figure 17

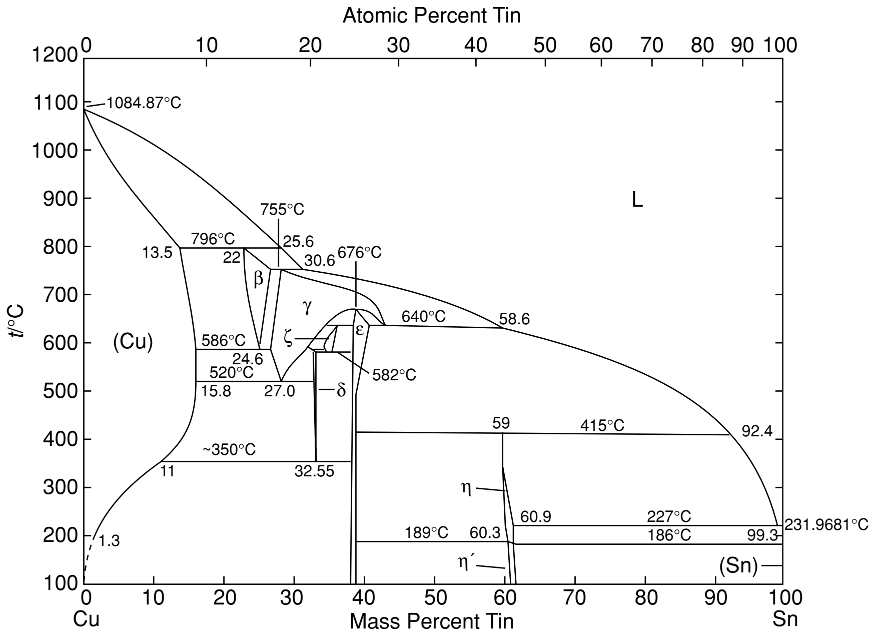


Figure 17. Cu-Sn system.

Phase	Composition, mass % Sn	Pearson symbol	Space group
α	0 to 15.8	*cF*4	$Fm\bar{3}m$
β	22.0 to 27.0	*cI*2	$Im\bar{3}m$
γ	25.5 to 41.5	*cF*16	$Fm\bar{3}m$
δ	32 to 33	*cF*416	$F\bar{4}3m$
ζ	32.2 to 35.2	*hP*26	$P6_3$
ε	27.7 to 39.5	*oC*80	*Cmcm*
η	59.0 to 60.9	*hP*4	$P6_3/mmc$
η′	44.8 to 60.9	(a)	—
(βSn)	~100	*tI*4	$I4_1/amd$
(αSn)	100	*cF*8	$Fd\bar{3}m$

(a) Hexagonal; superlattice based on NiAs-type structure.

Figure 18

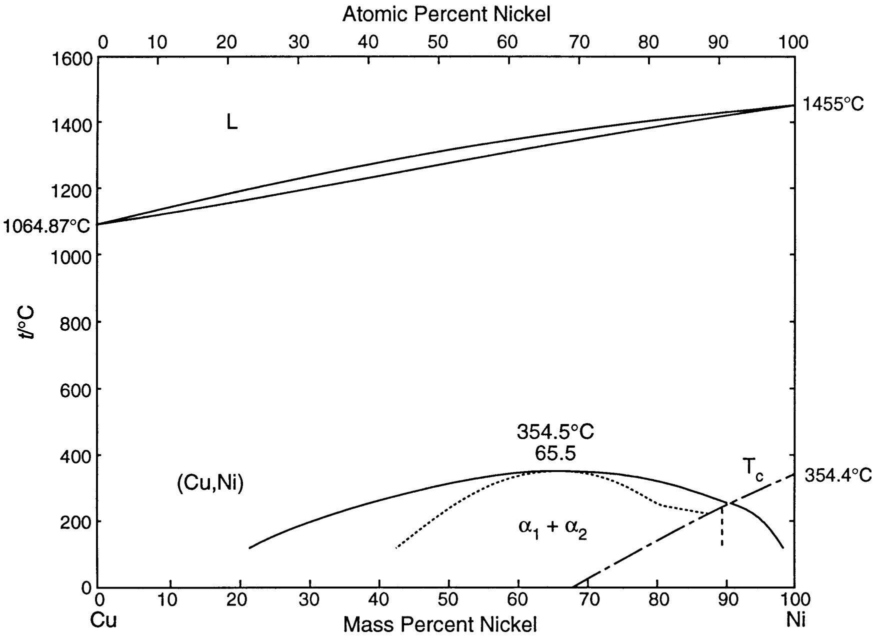


Figure 18. Cu-Ni system.

Phase	Composition, mass % Ni	Pearson symbol	Space group
(Cu, Ni) (above 354.5°C)	0 to 100	*cF*4	$Fm\bar{3}m$

Figure 19

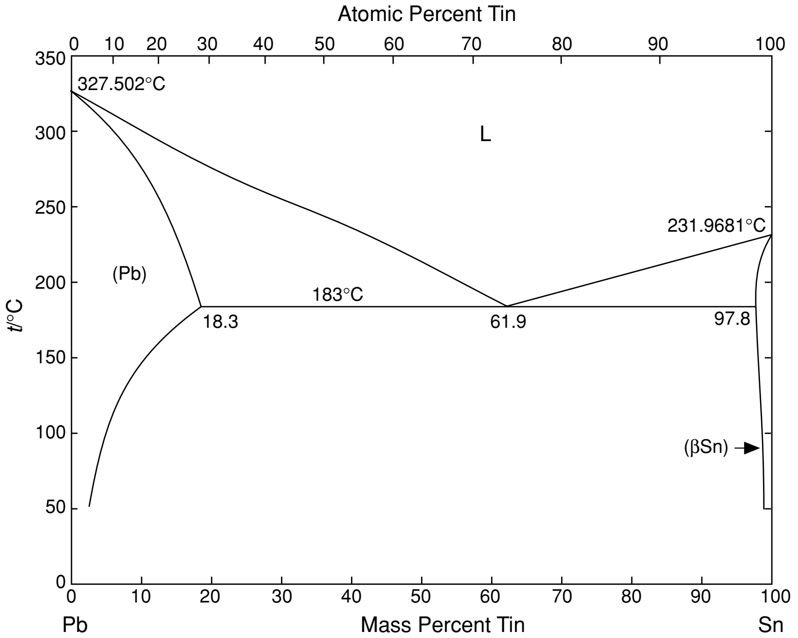


Figure 19. Pb-Sn system.

Figure 19 (continued)

Phase	Composition, mass % Sn	Pearson symbol	Space group
(Pb)	0 to 18.3	*cF*4	$Fm\bar{3}m$
(βSn)	97.8 to 100	*tI*4	$I4_1/amd$
(αSn)	100	*cF*8	$Fd\bar{3}m$
High-pressure phases			
ε(a)	52 to 74	*hP*1	*P*6/*mmm*
ε′(b)	52	*hP*2	$P6_3/mmc$

(a) From phase diagram calculated at 2500 MPa. (b) This phase was claimed for alloys at 350°C and 5500 MPa.

Figure 20

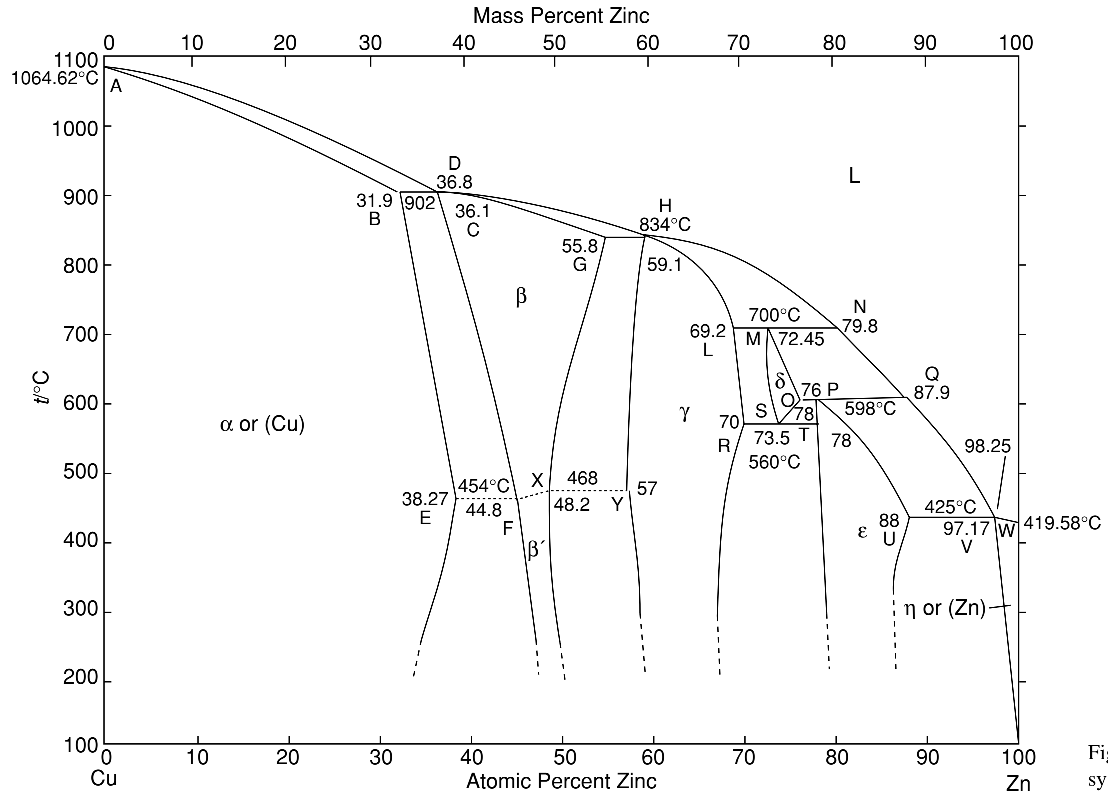


Figure 20. Cu-Zn system.

Phase	Composition, mass % Zn	Pearson symbol	Space group
α or (Cu)	0 to 38.95	*cF*4	$Fm\bar{3}m$
β	36.8 to 56.5	*cI*2	$Im\bar{3}m$
β′	45.5 to 50.7	*cP*2	$Pm\bar{3}m$
γ	57.7 to 70.6	*cI*52	$I\bar{4}3m$
δ	73.02 to 76.5	*hP*3	$P\bar{6}$
ε	78.5 to 88.3	*hP*2	$P6_3/mmc$
η or (Zn)	97.25 to 100	*hP*2	$P6_3/mmc$

Figure 21

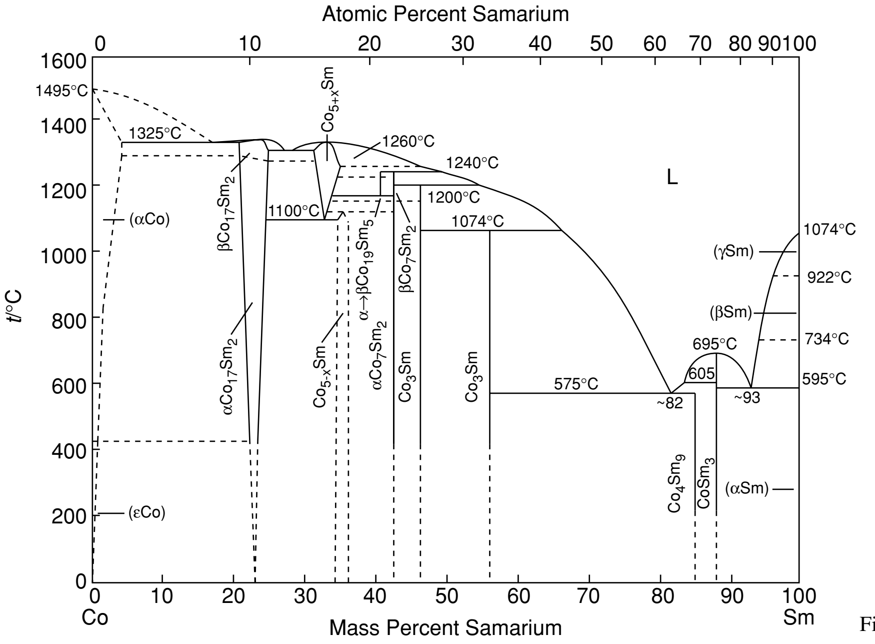


Figure 21. Co-Sm system.

Phase	Composition, mass % Sm	Pearson symbol	Space group
(αCo)	0 to ~3.7	*cF*4	$Fm\bar{3}m$
(εCo)	~0	*hP*2	$P6_3/mmc$
$\beta Co_{17}Sm_2$	~23.0	*hP*38	$P6_3/mmc$
$\alpha Co_{17}Sm_2$	~23.0	*hR*19	$R\bar{3}m$
		*hP*8	$P6/mmm$
$Co_{5+x}Sm$	~33 to 34	—	—
$Co_{5-x}Sm$	~34 to 35	—	—
$Co_{19}Sm_5$	~40.1	*hR*24	$R\bar{3}m$
		*hP*48	$P6_3/mmc$
αCo_7Sm_2	~42.1	*hR*18	$R\bar{3}m$
βCo_7Sm_2	~42.1	*hP*36	$P6_3/mmc$
Co_3Sm	46	*hR*12	$R\bar{3}m$
Co_2Sm	56.0	*hR*4	$R\bar{3}m$
		*cF*24	$Fd\bar{3}m$
Co_4Sm_9	~85.1	*o***	—
$CoSm_3$	88	*oP*16	*Pnma*
(γSm)	~100	*cI*2	$Im\bar{3}m$
(βSm)	~100	*hP*2	$P6_3/mmc$
(αSm)	~100	*hR*3	$R\bar{3}m$
Other reported phases			
Co_5Sm	~33.8	*hP*6	$P6/mmm$
Co_2Sm_5	~86.4	*mC*28	$C2/c$

Figure 22

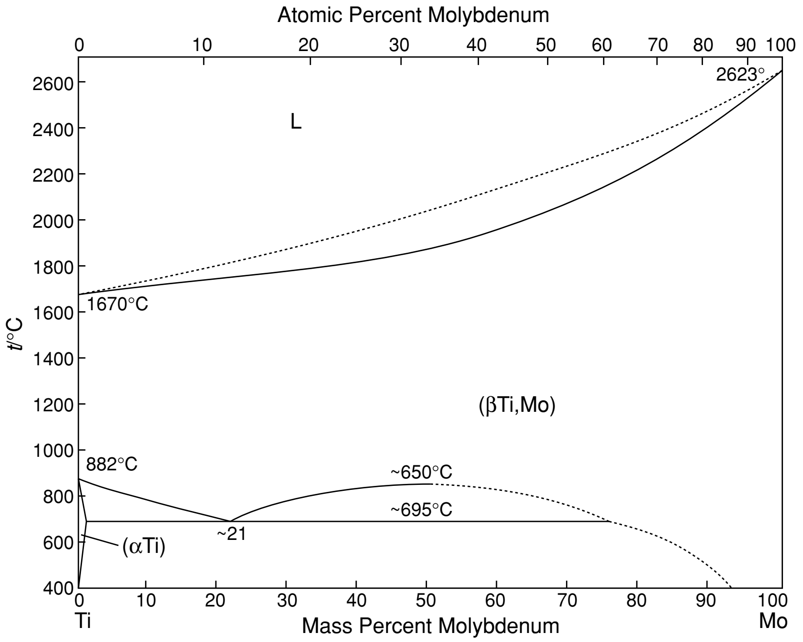
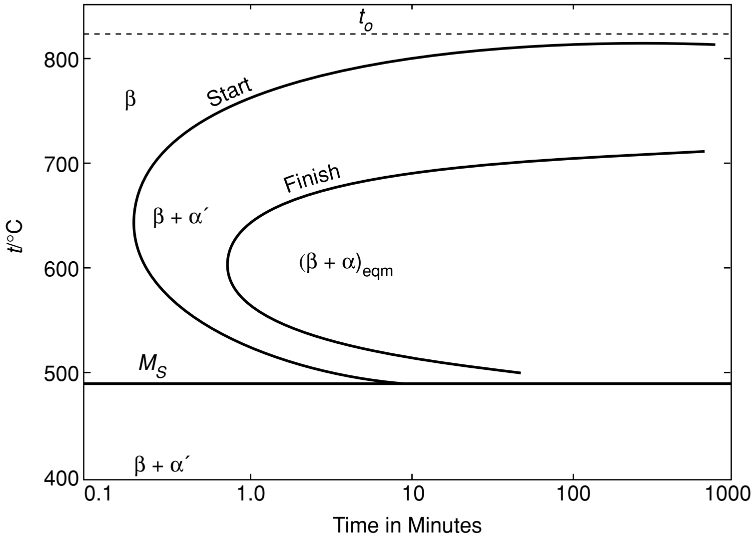


Figure 22. Ti-Mo system.

Phase	Composition, mass % Mo	Pearson symbol	Space group
(βTi, Mo)	0 to 100	*cI*2	$Im\bar{3}m$
(αTi)	0 to 0.8	*hP*2	$P6_3/mmc$
α′	(a)	*hP*2	$P6_3/mmc$
α″	(a)	*oC*4	*Cmcm*
ω	(a)	*hP*3	*P*6/*mmm*

(a) Metastable.



Experimental time-temperature-transformation (TTT) diagram for Ti-Mo. The start and finish times of the isothermal precipitation reaction vary with temperature as a result of the temperature dependence of the nucleation and growth processes. Precipitation is complete, at any temperature, when the equilibrium fraction of α is established in accordance with the lever rule. The solid horizontal line represents the athermal (or nonthermally activated) martensitic transformation that occurs when the β phase is quenched.

Figure 23

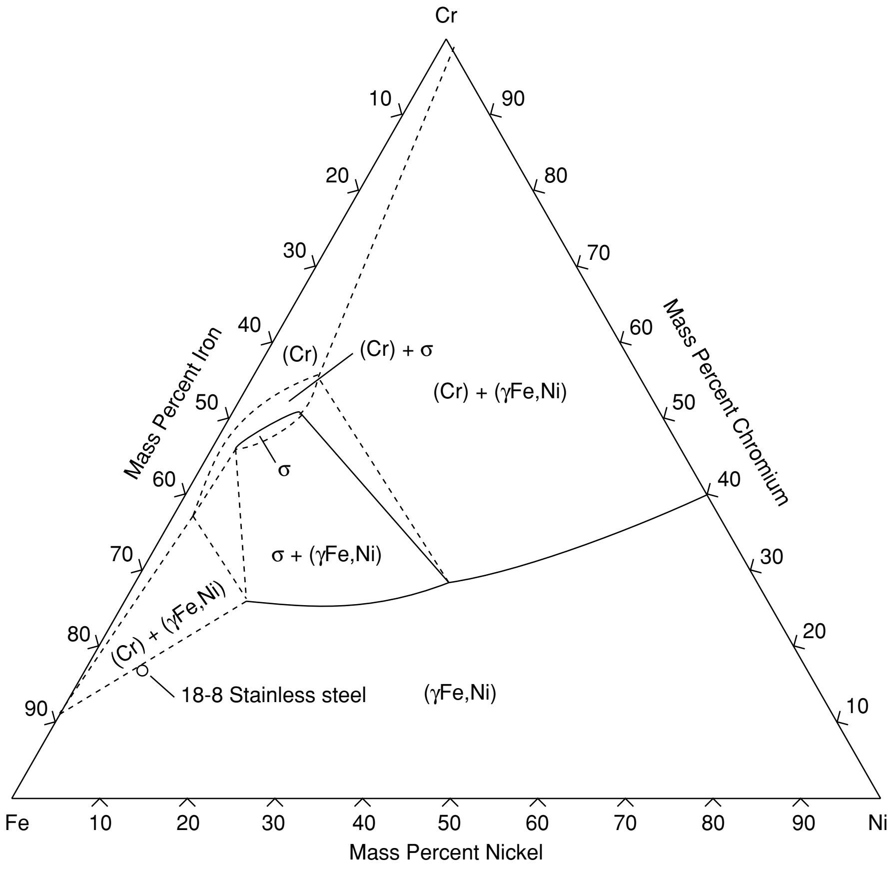


Figure 23. The isothermal section at 900°C (1652°F) of the iron-chromium-nickel ternary phase diagram, showing the nominal composition of 18-8 stainless steel.

HEAT CAPACITY OF SELECTED SOLIDS

This table gives the molar heat capacity at constant pressure of representative metals, semiconductors, and other crystalline solids as a function of temperature in the range 200 to 600 K.

REFERENCES

1. Chase, M. W., et al., *JANAF Thermochemical Tables, 3rd ed., J. Phys. Chem. Ref. Data,* 14, Suppl. 1, 1985.
2. Garvin, D., Parker, V. B., and White, H. J., *CODATA Thermodynamic Tables,* Hemisphere Press, New York, 1987.
3. DIPPR Database of Pure Compound Properties, Design Institute for Physical Properties Data, American Institute of Chemical Engineers, New York, 1987.

	C_p in J/mol K						
Name	**200 K**	**250 K**	**300 K**	**350 K**	**400 K**	**500 K**	**600 K**
Aluminum	21.33	23.08	24.25	25.11	25.78	26.84	27.89
Aluminum oxide	51.12	67.05	79.45	88.91	96.14	106.17	112.55
Anthracene	138.6	173.9	210.7	248.8	288.4		
Benzoic acid	102.7	123.5	147.4	172.0			
Beryllium	9.98	13.58	16.46	18.53	19.95	21.94	23.34
Biphenyl	131.0	162.5	197.2				
Boron	5.99	8.82	11.40	13.65	15.69	18.72	20.78
Calcium	24.54	25.41	25.94	26.32	26.87	28.49	30.38
Calcium carbonate	66.50	75.66	83.82	91.51	96.97	104.52	109.86
Calcium oxide	33.64	38.59	42.18	45.07	46.98	49.33	50.72
Cesium chloride	50.13	51.34	52.48	53.58	54.68	56.90	59.10
Chromium	19.86	22.30	23.47	24.39	25.23	26.63	27.72
Cobalt	22.23	23.98	24.83	25.68	26.53	28.20	29.66
Copper	22.63	23.77	24.48	24.95	25.33	25.91	26.48
Copper oxide	34.80		42.41	44.95	46.78	49.19	50.83
Copper sulfate	77.01	89.25	99.25	107.65	114.93	127.19	136.31
Germanium			23.25	23.85	24.31	24.96	25.45
Gold			25.41	25.37	25.51	26.06	26.65
Graphite	5.01	6.82	8.58	10.24	11.81	14.62	16.84
Hexachlorobenzene	162.7	183.6	202.4				
Iodine	51.57	53.24	54.51	58.60			
Iron	21.59	23.74	25.15	26.28	27.39	29.70	32.05
Lead	25.87	26.36	26.85	27.30	27.72	28.55	29.40
Lithium	21.57	23.42	24.64	25.96	27.60	29.28	
Lithium chloride	43.35	46.08	48.10	49.66	50.97	53.34	55.59
Magnesium	22.72	24.02	24.90	25.57	26.14	27.17	28.18
Magnesium oxide			37.38	40.59	42.77	45.56	47.30
Manganese	23.05	24.95	26.35	27.52	28.53	30.29	31.90
Naphthalene	105.8	134.1	167.8	204.1			
Potassium	27.00	28.01	29.60				
Potassium chloride	48.44	50.10	51.37	52.31	53.08	54.71	56.35
Silicon	15.64	18.22	20.04	21.28	22.14	23.33	24.15
Silicon dioxide	32.64	39.21	44.77	49.47	53.43	59.64	64.42
Silver			25.36	25.55	25.79	26.36	26.99
Sodium	22.45	27.01	28.20	30.14			
Sodium chloride	46.89	48.85	50.21	51.25	52.14	53.96	55.81
Tantalum	24.08	24.86	25.31	25.60	25.84	26.35	26.84
Titanium	22.37	24.07	25.28	26.17	26.86	27.88	28.60
Tungsten	22.49	23.69	24.30	24.65	24.92	25.36	25.79
Vanadium	21.88	23.70	24.93	25.68	26.23	26.94	27.49
Zinc	24.05	25.02	25.45	25.88	26.35	27.39	28.59
Zirconium	23.87	24.69	25.22	25.61	25.93	26.56	27.28

THERMAL AND PHYSICAL PROPERTIES OF PURE METALS

This table gives the following properties for the metallic elements:

t_m: Melting point in °C
t_b: Normal boiling point in °C, at a pressure of 101.325 kPa (760 Torr)
$\Delta_{fus} H$: Enthalpy of fusion at the melting point in J/g
ρ_{25}: Density at 25°C in g/cm^3
α: Coefficient of linear expansion at 25°C in K^{-1} (the quantity listed is $10^6 \times \alpha$)
c_p: Specific heat capacity at constant pressure at 25°C in J/g K
λ: Thermal conductivity at 27°C in W/cm K

REFERENCES

1. Dinsdale, A. T., *CALPHAD*, 15, 317, 1991 (melting points, enthalpy of fusion).
2. Touloukian, Y. S., *Thermophysical Properties of Matter*, Vol. 12, Thermal Expansion, IFI/Plenum, New York, 1975 (coefficient of expansion, density).
3. Ho, C. Y., Powell, R. W., and Liley, P. E., *J. Phys. Chem. Ref. Data*, 3, Suppl. 1, 1974 (thermal conductivity).
4. Cox, J. D., Wagman, D. D., and Medvedev, V. A., *CODATA Key Values for Thermodynamics*, Hemisphere Publishing Corp., New York, 1989 (heat capacity).
5. Glushko, V. P., Ed., *Thermal Constants of Substances*, VINITI, Moscow, (enthalpy of fusion, heat capacity).
6. Wagman, D. D., et. al., *The NBS Tables of Chemical Thermodynamic Properties, J. Phys. Chem. Ref. Data*, 11, Suppl. 2, 1982 (heat capacity).
7. Chase, M. W., et. al., *JANAF Thermochemical Tables*, 3rd ed., J. Phys. Chem. Ref. Data, 14, Suppl. 1, 1985 (heat capacity, enthalpy of fusion).
8. Gschneidner, K. A., *Bull. Alloy Phase Diagrams*, 11, 216—224, 1990 (various properties of the rare earth metals).
9. Hellwege, K. H., Ed., *Landolt Börnstein, Numerical Values and Functions in Physics, Chemistry, Astronomy, Geophysics, and Technology*, Vol. 2, Part 1, Mechanical-Thermal Properties of State, 1971 (density).
10. *Physical Encyclopedic Dictionary*, Vol. 1–5, Encyclopedy Publishing House, Moscow, 1960–66.

Metal (symbol)	Atomic weight	t_m °C	t_b °C	$\Delta_{fus} H$ J/g	ρ_{25} g/cm^3	$\alpha \times 10^6$ K^{-1}	c_p J/g K	λ W/cm K
Actinium (Ac)		1051	3198		10			
Aluminum (Al)	26.98	660.32	2519	399.9	2.70	23.1	0.897	2.37
Antimony (Sb)	121.76	630.63	1587	162.5	6.68	11.0	0.207	0.243
Barium (Ba)	137.33	727	1897	51.8	3.62	20.6	0.204	0.184
Beryllium (Be)	9.01	1287	2471	876.0	1.85	11.3	1.825	2.00
Bismuth (Bi)	208.98	271.40	1564	53.3	9.79	13.4	0.122	0.0787
Cadmium (Cd)	112.41	321.07	767	55.2	8.69	30.8	0.232	0.968
Calcium (Ca)	40.08	842	1484	213.1	1.54	22.3	0.647	2.00
Cerium (Ce)	140.11	798	3443	39.0	6.77	6.3	0.192	0.113
Cesium (Cs)	132.91	28.44	671	15.7	1.93	97	0.242	0.359
Chromium (Cr)	52.00	1907	2671	404	7.15	4.9	0.449	0.937
Cobalt (Co)	58.93	1495	2927	272.5	8.86	13.0	0.421	1.00
Copper (Cu)	63.55	1084.62	2562	203.5	8.96	16.5	0.385	4.01
Dysprosium (Dy)	162.50	1412	2567	68.1	8.55	9.9	0.170	0.107
Erbium (Er)	167.26	1529	2868	119	9.07	12.2	0.168	0.145
Europium (Eu)	151.96	822	1529	60.6	5.24	35.0	0.182	0.139[a]
Gadolinium (Gd)	157.25	1313	3273	63.6	7.90	9.4[b]	0.236	0.105
Gallium (Ga)	69.72	29.76	2204	80.0	5.91	18	0.371	0.406
Gold (Au)	196.97	1064.18	2856	64.6	19.3	14.2	0.129	3.17
Hafnium (Hf)	178.49	2233	4603	152.4	13.3	5.9	0.144	0.230
Holmium (Ho)	164.93	1474	2700	103[a]	8.80	11.2	0.165	0.162
Indium (In)	114.82	156.60	2072	28.6	7.31	32.1	0.233	0.816
Iridium (Ir)	192.22	2446	4428	213.9	22.5	6.4	0.131	1.47
Iron (Fe)	55.85	1538	2861	247.3	7.87	11.8	0.449	0.802
Lanthanum (La)	138.91	918	3464	44.6	6.15	12.1	0.195	0.134
Lead (Pb)	207.20	327.46	1749	23.1	11.3	28.9	0.129	0.353
Lithium (Li)	6.94	180.5	1342	432	0.534	46	3.582	0.847
Lutetium (Lu)	174.97	1663	3402	126[a]	9.84	9.9	0.154	0.164
Magnesium (Mg)	24.30	650	1090	348.9	1.74	24.8	1.023	1.56

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THERMAL AND PHYSICAL PROPERTIES OF PURE METALS (continued)

Metal (symbol)	Atomic weight	t_m °C	t_b °C	$\Delta_{fus} H$ J/g	ρ_{25} g/cm^3	$\alpha \times 10^6$ K^{-1}	c_p J/g K	λ W/cm K
Manganese (Mn)	54.94	1246	2061	235.0	7.3	21.7	0.479	0.0782
Mercury (Hg)	200.59	-38.83	356.73	11.4	13.5336	60.4	0.140	0.0834
Molybdenum (Mo)	95.94	2623	4639	390.7	10.2	4.8	0.251	1.38
Neodymium (Nd)	144.24	1021	3074	49.5	7.01	9.6	0.190	0.165
Neptunium (Np)		644		13.5	20.2			0.063
Nickel (Ni)	58.69	1455	2913	290.3	8.90	13.4	0.444	0.907
Niobium (Nb)	92.91	2477	4744	323	8.57	7.3	0.265	0.537
Osmium (Os)	190.23	3033	5012	304.1	22.59	5.1	0.130	0.876
Palladium (Pd)	106.42	1554.9	2963	157.3	12.0	11.8	0.246	0.718
Platinum (Pt)	195.08	1768.4	3825	113.6	21.5	8.8	0.133	0.716
Plutonium (Pu)		640	3228	11.6	19.7	46.7		0.0674
Polonium (Po)		254	962		9.20	23.5		0.20
Potassium (K)	39.10	63.38	759	59.6	0.89	83.3	0.757	1.024
Praseodymium (Pr)	140.91	931	3520	48.9	6.77	6.7	0.193	0.125
Promethium (Pm)		1042	3000[a]		7.26	11[a]	0.19[a]	0.15[a]
Protactinium (Pa)	231.04	1572		53.4	15.4			
Radium (Ra)		700			5			
Rhenium (Re)	186.21	3186	5596	324.5	20.8	6.2	0.137	0.479
Rhodium (Rh)	102.91	1964	3695	258.4	12.4	8.2	0.243	1.50
Rubidium (Rb)	85.47	39.30	688	25.6	1.53		0.363	0.582
Ruthenium (Ru)	101.07	2334	4150	381.8	12.1	6.4	0.238	1.17
Samarium (Sm)	150.36	1074	1794	57.3	7.52	12.7	0.197	0.133
Scandium (Sc)	44.96	1541	2836	314	2.99	10.2	0.568	0.158
Silver (Ag)	107.87	961.78	2162	104.6	10.5	18.9	0.235	4.29
Sodium (Na)	22.99	97.72	883	113.1	0.97	71	1.228	1.41
Strontium (Sr)	87.62	777	1382	84.8	2.64	22.5	0.301	0.353
Tantalum (Ta)	180.95	3017	5458	202.1	16.4	6.3	0.140	0.575
Technetium (Tc)		2157	4265	339.7	11			0.506
Terbium (Tb)	158.93	1356	3230	67.9	8.23	10.3	0.182	0.111
Thallium (Tl)	204.38	304	1473	20.3	11.8	29.9	0.129	0.461
Thorium (Th)	232.04	1750	4788	59.5	11.7	11.0	0.113	0.540
Thulium (Tm)	168.93	1545	1950	99.7	9.32	13.3	0.160	0.169
Tin (Sn)	118.71	231.93	2602	60.4	7.26	22.0	0.228	0.666
Titanium (Ti)	47.88	1668	3287	295.6	4.51	8.6	0.523	0.219
Tungsten (W)	183.84	3422	5555	284.5	19.3	4.5	0.132	1.74
Uranium (U)	238.03	1135	4131	38.4	19.1	13.9	0.116	0.276
Vanadium (V)	50.94	1910	3407	422	6.0	8.4	0.489	0.307
Ytterbium (Yb)	173.04	819	1196	44.3	6.90	26.3	0.155	0.385
Yttrium (Y)	88.91	1522	3345	128	4.47	10.6	0.298	0.172
Zinc (Zn)	65.39	419.53	907	108.1	7.14	30.2	0.388	1.16
Zirconium (Zr)	91.22	1855	4409	230.2	6.52	5.7	0.278	0.227

[a] Estimated.
[b] At 100°C.

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THERMAL CONDUCTIVITY OF METALS AND SEMICONDUCTORS AS A FUNCTION OF TEMPERATURE

This table gives the temperature dependence of the thermal conductivity of several metals and of carbon, germanium, and silicon. For graphite, separate entries are given for the thermal conductivity parallel (‖) and perpendicular (⊥) to the layer planes. The thermal conductivity of all these materials is very sensitive to impurities at low temperatures, especially below 100 K. Therefore, the values given here should be regarded as typical values for a highly purified specimen; the thermal conductivity of different specimens can vary by more than an order of magnitude in the low-temperature range. See Reference 2 for details.

REFERENCES

1. Ho, C. Y., Powell, R. W., and Liley, P. E., *J. Phys. Chem. Ref. Data*, 1, 279, 1972.
2. White, G. K., and Minges, M. L., *Thermophysical Properties of Some Key Solids*, CODATA Bulletin No. 59, 1985.

Thermal Conductivity in W/cm K

				Carbon (C)						
				Diamond (type)			Pyrolytic graphite			
T/K	Ag	Al	Au	I	IIa	IIb	‖	⊥	Cr	Cu
1	39.4	41.1	5.46						0.402*	42.2
2	78.3	81.8	10.9	0.0138*	0.033*	0.0200*			0.803	84.0
3	115	121	16.1	0.0461	0.111	0.0676			1.20	125
4	147	157	20.9	0.108	0.261	0.160			1.60	162
5	172	188	25.2	0.206	0.494	0.307			2.00	195
6	187	213	28.5	0.344	0.820	0.510			2.39	222
7	193	229	30.9	0.523	1.24	0.778			2.27	239
8	190	237	32.3	0.762	1.77	1.12			3.14	248
9	181	239	32.7	1.05	2.41	1.53			3.50	249
10	168	235	32.4	1.40	3.17	2.03	0.811	0.0116	3.85	243
15	96.0	176	24.6	3.96	8.65	5.66			5.24	171
20	51.0	117	15.8	7.87	16.8	11.2	4.20	0.0397	5.93	108
30	19.3	49.5	7.55	18.8	38.9	26.5	9.86	0.0786	5.49	44.5
40	10.5	24.0	5.15	29.4	65.9	44.0	16.4	0.120	4.25	21.7
50	7.0	13.5	4.21	35.3	92.1	59.1	23.1	0.152	3.17	12.5
60	5.5	8.5	3.74	37.4	112	67.5	29.8	0.173	2.48	8.29
70	4.97	5.85	3.48	36.9	119	69.1	36.6	0.181	2.07	6.47
80	4.71	4.32	3.32	35.1	117	65.7	42.8	0.181	1.84	5.57
90	4.60	3.42	3.28	32.7	109	60.0	47.5	0.176	1.69	5.08
100	4.50	3.02	3.27	30.0	100	54.2	49.7	0.168	1.59	4.82
150	4.32	2.48	3.25	19.5	60.2	32.5	45.1	0.125	1.29	4.29
200	4.30	2.37	3.23	14.1	40.3	22.6	32.3	0.0923	1.11	4.13
250	4.29	2.35	3.21	11.0	29.7	17.0	24.4	0.0711	1.00	4.06
300	4.29	2.37	3.17	8.95	23.0	13.5	19.5	0.0570	0.937	4.01
350	4.27	2.40	3.14	7.55*	18.5*	11.1*	16.2	0.0477	0.929	3.96
400	4.25	2.40	3.11	6.5*	15.4*	9.32*	13.9	0.0409	0.909	3.93
500	4.19	2.36	3.04				10.8	0.0322	0.860	3.86
600	4.12	2.31	2.98				8.92	0.0268	0.807	3.79
800	3.96	2.18	2.84				6.67	0.0201	0.713	3.66
1000	3.79		2.70				5.34	0.0160	0.654	3.52
1200	3.61*		2.55				4.48	0.0134	0.619	3.39
1400							3.84	0.0116	0.588	
1600							3.33	0.0100	0.556	
1800							2.93	0.00895	0.526*	
2000							2.62	0.00807	0.494*	

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THERMAL CONDUCTIVITY OF METALS AND SEMICONDUCTORS AS A FUNCTION OF TEMPERATURE (continued)

T/K	Fe	Ge[a]	Mg	Ni	Pb	Pt	Si[a]	Sn	Ti	W
1	1.71	0.274	9.86	2.17	27.9	2.31	0.0693*	183	0.0144*	14.4
2	3.42	2.06	19.6	4.34	44.6	4.60	0.454	323	0.0288*	28.7
3	5.11	5.35	29.0	6.49	35.8	6.79	1.38	297	0.0432	42.8
4	6.77	8.77	37.6	8.59	22.2	8.8	2.97	181	0.0575	56.3
5	8.39	11.6	45.0	10.6	13.8	10.5	5.27	117	0.0719	68.7
6	9.93	13.9	50.8	12.5	8.10	11.8	8.23	76	0.0863	79.5
7	11.4	15.5	54.7	14.2	4.86	12.6	11.7	52	0.101	88.0
8	12.7	16.6	56.7	15.8	3.20	12.9	15.5	36	0.115	93.8
9	13.9	17.3	57.0	17.1	2.30	12.8	19.5	26	0.129	96.8
10	14.8	17.7	55.8	18.1	1.78	12.3	23.3	19.3	0.143	97.1
15	17.0	17.3	41.1	19.5	0.845	8.41	41.6	6.3	0.212	72.0
20	15.4	14.9	27.2	16.5	0.591	4.95	49.8	3.2	0.275	40.5
30	10.0	10.8	12.9	9.56	0.477	2.15	48.1	1.79	0.365	14.4
40	6.23	7.98	7.19	5.82	0.451	1.39	35.3	1.33	0.390	6.92
50	4.05	6.15	4.65	4.00	0.436	1.09	26.8	1.15	0.374	4.27
60	2.85	4.87	3.27	3.08	0.425	0.947	21.1	1.04	0.355	3.14
70	2.16	3.93	2.49	2.50	0.416	0.862	16.8	0.96	0.340	2.58
80	1.75	3.25	2.02	2.10	0.409	0.815	13.4	0.915	0.326	2.29
90	1.50	2.70	1.78	1.83	0.403	0.789	10.8	0.880	0.315	2.17
100	1.34	2.32	1.69	1.64	0.397	0.775	8.84	0.853	0.305	2.08
150	1.04	1.32	1.61	1.22	0.379	0.740	4.09	0.779	0.270	1.92
200	0.94	0.968	1.59	1.07	0.367	0.726	2.64	0.733	0.245	1.85
250	0.865	0.749	1.57	0.975	0.360	0.718	1.91	0.696	0.229	1.80
300	0.802	0.599	1.56	0.907	0.353	0.716	1.48	0.666	0.219	1.74
350	0.744	0.495	1.55	0.850	0.347	0.717	1.19	0.642	0.210	1.67
400	0.695	0.432	1.53	0.802	0.340	0.718	0.989	0.622	0.204	1.59
500	0.613	0.338	1.51	0.722	0.328	0.723	0.762	0.596	0.197	1.46
600	0.547	0.273	1.49	0.656	0.314	0.732	0.619		0.194	1.37
800	0.433	0.198	1.46*	0.676		0.756	0.422		0.197	1.25
1000	0.323	0.174		0.718		0.787	0.312		0.207	1.18
1200	0.283	0.174		0.762		0.826	0.257		0.220	1.12
1400	0.312			0.804		0.871	0.235		0.236	1.08
1600	0.330					0.919	0.221		0.253	1.04
1800	0.345*					0.961			0.270*	1.01
2000						0.994*				0.98

[a] Values below 300 K are typical values.
* Extrapolated.

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THERMAL CONDUCTIVITY OF ALLOYS AS A FUNCTION OF TEMPERATURE

This table lists the thermal conductivity of selected alloys at various temperatures. The indicated compositions refer to weight percent. Since the thermal conductivity is sensitive to exact composition and processing history, especially at low temperatures, these values should be considered approximate.

REFERENCES

1. Powell, R. L., and Childs, G. E., in *American Institute of Physics Handbook, 3rd Edition*, Gray, D. E., Ed., McGraw-Hill, New York, 1972.
2. Ho, C. Y., et al., *J. Phys. Chem. Ref. Data*, 7, 959, 1978.

Thermal conductivity in W/m K

	Alloy	**4 K**	**20 K**	**77 K**	**194 K**	**273 K**	**373 K**	**573 K**	**973 K**
Aluminum:	1100	50	240	270	220	220			
	2024	3.2	17	56	95	130			
	3003	11	58	140	150	160			
	5052	4.8	25	77	120	140			
	5083, 5086	3	17	55	95	120			
	Duralumin	5.5	30	91	140	160	180		
Bismuth:	Rose metal		5.5	8.3	14	16			
	Wood's metal	4	17	23					
Copper:	electrolytic tough pitch	330	1300	550	400	390	380	370	350
	free cutting, leaded	200	800	460	380	380			
	phosphorus, deoxidized	7.5	42	120	190	220			
	brass, leaded	2.3	12	39	70	120			
	bronze, 68% Cu; 32% Zn	2.3	16	48	92	110			
	beryllium	2	17	36	70	90	113	172	
	german silver	0.75	7.5	17	20	23	25	30	40
	silicon bronze A		3.4	11	23	30			
	manganin	0.48	3.2	14	17	22			
	constantan	0.9	8.6	17	19	22			
Ferrous:	commercial pure iron	15	72	106	82	76	66	54	34
	plain carbon steel(AISI 1020)	13	20	58	65	65			
	plain carbon steel(AISI 1095)		8.5	31	41	45			
	3% Ni; 0.7% Cr; 0.6% Mo		6	22		33	35	36	30
	4% Si					20	24	28	26
	stainless steel	0.3	2	8	13	14	16	19	25
	27% Ni; 15% Cr		1.7	55		11	12	16	21
Gold:	colbalt thermocouple	1.2	8.6	20					
	65% Au; 35% Ag		12	24		61	89		
Indium:	85.5% In; 14.5% Pb	1.9	7.8	24	41				
Lead:	60% Pb; 40% Sn (soft solder)		28	44					
	64.35% Pb; 35.65% In	0.8	3.26	9.1		20.2			
Nickel:	80% Ni; 20% Cr					12	14	17	23
	contracid	0.2	2	7.3	9.5	13			
	inconel	0.5	4.2	12.5	13	15	16	19	26
	monel	0.9	7.1	15	20	21	24	30	43
Platinum:	90% Pt; 10% Ir					31	31.4		
	90% Pt; 10% Rh					30.1	30.5		
Silver:	silver solder		12	34	58				
	normal Ag thermocouple	48	230	310					
Tin:	60% Sn; 40% Pb	16	55	51					
Titanium:	5.5% Al; 2.5% Sn;0.2% Fe		1.8	4.3	6.4	7.8	8.4	10.8	
	4.7% Mn; 3.99% Al; 0.14% C		1.7	4.5	6.5	8.5			

THERMAL CONDUCTIVITY OF CRYSTALLINE DIELECTRICS

This table lists the thermal conductivity of a number of crystalline dielectrics, including some which find use as optical materials. Values are given at temperatures for which data are available.

REFERENCE

Powell, R. L., and Childs, G. E., in *American Institute of Physics Handbook, 3rd Edition,* Gray, D. E., Ed., McGraw-Hill, New York, 1972.

Material	*T*/K	Ther. cond. W/m K
AgCl	223	1.3
	273	1.2
	323	1.1
	373	1.1
Al,B silicate (tourmaline)	398	2.9
|| to *c* axis	540	3.2
	723	3.5
Al,Be silicate (beryl)	315	6.4
Al,F silicate (topaz)	315	17.7
|| to *c* axis	358	15.6
	417	13.3
Al,Fe silicate (garnet)	315	35.8
	358	35.4
	377	35.6
Al_2O_3 (sapphire):		
36° to *c* axis	4.2	110
	20	3500
	35	6000
	77	1100
⊥ to *c* axis	373	2.6
	523	3.9
	773	5.8
Al_2O_3 (sintered)	4.2	0.5
	20	23
	77	150
	194	48
	273	35
	373	26
	973	8
Ar	8	6.0
	10	3.7
	20	1.4
	77	0.31
As_2S_3 (glass)	283	0.16
	323	0.21
	373	0.27
BN	1047	36.2
	1475	22.7
	1928	21.9
	2111	18.5
BaF_2	225	20
	260	13.4
	305	10.9
	370	10.5
$BaTiO_3$	5	4.2
	30	24.0
	40	25.0
	100	12.0
	250	4.8
	300	6.2
BeO	4.2	0.3
	20	16
	77	270
	373	210
	573	120
	1273	29
Bi_2Te_3	80	6.4
	204	2.8
	303	3.6
	370	4.6
C (diamond)	4.2	13
type I	20	800
	77	3550
	194	1450
	273	1000
$CaCO_3$		
|| to *c* axis	83	25
	273	5.5
⊥ to *c* axis	83	17
	194	6.5
	273	4.6
	373	3.6
CaF_2	83	39
	223	18
	273	10
	323	9.2
	373	9
$CaWO_4$ (scheelite)	422	11.3
CdTe	160	7.0
	297	3.6
	422	2.9
CsBr	223	1.2
	273	0.94
	323	0.81
	373	0.77
CsI	223	1.4
	273	1.2
	323	1
	373	0.95
Cu_2O (cuprite)	102	3.74
	163	7.76
	299	5.58
	360	4.86
Fe_3O_4 (magnetite)	4.5	27.4
	20.5	293.0
	126.5	7.4
	304	7.0
Glass:		
phoenix	4.2	0.095
	20	0.13
	77	0.37

Material	T/K	Ther. cond. W/m K
plastic perspex	4.2	0.058
	20	0.074
pyrex	77	0.44
	194	0.88
	273	1
H_2 (para + 0.5% ortho)	2.5	100
	3	150
	4	200
	6	30
	10	3
H_2O (ice)	173	3.5
	223	2.8
	273	2.2
He^3 (high pressure)	0.6	25
	1	2
	1.5	0.57
	2	0.21
He^4 (high pressure)	0.5	42
	0.8	120
	1	24
	2	0.18
I_2	300	0.45
	325	0.42
	350	0.4
KBr	2	150
	4.2	360
	100	12
	273	5
	323	4.8
	373	4.8
KCl	4.2	500
	25	140
	80	35
	194	10
	273	7.0
	323	6.5
	373	6.3
KI	4.2	700
	80	13
	194	4.6
	273	3.1
Kr	4.2	0.48
	10	1.7
	20	1.2
	77	0.36
LaF_3	78	7.8
	197	5.0
	274	5.4
LiF	4.2	620
	20	1800
	77	150
$MgO·Al_2O_3$ (spinel)	373	13
	773	8.5
MnO	4.2	0.25
	40	55
	120	8
	573	3.5
NaCl	4.2	440
	20	300
	77	30
	273	6.4
	323	5.6
	373	5.4
NaF	5	1100
	50	250
	100	90
Ne	2	3.0
	3	4.6
	4.2	4.2
	10	0.8
	20	0.3
NH_4Cl	77	17
	194	23
	230	38
	273	27
$NH_4H_2PO_4$		
‖ to optic axis	315	0.71
	339	0.71
⊥ to optic axis	313	1.26
	342	1.34
NiO	4.2	5.9
	40	400
	194	82
SiO_2 (quartz)		
‖ to *c* axis	20	720
	194	20
	273	12
⊥ to *c* axis	20	370
	194	10
	273	6.8
SiO_2 (fused silica)	4.2	0.25
	20	0.7
	77	0.8
	194	1.2
	273	1.4
	373	1.6
	673	1.8
$SrTiO_3$	5	2.4
	30	21.0
	40	19.2
	100	18.5
	250	12.5
	300	11.2
TlBr	316	0.59
TlCl	311	0.75
TiO_2 (rutile)		
‖ to optic axis	4.2	200
	20	1000
	273	13
⊥ to optic axis	4.2	160
	20	690
	273	9

THERMAL CONDUCTIVITY OF CERAMICS AND OTHER INSULATING MATERIALS

Thermal conductivity values for ceramics, refractory oxides, and miscellaneous insulating materials are given here. The thermal conductivity refers to samples with density indicated in the second column. Since most of these materials are highly variable, the values should only be considered as a rough guide.

REFERENCES

1. Powell, R. L., and Childs, G. E., in *American Institute of Physics Handbook, 3rd Edition*, Gray, D. E., Ed., McGraw-Hill, New York, 1972.
2. Perry, R. H., and Green, D., *Perry's Chemical Engineers' Handbook, Sixth Edition*, McGraw-Hill, New York, 1984.

Material	Dens. g/cm³	*t* °C	Ther. cond. W/m K
Alumina (Al_2O_3)	3.8	100	30
		400	13
		1300	6
		1800	7.4
	3.5	100	17
		800	7.6
Al_2O_3 + MgO		100	15
		400	10
		1000	5.6
Asbestos	0.4	-100	0.07
		100	1
		0	0.09
Asbestos + 85% MgO	0.3	30	0.08
Asphalt	2.1	20	0.06
Beryllia (BeO)	2.8	100	210
		400	90
		1000	20
		1800	15
	1.85	50	64
		200	40
		600	23
Brick, dry	1.54	0	0.04
Brick, refractory:			
alosite		1000	1.3
aluminous	1.99	400	1.2
		1000	1.3
diatomaceous	0.77	100	0.2
		500	0.24
	0.4	100	0.08
		500	0.1
fireclay	2	400	1
		1000	1.2
silicon carbide	2	200	2
		600	2.4
vermiculite	0.77	200	0.26
		600	0.31
Calcium oxide		100	16
		400	9
		1000	7.5
Cement mortar	2	90	0.55
Charcoal	0.2	20	0.055
Coal	1.35	20	0.26
Concrete	1.6	0	0.8
Cork	0.05	0	0.03
		100	0.04
	0.35	0	0.06
		100	0.08
Cotton wool	0.08	30	0.04
Diatomite	0.2	0	0.05
		400	0.09
	0.5	0	0.09
		400	0.16
Ebonite	1.2	0	0.16
Felt, flax	0.2	30	0.05
	0.3	30	0.04
Fuller's earth	0.53	30	0.1
Glass wool	0.2	-200 to 20	0.005
		50	0.04
		100	0.05
		300	0.08
Graphite			
100 mesh	0.48	40	0.18
20-40 mesh	0.7	40	1.29
Linoleum cork	0.54	20	0.08
Magnesia (MgO)		100	36
		400	18
		1200	5.8
		1700	9.2
MgO + SiO_2		100	5.3
		400	3.5
		1500	2.3
Mica:			
muscovite		100	0.72
		300	0.65
		600	0.69
phlogopite		100	0.66
Canadian		300	0.19
		600	0.2
Micanite		30	0.3
Mineral wool	0.15	30	0.04
Perlite, expanded	0.1	-200 to 20	0.002
Plastics:			
bakelite	1.3	20	1.4
celluloid	1.4	30	0.02
polystyrene foam	0.05	-200 to 20	0.033
mylar foil	0.05	-200 to 20	0.0001
nylon		-253	0.10
		-193	0.23
		25	0.30
polytetrafluoroethylene		-253	0.13
		-193	0.16
		25	0.26
		230	2.5
urethane foam	0.07	20	0.06
Porcelain		90	1

THERMAL CONDUCTIVITY OF CERAMICS AND OTHER INSULATING MATERIALS (continued)

Material	Dens. g/cm³	*t* °C	Ther. cond. W/m K
Rock:			
basalt		20	2
chalk		20	0.92
granite	2.8	20	2.2
limestone	2	20	1
sandstone	2.2	20	1.3
slate, ⊥		95	1.4
slate, ||		95	2.5
Rubber:			
sponge	0.2	20	0.05
92 percent		25	0.16
Sand, dry	1.5	20	0.33
Sawdust	0.2	30	0.06
Shellac		20	0.23
Silica aerogel	0.1	-200 to 20	0.003
Snow	0.25	0	0.16
Steel wool	0.1	55	0.09
Thoria (ThO_2)		100	10
		400	5.8
		1500	2.4
Titanium dioxide		100	6.5
		400	3.8
		1200	3.3
Uranium dioxide		100	9.8
		400	5.5
		1000	3.4
Wood:			
balsa, ⊥	0.11	30	0.04
fir, ⊥	0.54	20	0.14
fir, ||	0.54	20	0.35
oak		20	0.16
plywood		20	0.11
pine, ⊥	0.45	60	0.11
pine, ||	0.45	60	0.26
walnut, ⊥	0.65	20	0.14
Wool	0.09	30	0.04
Zinc oxide		200	17
		800	5.3
Zirconia (ZrO_2)		100	2
		400	2
		1500	2.5
Zirconia + silica		200	5.6
		600	4.6
		1500	3.7

THERMAL CONDUCTIVITY OF GLASSES

This table gives the composition of various types of glasses and the thermal conductivity *k* as a function of temperature. Because of the variability of glasses, the data should be regarded as only approximate.

Type of glass	Composition SiO_2 (wt%)	Other oxides (wt%)		*t* °C	*k* W/m K
Vitreous silica	100			–150	0.85
				–100	1.05
				–50	1.20
				0	1.30
				50	1.40
				100	1.50
Vycor glass	96	B_2O_3	3	–100	1.00
				0	1.25
				100	1.40
Pyrex type chemically-resistant borosilicate glasses	80–81	B_2O_3	12–13	–100	0.90
		Na_2O	4	0	1.10
		Al	2	100	1.25
Borosilicate crown glasses	60–65	B_2O_3	15–20	–100	0.65–0.75
				0	0.90–0.95
				100	1.00–1.05
	65–70	B_2O_3	10–15	–100	0.75–0.80
				0	0.95–1.00
				100	1.05–1.15
	70–75	B_3O_3	5–10	–100	0.80–0.85
				0	1.05–1.10
				100	1.15–1.20
Zinc crown glasses (i)	55–65	ZnO	5–15	–100	0.88–0.92
		Remainder:		0	1.10–1.15
		B_2O_3, Al_2O_3		100	1.15–1.25
		ZnO	5–15	–100	0.60–0.70
		Remainder:		0	0.70–0.90
		Na_2O, K_2O		100	0.85–0.95
		ZnO	15–25	–100	0.88–0.92
		Remainder:		0	1.10–1.15
		B_2O_3, Al_2O_3		100	1.15–1.20
		ZnO	15–25	–100	0.65–0.80
		Remainder:		0	0.85–0.95
		Na_2O, K_2O		100	0.90–1.05
Zinc crown glasses (ii)	65–75	ZnO	5–15	–100	0.88–0.92
		Remainder:		0	1.15–1.15
		B_2O_3, Al_2O_3		100	1.20–1.30
		ZnO	5–15	–100	0.70–0.85
		Remainder:		0	0.90–1.05
		Na_2O, K_2O		100	1.00–1.15

Type of glass	Composition: SiO_2 (wt%)	Composition: Other oxides (wt%)		t °C	k W/m K
		ZnO	15–25	–100	0.90–0.95
		Remainder:		0	1.15–1.15
		B_2O_3, Al_2O_3		100	1.20–1.25
		ZnO	15–25	–100	0.65–0.85
		Remainder:		0	0.85–1.00
		Na_2O, K_2O		100	1.05–1.20
Barium crown glasses	31	B_2O_3	12	–100	0.55
		Al_2O_3	8	0	0.70
		BaO	48	100	0.80
	41	B_2O_3	6	–100	0.60
		Al_2O_3	2	0	0.75
		ZnO	8	100	0.85
		BaO	43		
	47	B_2O_3	4	–100	0.65
		Na_2O	1	0	0.75
		K_2O	7	100	0.90
		ZnO	8		
		BaO	32		
	65	B_2O_3	2	–100	0.70
		Na_2O	5	0	0.90
		K_2O	15	100	1.00
		ZnO	2		
		BaO	10		
Borate glasses					
Borate flint glass	9	B_2O_3	36	–100	0.55
		Na_2O	1	0	0.65
		K_2O	2	100	0.80
		PbO	36		
		Al_2O_3	10		
		ZnO	6		
Borate flint glass	0	B_2O_3	56	–100	0.50
		Al_2O_3	12	0	0.65
		PbO	32	100	0.85
Borate flint glass	0	B_2O_3	43	–100	0.40
		Al_2O_3	5	0	0.55
		PbO	52	100	0.70
Borate glass	4	B_2O_3	55	–100	0.65
		Al_2O_3	14	0	0.80
		PbO	11	100	0.90
		K_2O	4		
		ZnO	12		
Borate crown glass	0	B_2O_3	64	–100	0.50
		Na_2O	8	0	0.65
		K_2O	3	100	0.85
		BaO	4		
		PbO	3		
		Al_2O_3	18		

Type of glass	Composition: SiO_2 (wt%)	Other oxides (wt%)		t °C	k W/m K
Light borate crown glass	0	B_2O_3	69	–100	0.55
		Na_2O	8	0	0.70
		BaO	5	100	0.90
		Al_2O_3	18		
Zinc borate glass	0	B_2O_3	40	–100	0.65
		ZnO	60	0	0.75
				100	0.85
Phosphate crown glasses					
Potash phosphate glass	0	P_2O_5	70	0	0.75
		B_2O_3	3	100	0.85
		K_2O	12		
		Al_2O_3	10		
		MgO	4		
Baryta phosphate glass	0	P_2O_5	60	45	0.75
		B_2O_3	3		
		Al_2O_3	8		
		BaO	28		
Soda-lime glasses	75	Na_2O	17	–100	0.75
		CaO	8	0	0.95
				100	1.10
	75	Na_2O	12	–100	0.90
		CaO	13	0	1.10
				100	1.15
	72	Na_2O	15	–100	0.80
		CaO	11	0	1.00
		Al_2O_3	2	100	1.15
	65	Na_2O	25	–100	0.65
		CaO	10	0	0.85
				100	0.95
	65	Na_2O	15	–100	0.85
		CaO	20	0	1.00
				100	1.10
	60	Na_2O	20	–100	0.75
		CaO	20	0	0.90
				100	1.00
Other crown glasses					
Crown glass	75	Na_2O	9	–100	0.80
		K_2O	11	0	1.00
		CaO	5	100	1.10
High dispersion crown glass	68	Na_2O	16	–100	0.65
		ZnO	3	0	0.85
		PbO	13	100	1.00

THERMAL CONDUCTIVITY OF GLASSES (continued)

Type of glass	Composition: SiO_2 (wt%)	Other oxides (wt%)		t °C	k W/m K
Miscellaneous flint glasses					
(i) Silicate flint glasses					
Light flint glasses	65	PbO	25	–100	0.65–0.70
		Others	10	0	0.88–0.92
				100	1.00–1.05
	55	PbO	35	–100	0.60–0.65
		Others	10	0	0.75–0.85
				100	0.88–0.92
Ordinary flint glass	45	PbO	45	–100	0.50–0.60
		Others	10	0	0.65–0.75
				100	0.80–0.85
Heavy flint glass	35	PbO	60	–100	0.45–0.50
		Others	5	0	0.60–0.65
				100	0.70–0.75
Very heavy flint glasses	25	PbO	73	–100	0.40–0.45
		Others	2	0	0.55–0.60
				100	0.63–0.67
	20	PbO	80	–100	0.40
				0	0.50
				100	0.60
(ii) Borosilicate flint glass	33	B_2O_3	31	–100	0.65
		PbO	25	0	0.85
		Al_2O_3	7	100	0.95
		K_2O	3		
		Na_2O	1		
(iii) Barium flint glass	50	BaO	24	–100	0.60
		PbO	6	0	0.70
		K_2O	8	100	0.85
		Na_2O	3		
		ZnO	8		
		Sb_2O_3	1		
Other glasses					
Potassium glass	59	K_2O	33	50	0.88–0.92
		CaO	8		
Iron glasses	63	Fe_2O_3	10	–100	0.80
		Na_2O	17	0	0.95
		MgO	4	100	1.05
		CaO	3		
		Al_2O_3	2		
	67	Fe_2O_3	15	0	0.88—0.92
		Na_2O_3	18	100	1.00—1.05
	62	Fe_2O_3	20	0	0.85—0.90
		Na_2O	18	100	0.95—1.00
Rock glasses					
Obsidian				0	1.35
Artificial diabase				100	1.25

COMMERCIAL METALS AND ALLOYS

This table gives typical values of mechanical, thermal, and electrical properties of several common commercial metals and alloys. Values refer to ambient temperature (0 to 25°C). All values should be regarded as typical, since these properties are dependent on the particular type of alloy, heat treatment, and other factors. Values for individual specimens can vary widely.

REFERENCES

1. *ASM Metals Reference Book, Second Edition*, American Society for Metals, Metals Park, OH, 1983.
2. Lynch, C. T., *CRC Practical Handbook of Materials Science*, CRC Press, Boca Raton, FL, 1989.
3. Shackelford, J. F., and Alexander, W., *CRC Materials Science and Engineering Handbook*, CRC Press, Boca Raton, FL, 1991.

Common name	Thermal conductivity W/cm K	Density g/cm³	Coeff. of linear expansion 10^{-6}/°C	Electrical resistivity μΩ cm	Modulus of elasticity GPa	Tensile strength MPa	Approx. melting point °C
Ingot iron	0.7	7.86	11.7	9.7	205	-	1540
Plain carbon steel AISI-SAE 1020	0.52	7.86	11.7	18	205	450	1515
Stainless steel type 304	0.15	7.9	17.3	72	195	550	1425
Cast gray iron	0.47	7.2	10.5	67	90	180	1175
Malleable iron		7.3	12	30	170	345	1230
Hastelloy C	0.12	8.94	11.3	125	200	780	1350
Inconel	0.15	8.25	11.5	103	200	800	1370
Aluminum alloy 3003, rolled	1.9	2.73	23.2	3.7	70	110	650
Aluminum alloy 2014, annealed	1.9	2.8	23.0	3.4	70	185	650
Aluminum alloy 360	1.5	2.64	21.0	7.5	70	325	565
Copper, electrolytic (ETP)	3.9	8.94	16.5	1.7	120	300	1080
Yellow brass (high brass)	1.2	8.47	20.3	6.4	100	300-800	930
Aluminum bronze	0.7	7.8	16.4	12	120	400-600	1050
Beryllium copper 25	0.8	8.23	17.8	7	130	500-1400	925
Cupronickel 30%	0.3	8.94	16.2		150	400-600	1200
Red brass, 85%	1.6	8.75	18.7	11	90	300-700	1000
Chemical lead	0.35	11.34	29.3	21	13	17	327
Antimonial lead (hard lead)	0.3	10.9	26.5	23	20	47	290
Solder 50-50	0.5	8.89	23.4	15	-	42	215
Magnesium alloy AZ31B	1.0	1.77	26	9	45	260	620
Monel	0.3	8.84	14.0	58	180	545	1330
Nickel (commercial)	0.9	8.89	13.3	10	200	460	1440
Cupronickel 55-45 (constantan)	0.2	8.9	18.8	49	160	-	1260
Titanium (commercial)	1.8	4.5	8.5	43	110	330-500	1670
Zinc (commercial)	1.1	7.14	32.5	6	-	130	419
Zirconium (commercial)	0.2	6.5	5.85	41	95	450	1855

HARDNESS OF MINERALS AND CERAMICS

There are several hardness scales for describing the resistance of a material to indentation or scratching. This table lists a number of common materials in order of increasing hardness. Values are given, when available, on three different hardness scales: the original Mohs Scale (range 1 to 10); the modified Mohs Scale (range 1 to 15), and the Knoop Hardness Scale. In the last case, a load of 100 g is assumed.

REFERENCE

Shackelford, J. F. and Alexander, W., *CRC Materials Science and Engineering Handbook*, CRC Press, Boca Raton, FL, 1991.

Material	Formula	Mohs	Modified mohs	Knoop
Graphite	C	0.5		
Talc	$3MgO \cdot 4SiO_2 \cdot H_2O$	1	1	
Alabaster	$CaSO_4 \cdot 2H_2O$	1.7		
Gypsum	$CaSO_4 \cdot 2H_2O$	2	2	32
Halite (rock salt)	NaCl	2		
Stibnite (antimonite)	Sb_2S_3	2.0		
Galena	PbS	2.5		
Mica		2.8		
Calcite	$CaCO_3$	3	3	135
Barite	$BaSO_4$	3.3		
Marble		3.5		
Aragonite	$CaCO_3$	3.5		
Dolomite	$CaMg(CO_3)_2$	3.5		
Fluorite	CaF_2	4	4	163
Magnesia	MgO	5		370
Apatite	$CaF_2 \cdot 3Ca_3(PO_4)_2$	5	5	430
Opal		5		
Feldspar (orthoclase)	$K_2O \cdot Al_2O \cdot 6SiO_2$	6	6	560
Augite		6		
Hematite	Fe_2O_3	6		750
Magnetite	Fe_3O_4	6		
Rutile	TiO_2	6.2		
Pyrite	FeS_2	6.3		
Agate	SiO_2	6.5		
Uranium dioxide	UO_2	6.7		600
Silica (fused)	SiO_2		7	
Quartz	SiO_2	7	8	820
Flint		7		
Silicon	Si	7		
Andalusite	Al_2OSiO_4	7.5		
Zircon	$ZrSiO_4$	7.5		
Zirconia	ZrO_2			1200
Aluminum nitride	AlN			1225
Beryl	$Be_3Al_2Si_6O_{18}$	7.8		
Beryllia	BeO			1300
Topaz	$Al_2SiO_4(OH,F)_2$	8	9	1340
Garnet	$Al_2O_3 \cdot 3FeO \cdot 3SiO_2$		10	1360
Emery	Al_2O_3 (impure)	8		
Zirconium nitride	ZrN	8+		1510
Zirconium boride	ZrB_2			1560
Titanium nitride	TiN	9		1770
Zirconia (fused)	ZrO_2		11	
Tantalum carbide	TaC			1800
Tungsten carbide	WC			1880
Corundum (alumina)	Al_2O_3	9		2025
Zirconium carbide	ZrC			2150
Alumina (fused)	Al_2O_3		12	
Beryllium carbide	Be_2C			2400

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HARDNESS OF MINERALS AND CERAMICS (continued)

Material	Formula	Mohs	Modified mohs	Knoop
Titanium carbide	TiC			2470
Carborundum (silicon carbide)	SiC	9.3	13	2500
Aluminum boride	AlB			2500
Tantalum boride	TaB_2			2600
Boron carbide	B_4C		14	2800
Boron	B	9.5		
Titanium boride	TiB_2			2850
Diamond	C	10	15	7000

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ORGANIC MAGNETS

J.S. Miller

Magnetic ordering, e.g., ferromagnetism, like superconductivity, is a property of a solid, not of an individual molecule or ion, and very rarely occurs for organic compounds. In contrast to superconductivity, where all electron spins pair to form a perfect diamagnetic material, magnetic ordering requires unpaired electron spins; hence, superconductivity and ferromagnetism are mutually exclusive.

The vast majority of organic compounds are diamagnetic (i.e., all electron spins are paired), and a relative few possess unpaired electrons (designated by an arrow, ↑) and are paramagnetic (PM), i.e., they are oriented in random directions. A few organic solids, however, exhibit strong magnetic behavior and magnetically order as ferromagnets (FO) with all spins aligned in the same direction. In some cases the spins align in the opposite direction and compensate to form an antiferromagnet (AF). In some cases these spins are not opposed to each other and do not compensate and lead to a canted antiferromagnet or weak ferromagnet (WF). If the number of spins that align in one direction differs from the number of spins that align in the opposite direction, the spins cannot compensate and a ferrimagnet (FI) results. Metamagnets (MM) are antiferromagnets in which all the spins become aligned like a ferromagnet in an applied magnetic field. Above the ordering or critical temperature, T_c, all magnets are paramagnets (PM). Organic magnets all possess electron spins in *p*-orbitals, but these may be in conjunction with metal ion-based spins.

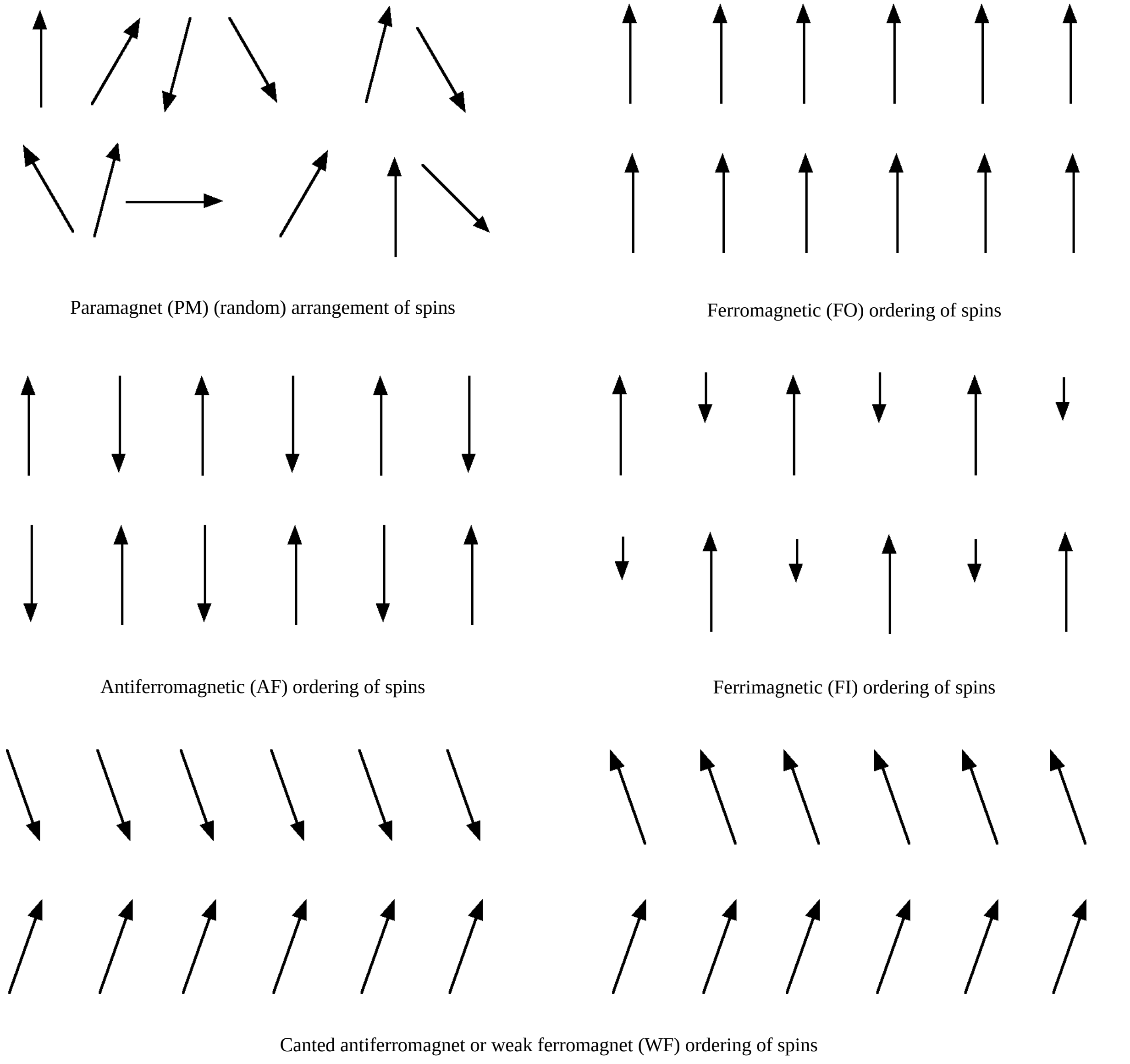

Figure 1. Schematic illustration of the different types of magnetic behavior.

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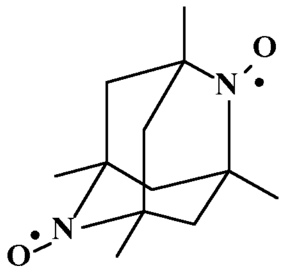
Summary of the Critical Temperature, T_c, Saturation Magnetization, M_s, Coercive Field, H_{cr}, and Remanent Magnetization, M_r, for Selected Organic-Based Magnets

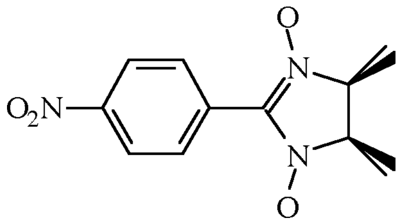
Magnet	Type	T_C/K	M_S/A m^{-1}	H_{cr}/T	M_r/A m^{-1}
α-1,3,5,7-Tetramethyl-2,6-diazaadamantane-*N*,*N'*-doxyl	FO	1.48	48,300	<0.00001	—
β-2-(4'-Nitrophenyl)-4,4,5,5-tetramethyl-4,5-dihydro-1H-imidazol-1-oxyl-3-*N*-oxide	FO	0.6	22,300	0.00008	<200
$\{Fe^{III}[C_5(CH_3)_5]_2\}$[TCNE]	FO	4.8	37,600	0.10	2,300
$\{Mn^{III}[C_5(CH_3)_5]_2\}$[TCNE]	FO	8.8	58,200	0.12	3,700
$\{Cr^{III}[C_5(CH_3)_5]_2\}$[TCNE]	FO	3.65	46,300	—	—
α-$\{Fe^{III}[C_5(CH_3)_5]_2\}$[TCNQ]	MM	2.55	34,200	—	—
β-$\{Fe^{III}[C_5(CH_3)_5]_2\}$[TCNQ]	FO	3.0	21,600	—	—
Tanol subarate	MM	0.38	20,700	—	—
$NCC_6F_4CN_2S_2$	WF	35.5	45	0.00009	—
$Mn^{II}(hfac)_2NITC_2H_5$	FI	7.8	39,400	0.03	27,600
$Mn^{II}(hfac)_2NIT(i\text{-}C_3H_8)$	FI	7.6	42,400	<0.0005	<420
$[Mn(hfac)_2]_3[\{ON[C_6H_3(t\text{-}C(CH_3)_3]_2NO]_2\}$	FI	46	24,400	—	—
$[MnTPP][TCNE]\cdot 2C_6H_5CH_3$	FI	13	18,400	2.4	10,300
$V[TCNE]_x.yCH_2Cl_2$ (x ~ 2; y ~ 0.5)	FI	~400	28,200	0.0015 - 0.006	1,650
$Mn[TCNE]_x.yCH_2Cl_2$ (x ~ 2; y ~ 0.5)	FI	75	52,000	0.002	270
$Fe[TCNE]_x.yCH_2Cl_2$ (x ~ 2; y ~ 0.5)	FI	97	46,300	0.23	3
$Co[TCNE]_x.yCH_2Cl_2$ (x ~ 2; y ~ 0.5)	FI	44	22,000	0.65	—

List of Symbols and Abbreviations

M_s	Saturation magnetization at 2 K
H_{cr}	Coercive Field
T_c	Critical Temperature
M_r	Remanent magnetization at 2 K
TCNE	Tetracyanoethylene
TCNQ	7,7,8,8-Tetracyano-*p*-quinodimethane
hfac	Hexafluoroacetonate
NIT	Nitronyl nitroxide
FO	Ferromagnet
FI	Ferrimagnet
MM	Metamagnet
WF	Weak ferromagnet



1,3,5,7-Tetramethyl-2,6-diazaadamantane-N,N'-doxyl



2-(4'-Nitrophyenyl)-4,4,5,5-tetramethyl-4,5-dihydro-1H-imidazol-1-oxyl-3-*N*-oxide

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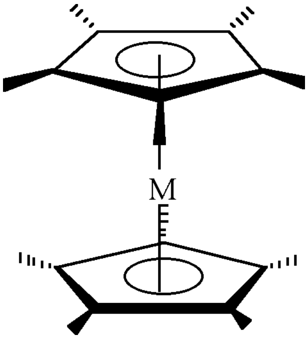
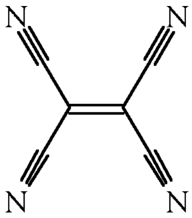
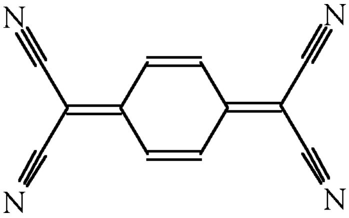
ORGANIC MAGNETS (continued)



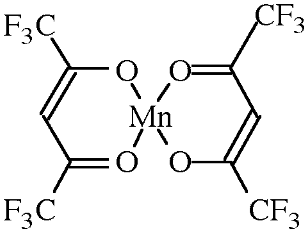
$M[C_5(CH_3)_5]_2$(M = Cr, Mn, Fe)



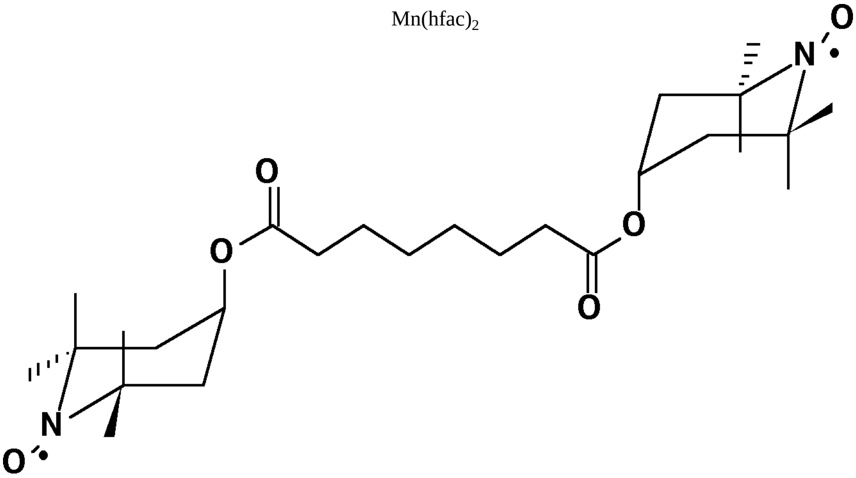
TCNE



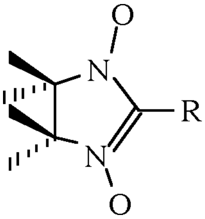
TCNQ



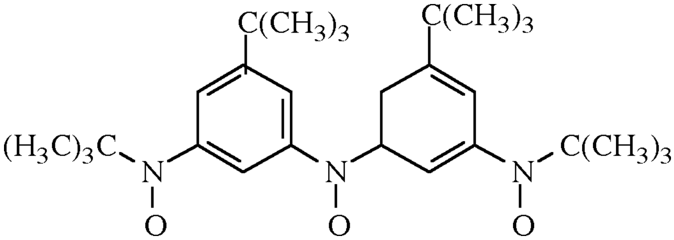
$Mn(hfac)_2$



Tanol subarate



NITR (R = C_2H_5, i-C_3H_8, n-C_3H_8)



$\{ON[C_6H_3(t\text{-}C(CH_3)_3]_2NO]_2\}$

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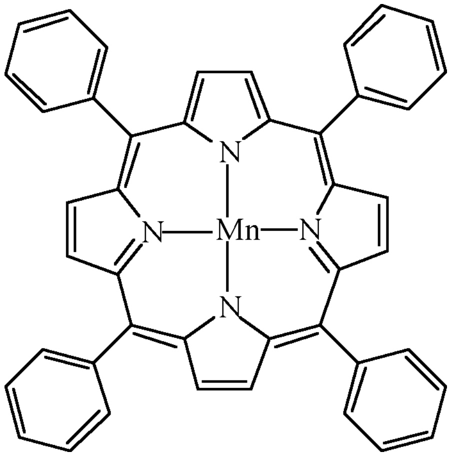
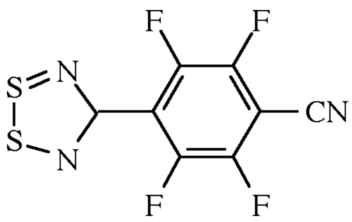


MnTPP



$NCC_6F_4CN_2S_2$

REFERENCES

1. Miller, J. S. and Epstein, A. J., *Angew. Chem. Internat. Ed.*, 33, 385, 1994.
2. Chiarelli, R., Rassat, A., Dromzee, Y., Jeannin, Y., Novak, M. A., and Tholence, J. L., *Phys. Scrip.*, T49, 706, 1993.
3. Kinoshita, M., *Jap. J. Appl. Phys.*, 33, 5718, 1994.
4. Gatteschi, D., *Adv. Mat.*, *6*, 635, 1994.
5. Miller, J. S. and Epstein, A. J., *J. Chem. Soc., Chem. Commun*., 1319, 1998.
6. Broderick, W. E., Eichorn, D. M., Lu, X., Toscano, P. J., Owens, S. M. and Hoffman, B. M., *J. Am. Chem. Soc.*, 117, 3641, 1995.
7. Banister, A. J., Bricklebank, N., Lavander, I., Rawson, J., Gregory, C. I., Tanner, B. K., Clegg, W. J., Elsegood, M. R., and Palacio, F., *Angew. Chem. Internat. Ed.*, 35, 2533, 1996.

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OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS

L. I. Berger

Optical properties of materials are closely related to their dielectric properties. The complex dielectric function (relative permittivity) of a material is equal to

$$\varepsilon(\omega) = \varepsilon'(\omega) - j\varepsilon''(\omega),$$

where $\varepsilon'(\omega)$ and $\varepsilon''(\omega)$ are its real and imaginary parts, respectively, and ω is the angular frequency of the applied electric field. For a non-absorbing medium, the index of refraction is $n = (\varepsilon\mu)^{1/2}$, where μ is the relative magnetic permeability of the medium (material); in the majority of dielectrics, $\mu \cong 1$.

For many applications, the most important optical properties of materials are the index of refraction, the extinction coefficient, k, and the reflectivity, R. The common index of refraction of a material is equal to the ratio of the phase velocity of propagation of an electromagnetic wave of a given frequency in vacuum to that in the material. Hence, $n \geqq 1$. The optical properties of highly conductive materials like metals and semiconductors (at photon energy range above the energy gap) differ from those of optically transparent media. Free electrons absorb the incident electromagnetic wave in a thin surface layer (a few hundred nanometers thick) and then release the absorbed energy in the form of secondary waves reflected from the surface. Thus, the light reflection becomes very strong; for example, highly conductive sodium reflects 99.8% of the incident wave (at 589 nm). Introduction of the effective index of refraction, $n_{eff} = (\varepsilon')^{1/2} = n - jk$, where $\varepsilon' = \varepsilon - j\delta/\omega\ \varepsilon_o$, δ is the electrical conductivity of the material in S/m, and $\varepsilon_o = 8.8542 \cdot 10^{-12}$ F/m is the permittivity of vacuum, allows one to apply the expressions of the optics of transparent media to the conductive materials. It is clear that the effective index of refraction may be smaller than 1. For example, $n = 0.05$ for pure sodium and $n = 0.18$ for pure silver (at 589.3 nm). At very high photon energies, the quantum effects, such as the internal photoeffect, start playing a greater role, and the optical properties of these materials become similar to those of insulators (low reflectance, existence of Brewster's angle, etc.).

The extinction coefficient characterizes absorption of the electromagnetic wave energy in the process of propagation of a wave through a material. The wave intensity, I, after it passes a distance x in an isotropic medium is equal to

$$I = I_0 \exp(-\alpha x),$$

where I_0 is the intensity at $x = 0$ and α is called the absorption coefficient. For many applications, the extinction coefficient, k, which is equal to

$$k = \alpha\frac{\lambda}{4\pi},$$

where λ is the wavelength of the wave in the medium, is more commonly used for characterization of the electromagnetic losses in materials.

Reflection of an electromagnetic wave from the interface between two media depends on the media indices of refraction and on the angle of incidence. It is characterized by the reflectivity, which is equal to the ratio of the intensity of the wave reflected back into the first medium to the intensity of the wave approaching the interface. For polarized light and two non-absorbing media,

$$R = \frac{(N_1 - N_2)^2}{(N_1 + N_2)^2},$$

where $N_1 = n_1/\cos\theta_1$ and $N_2 = n_2/\cos\theta_2$ for the wave polarized in the plane of incidence, and $N_1 = n_1\cos\theta_1$ and $N_2 = n_2\cos\theta_2$ for the wave polarized normal to the plane of incidence; θ_1 and θ_2 are the angles between the normal to the interface in the point of incidence and the directions of the beams in the first and second medium, respectively. The reflectivity at normal incidence in this case is

$$R = [(n_1 - n_2)/(n_1 + n_2)]^2$$

For any two opaque (absorbing) media, the normal incidence reflectivity is

$$R = \frac{(n_1 - n_2)^2 + k_2^2}{(n_1 + n_2)^2 + k_2^2}.$$

In the majority of experiments, the first medium is air ($n \approx 1$), and hence,

$$R = \frac{(1 - n)^2 + k^2}{(1 + n)^2 + k^2}.$$

The data on n and k in the following table are abridged from the sources listed in the references. The reflectivity at normal incidence, R, has been calculated from the last equation. For convenience, the energy E, wavenumber ν, and wavelength λ are given for the incidence radiation.

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
Crystalline Arsenic Selenide (As_2Se_3) [Ref. 1]*											
2.194	17700	0.565					0.30				
2.168	17480	0.572					0.25				
2.141	17270	0.579					0.20				
2.123	17120	0.584					0.17				
2.098	16920	0.591					0.13				
2.094	16890	0.592						0.26			
2.091	16860	0.593						0.26			
2.073	16720	0.598					0.10	0.23			
2.060	16610	0.602						0.20			
2.049	16530	0.605					0.079	0.17			
2.036	16420	0.609						0.15			
2.023	16310	0.613						0.12			
2.013	16230	0.616					0.050				
2.009	16210	0.617						0.097			
2.000	16130	0.620						0.082			
1.987	16030	0.624						0.063			
1.977	15940	0.627					0.031				
1.974	15920	0.628						0.051			
1.962	15820	0.632						0.038			
1.953	15750	0.635						0.030			
1.949	15720	0.636					0.020				
1.937	15630	0.640						0.022			
1.925	15530	0.644						0.017			
1.922	15500	0.645					0.012				
1.905	15360	0.651					$8.6 \cdot 10^{-3}$				
1.893	15270	0.655					6.4				
1.881	15170	0.659					5.2				
1.859	14990	0.667					3.1				
1.848	14900	0.671						$1.7 \cdot 10^{-3}$			
1.845	14880	0.672					2.0				
1.842	14860	0.673						$1.2 \cdot 10^{-3}$			
1.831	14770	0.677					$1.3 \cdot 10^{-3}$	$9.0 \cdot 10^{-4}$			
1.826	14730	0.679						6.4			
1.821	14680	0.681						4.7			
1.818	14660	0.682					$8.6 \cdot 10^{-4}$				
1.815	14640	0.683						3.4			
1.807	14580	0.686					5.5				
1.802	14530	0.688					4.1				
0.06199	500.0	20.0		3.2	2.9		$1.7 \cdot 10^{-3}$	$1.8 \cdot 10^{-3}$		0.27	0.24
0.05904	476.2	21.0		3.1	2.9		$2.1 \cdot 10^{-3}$	$2.2 \cdot 10^{-3}$		0.26	0.24
0.05636	454.5	22.0		3.1	2.9		$2.5 \cdot 10^{-3}$	$2.6 \cdot 10^{-3}$		0.26	0.24
0.05391	434.8	23.0		3.1	2.9		$3.0 \cdot 10^{-3}$	$3.1 \cdot 10^{-3}$			
0.04592	370.4	27.0		3.0	2.8		$6.3 \cdot 10^{-3}$	$6.4 \cdot 10^{-3}$		0.25	0.22
0.04428	357.1	28.0		3.0	2.8		$7.6 \cdot 10^{-3}$	$7.7 \cdot 10^{-3}$		0.25	0.22
0.04275	344.8	29.0		3.0	2.8		0.0092	0.0093		0.25	0.22
0.04133	333.3	30.0		3.0	2.7		0.011	0.011		0.25	0.21
0.03542	285.7	35.0		2.7	2.5			0.037	0.034	0.21	0.18
0.03100	250.0	40.0		1.9	1.7			0.38	1.0	0.19	0.18
0.03061	247.0	40.5		2.0	2.6			0.33	0.95	0.12	0.25
0.03024	244.0	41.0		1.7	2.4			0.41	0.46	0.088	0.18
0.02883	232.6	43.0		1.2	1.3			2.2	0.94	0.50	0.16
0.02850	229.9	43.5		1.6	1.2			2.8	1.4	0.56	0.29
0.02818	227.3	44.0		2.3	1.2		3.3	2.0		0.58	0.48
0.02755	222.2	45.0		4.2	2.0		2.5	3.3		0.50	0.60
0.02480	200.0	50.0		6.5	4.0		3.6	0.26		0.62	0.36
0.02254	181.8	55.0		4.5	3.5		0.17	0.10		0.40	0.31

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	n	n_a	n_c	k	k_a	k_c	R	R_a	R_c
0.02066	166.7	60.0		4.0	3.2		0.089	0.10		0.36	0.27
0.01907	153.8	65.0		3.8	3.1		0.097	0.16		0.34	0.26
0.01771	142.9	70.0		3.6	3.0		0.19	0.30		0.32	0.25
0.01653	133.3	75.0		3.7	3.0		0.41	0.44		0.34	0.26
0.01550	125.0	80.0		3.8	3.1		0.29	0.40		0.34	0.27
0.01459	117.6	85.0		3.6	2.9		0.20	0.34		0.32	0.24
0.01378	111.1	90.0		3.2	2.6		0.43	0.49		0.28	0.21
0.01305	105.3	95.0		4.7	3.0		1.5	1.5		0.46	0.34
0.01240	100.0	100.0		4.4	2.7		0.22	0.81		0.40	0.25
0.01181	95.24	105.0		4.2	3.0		0.094	3.9		0.38	0.62
0.01127	90.91	110.0		4.1	5.3		0.059	0.70		0.37	0.47
0.01033	83.33	120.0		3.9	4.2		0.034	0.13		0.35	0.38
0.009537	76.92	130.0		3.9	4.0		0.024	0.069		0.35	0.36
0.008856	71.43	140.0		3.9	3.8		0.019	0.048		0.35	0.34
0.007749	63.50	160.0		3.8	3.7		0.014	0.032		0.34	0.33
0.006888	55.55	180.0		3.8	3.7		0.011	0.024		0.34	0.33
0.006199	50.0	200.0		3.8	3.6		0.0091	0.019		0.34	0.32

*Indices a and c relate to the radiation electric field parallel to the a and c axes of the crystal, respectively.

Vitreous Arsenic Selenide (As_2Se_3) [Ref. 1]

2.056	16580	0.603				0.12					
2.026	16340	0.612				0.11					
2.006	16180	0.618				0.099					
1.990	16050	0.623				9.0					
1.925	15530	0.644				5.6					
1.826	14730	0.679				1.4					
1.810	14600	0.685				0.012					
1.794	14470	0.691				0.0089					
1.771	14290	0.700				6.2					
1.715	13830	0.723				2.6					
1.701	13720	0.729				0.0022					
1.647	13280	0.753				0.00046					
1.629	13140	0.761	3.07			4.0			0.62		
1.596	12870	0.777	3.06			2.7			0.49		
1.579	12740	0.785	3.05			1.9			0.39		
1.562	12590	0.794	3.05			0.00013			0.26		
1.544	12450	0.803	3.04			0.000094			0.25		
1.529	12330	0.811	3.03			6.3			0.78		
1.512	12200	0.820	3.03			4.2			0.64		
1.494	12050	0.830	3.02			2.8			0.50		
1.476	11910	0.840	3.01			1.8			0.38		
1.378	11110	0.90	2.98								
1.240	10000	1.00	2.93								
1.127	9091	1.10	2.90								
1.051	8475	1.18	2.89								
1.033	8333	1.20	2.88								
0.2555	1980	5.05				$1.6 \cdot 10^{-7}$					
0.2380	1919	5.21				$9.9 \cdot 10^{-8}$					
0.2344	1890	5.29				$1.1 \cdot 10^{-7}$					
0.1345	1085	9.22				4.4					
0.1339	1080	9.26				3.7					
0.1333	1075	9.30				4.4					
0.1308	1055	9.48				4.5					
0.1215	980	10.20				8.9					
0.1203	970	10.31				$9.9 \cdot 10^{-7}$					
0.1196	965	10.36				$1.0 \cdot 10^{-6}$					

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	n	n_a	n_c	k	k_a	k_c	R	R_a	R_c
0.1178	950	10.53				1.1					
0.1116	900	11.11				1.8					
0.1004	810	12.35				4.9					
0.09919	800	12.50				$7.0 \cdot 10^{-6}$					
0.09795	790	12.66				$1.0 \cdot 10^{-5}$					
0.09671	780	12.82				1.5					
0.09299	750	13.33				3.7					
0.08555	690	14.49				6.9					
0.08431	680	14.71				5.9					
0.08059	650	15.38				6.1					
0.07811	630	15.87				6.3					
0.07687	620	16.13				7.7					
0.07563	610	16.39				7.8					
0.07439	600	16.67				$9.3 \cdot 10^{-5}$					
0.07315	590	16.95	2.8			$1.2 \cdot 10^{-4}$			0.22		
0.07191	580	17.24	2.8			1.4			0.32		
0.07067	570	17.54	2.8			1.8			0.37		
0.06943	560	17.86	2.8			2.8			0.50		
0.06633	535	18.69	2.8			5.2			0.73		
0.06571	530	18.87	2.8			$7.2 \cdot 10^{-4}$			0.22		
0.06509	525	19.05	2.8			$1.2 \cdot 10^{-3}$			0.22		
0.06447	520	19.23	2.8			1.7			0.35		
0.06075	490	20.41	2.7			4.9			0.71		
0.06024	485.9	20.58	2.7			5.2			0.73		
0.05331	430	23.26	2.7			1.4			0.31		
0.05269	425	23.53	2.7			$1.1 \cdot 10^{-3}$			0.21		
0.05207	420	23.81	2.7			$8.5 \cdot 10^{-4}$			0.21		
0.05145	415	24.10	2.7			7.3			0.84		
0.05083	410	24.39	2.7			8.3			0.87		
0.05021	405	24.69	2.7			$9.4 \cdot 10^{-4}$			0.21		
0.04959	400	25.0	2.7			$1.2 \cdot 10^{-3}$			0.21		
0.04862	392.2	25.5	2.6			1.6			0.33		
0.04679	377.4	26.5	2.6			5.0			0.73		
0.04592	370.4	27.0	2.6			$8.0 \cdot 10^{-3}$			0.20		
0.04509	363.6	27.5	2.6			$1.2 \cdot 10^{-2}$			0.20		
0.04428	357.1	28.0	2.6			1.7			0.34		
0.03875	312.5	32.0	2.5			8.2			0.87		
0.03815	307.7	32.5	2.5			$9.3 \cdot 10^{-3}$			0.18		
0.03757	303.0	33.0	2.4			0.11			0.17		
0.02988	241.0	41.5	2.2			0.89			0.20		
0.02952	238.1	42.0	2.2			1.0			0.22		
0.02725	219.8	45.5	3.2			1.8			0.39		
0.02362	190.5	52.5	3.6			0.30			0.32		
0.01937	156.2	64.0	3.2			0.10			0.27		
0.01922	155.0	64.5	3.2			$9.6 \cdot 10^{-2}$			0.27		
0.01907	153.8	65.0	3.2			9.4			0.88		
0.01734	139.9	71.5	3.1			8.7			0.87		
0.01653	133.3	75.0	3.1			9.4			0.88		
0.01642	132.5	75.5	3.1			0.096			0.26		
0.01494	120.5	83.0	3.0			0.15			0.25		
0.01246	100.5	99.5	3.2			0.60			0.26		
0.007606	61.35	163.0	3.3			0.12			0.29		
0.006199	50.00	200.0	3.2								
0.004592	37.04	270.0	3.1			0.072			0.26		
0.002799	22.57	443.0	3.0			4.5			0.67		
0.001826	14.73	679.0	3.0			2.8			0.50		
0.001273	10.27	974.0	3.0			2.1			0.41		
0.0006491	5.236	1910.0	3.0			$1.1 \cdot 10^{-2}$			0.25		

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
0.0004376	3.530	2833.0	3.0			$7.5\cdot10^{-3}$			0.25		
0.0002903	2.341	4271.0	3.0			5.0			0.71		
0.0001716	1.384	7224.0	3.0			3.1			0.53		
0.00009047	0.7297	13704	3.0			$1.6\cdot10^{-3}$			0.25		
0.00005621	0.4534	22056	3.0			$9.9\cdot10^{-4}$			0.25		
0.00002774	0.2237	44699	3.0			5.2			0.72		
0.00001439	0.1161	86153	3.0			2.6			0.47		

Vitreous Arsenic Sulfide (As_2S_3) - [Ref. 2]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
4.959	40000	0.2500	2.48			1.21			0.27		
3.100	25000	0.40	3.09			0.34			0.27		
2.48	20000	0.4999	2.83			0.013			0.23		
1.879	15150	0.66	2.59			$1.7\cdot10^{-6}$			0.20		
1.240	10000	1.0	2.48			$2.4\cdot10^{-7}$			0.18		
0.6199	5000	2.0	2.43						0.17		
0.3100	2500	4.0	2.41						0.17		
0.2480	2000	5.0	2.41						0.17		
0.1736	1400	7.143	2.40			$7.4\cdot10^{-7}$			0.17		
0.1240	1000	10.00	2.38			$1.3\cdot10^{-4}$			0.17		
0.09299	750	13.33	2.35			$3.0\cdot10^{-3}$			0.16		
0.07439	600	16.67	2.31			$4.6\cdot10^{-4}$			0.16		
0.04959	400.0	25.0	1.79			0.2			0.085		
0.03757	303.0	33.0	3.59			1.4			0.38		
0.03100	250.0	40.0	2.98			0.15			0.25		
0.02480	200.0	50	2.66			0.11			0.21		
0.02066	166.7	60	2.64			0.57			0.22		
0.01771	142.9	70	2.99			0.17			0.25		
0.01550	125.0	80	2.89			0.14			0.24		
0.01378	111.1	90	2.84			0.12			0.23		
0.01240	100	100	2.81			0.10			0.23		
0.008183	66	152	2.76			0.072			0.22		
0.004029	32.5	308	2.74			0.044			0.22		
0.002418	19.5	513	2.74			0.031			0.22		
0.001984	16	625	2.74			0.025			0.22		
0.001048	8.45	1180	2.73			$8.8\cdot10^{-3}$			0.22		
0.0001033	0.833	12000	2.73			$1.3\cdot10^{-3}$			0.22		
$4.129\cdot10^{-12}$	$3.33\cdot10^{-8}$	$3\cdot10^{-11}$	2.73						0.22		

Cadmium Telluride (CdTe) - [Ref. 3]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
4.9	39520	0.2530	2.48			2.04			0.39		
4.1	33070	0.3024	2.33			1.59			0.32		
3.9	31460	0.3179	2.57			1.90			0.37		
3.5	28230	0.3542	2.89			1.52			0.34		
3.1	25000	0.4000	3.43			1.02			0.34		
3.0	24200	0.4133	3.37			0.861			0.32		
2.755	22220	0.45	3.080			0.485			0.27		
2.75	22180	0.4509	3.23			0.636			0.29		
2.610	21050	0.475	3.045								
2.5	20160	0.4959	3.14			0.525			0.28		
2.25	18150	0.5510	3.05			0.411			0.26		
1.771	14290	0.70	2.861			0.210			0.23		
1.512	12200	0.82	2.880			0.040			0.23		
1.50	12100	0.8266	2.98			0.319			0.25		
1.475	11900	0.840	2.905			0.00134			0.24		
1.47	11860	0.8434				0.000671					
1.465	11820	0.8463				3.37					

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	n	n_a	n_c	k	k_a	k_c	R	R_a	R_c
1.46	11780	0.8492				1.89					
1.459	11760	0.850	2.948						0.24		
1.455	11740	0.8521				$1.08 \cdot 10^{-4}$					
1.45	11690	0.8551	2.9565			$5.10 \cdot 10^{-5}$			0.24		
1.445	11650	0.8580				2.73					
1.442	11630	0.860	2.952						0.24		
1.44	11610	0.8610	2.9479			1.37			0.32		
1.43	11530	0.8670	2.9402						0.24		
1.30	10490	0.9537	2.8720						0.23		
1.24	10000	1.0	2.840						0.23		
1.20	9679	1.033	2.8353						0.23		
1.10	8872	1.127	2.8050						0.23		
1.00	8065	1.240	2.7793						0.22		
0.90	7259	1.378	2.7537						0.22		
0.80	6452	1.550	2.7384						0.22		
0.70	5646	1.771	2.7223						0.21		
0.60	4839	2.066	2.7086						0.21		
0.50	4033	2.480	2.6972						0.21		
0.40	3226	3.100	2.6878						0.21		
0.30	2420	4.133	2.6800						0.21		
0.20	1613	6.199	2.6722						0.21		
0.10	806.5	12.40	2.6535						0.20		
0.09	725.9	13.78	2.6482						0.20		
0.06819	550	18.18	2.623						0.20		
0.0573	462	21.6				$3.8 \cdot 10^{-6}$					
0.05	403.3	24.80	2.5801						0.19		
0.0469	378	26.5				$8.0 \cdot 10^{-5}$					
0.04592	370.3	27				$9.88 \cdot 10^{-5}$					
0.04133	333.3	30	2.55916			$2.86 \cdot 10^{-4}$			0.19		
0.04092	330	30.30	2.531			3.34			0.57		
0.03720	300	33.33	2.494			4.97			0.73		
0.03647	294.1	34.00				8.93					
0.03596	290	34.48	2.478			$5.77 \cdot 10^{-3}$			0.18		
0.03493	281.7	35.5				7.91					
0.03472	280	35.71	2.459			6.76			0.83		
0.03100	250	40	2.378			$1.18 \cdot 10^{-2}$			0.17		
0.02917	235.3	42.5				6.93					
0.02852	230	43.48	2.289			1.87			0.36		
0.02728	220	45.45	2.224			$2.47 \cdot 10^{-2}$			0.14		
0.02604	210	47.62	2.137			$3.4 \cdot 10^{-2}$			0.13		
0.02480	200	50.00	2.013			$4.97 \cdot 10^{-2}$			0.11		
0.02384	192.3	52.0				6.21					
0.01798	145	68.97	1.8			5.2			0.79		
0.01736	140	71.43	6.778			4.50			0.66		
0.01550	125	80.0	4.598			0.294			0.41		
0.01364	110	90.91	3.868			$9.47 \cdot 10^{-2}$			0.35		
0.01240	100	100	3.649			$5.68 \cdot 10^{-2}$			0.32		
0.009919	80	125	3.415			0.0262			0.30		
0.008679	70	142.9	3.348			0.0189			0.29		
0.007439	60	166.7	3.299			1.39			0.35		
0.006199	50	200	3.263			1.03			0.32		
0.004959	40	250	3.236			$7.52 \cdot 10^{-3}$			0.28		
0.003720	30	333.3	3.217						0.28		
0.023015	18.563		538.71			3.2096			0.28		
0.001550	12.50	800				6.18					

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
Gallium Arsenide (GaAs) - [Ref. 4]											
155		0.007999				0.0181					
145		0.008551				0.0203					
130		0.009537				0.0224					
110		0.01127				0.0278					
90		0.01378				0.0323					
70		0.01771				0.0376					
40		0.03100				0.0426					
23		0.05391	1.037			0.228					
7.0		0.1771	1.063			1.838					
6.0	48390	0.2066	1.264			2.472			0.61		
5.00	40330	0.2480	2.273			4.084			0.67		
4.00	32260	0.3100	3.601			1.920			0.42		
3.00	24200	0.4133	4.509			1.948			0.47		
2.50	20160	0.4959	4.333			0.441			0.39		
2.00	16130	0.6199	3.878			0.211			0.35		
1.80	14520	0.8888	3.785			0.151			0.34		
1.60	12900	0.7749	3.700			0.091			0.33		
1.50	12100	0.8266	3.666			0.080			0.33		
1.40	11290	0.8856	3.6140			$1.69 \cdot 10^{-3}$			0.32		
1.20	9679	1.033	3.4920						0.31		
1.00	8065	1.240	3.4232						0.30		
0.80	6452	1.550	3.3737						0.29		
0.50	4033	2.480	3.3240						0.29		
0.25	2016	4.959	3.2978						0.29		
0.15	1210	8.266	3.2831						0.28		
0.100	806.5	12.40	3.2597			$4.93 \cdot 10^{-6}$			0.28		
0.090	725.9	13.78	3.2493			$1.64 \cdot 10^{-5}$			0.28		
0.070	564.6	17.71	3.2081			$2.32 \cdot 10^{-4}$			0.28		
0.060	483.9	20.66	3.1609			$3.45 \cdot 10^{-3}$			0.27		
0.0495	399.2	25.05	3.058			$2.07 \cdot 10^{-3}$			0.26		
0.03968	320	31.25	2.495			$2.43 \cdot 10^{-2}$			0.18		
0.03496	282	35.46	0.307			$294 \cdot 10^{-2}$					
0.02976	240	41.67	4.57			$4.26 \cdot 10^{-2}$			0.41		
0.02066	166.7	60	3.77			$3.89 \cdot 10^{-3}$			0.34		
0.01550	125	80	3.681			$1.84 \cdot 10^{-3}$			0.33		
0.008266	66.67	150	3.62			$2.14 \cdot 10^{-3}$			0.32		
0.002480	20	500	3.607			$1.3 \cdot 10^{-3}$			0.32		
0.001240	10	1000	3.606						0.32		
Gallium Phosphide (GaP) - [Ref. 5]											
154.0		0.00805				$1.7 \cdot 10^{-2}$					
110.0		0.0113				$2.15 \cdot 10^{-2}$					
100.0		0.0124				$215 \cdot 10^{-2}$					
80.0		0.0155				$3.0 \cdot 10^{-2}$					
50.0		0.0248				$4.7 \cdot 10^{-2}$					
27.0		0.0459				$9.3 \cdot 10^{-2}$					
25.0		0.0496				0.122					
20.0		0.0620				0.180					
15.0		0.0826	0.748			0.628					
5.5	44360	0.2254	1.543			3.556			0.68		
4.68	37750	0.2649	4.181			2.634			0.50		
3.50	28230	0.3542	5.050			0.819			0.46		
3.00	24200	0.4133	4.081			0.224			0.37		
2.78	22420	0.4460	3.904			0.103			0.35		

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
2.621	21140	0.473	3.73			$6.37 \cdot 10^{-3}$			0.33		
2.480	20000	0.500	3.590			$2.47 \cdot 10^{-3}$			0.32		
2.18	17580	0.5687	3.411			$2.8 \cdot 10^{-7}$			0.30		
2.000	16130	0.62	3.3254						0.29		
1.6	12900	0.7749	3.209						0.28		
1.240	10000	1.0	3.1192						0.26		
0.6888	5556	1.8	3.0439						0.26		
0.4769	3846	2.6	3.0271						0.25		
0.1907	1538	6.5	2.995			$4.29 \cdot 10^{-4}$			0.25		
0.1550	1250	8.0	2.984						0.25		
0.1240	1000	10	2.964						0.25		
0.06199	500	20	2.615			$7.16 \cdot 10^{-3}$			0.20		
0.03100	250	40	3.594			$1.81 \cdot 10^{-2}$			0.32		
0.02480	200	50	3.461			$5.77 \cdot 10^{-3}$			0.30		
0.01727	139.27	71.80	3.3922			$4.34 \cdot 10^{-3}$			0.30		
0.01168	94.21	106.1	3.3621			$4.26 \cdot 10^{-3}$			0.29		
0.006199	50.00	200	3.3447			$1.3 \cdot 10^{-4}$			0.29		
0.004133	33.33	300	3.3413						0.29		
0.001240	10.00	1000	3.3319						0.29		

Indium Antimonide (InSb) - [Ref. 6]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
155		0.007999				$4.77 \cdot 10^{-3}$					
60		0.02066				$7.30 \cdot 10^{-2}$					
25		0.04959	1.15			.015					
24		0.05166	1.15			0.18					
15		0.08266	0.97			0.230					
10		0.1240	0.74			0.88					
5.00	40330	0.2480	1.307			2.441			0.53		
4.50	36290	0.2755	1.443			2.894			0.60		
4.00	32260	0.3100	2.632			3.694			0.61		
3.34	26940	0.3712	3.528			2.280			0.45		
2.84	22910	0.4366	3.340			2.021			0.45		
1.80	14520	0.6888	4.909			1.396			0.47		
1.50	12100	0.8266	4.418			0.643			0.41		
0.6	4839	2.066	4.03						0.36		
0.2480	2000	5.0	4.14			$9.1 \cdot 10^{-2}$			0.37		
0.1907	1538	6.5	4.30			$6.3 \cdot 10^{-2}$			0.39		
0.1653	1333	7.5	4.18			$2.7 \cdot 10^{-2}$			0.38		
0.06199	500	20.00	3.869			$2.0 \cdot 10^{-3}$			0.35		
0.03100	250	40.00	2.98			$2.6 \cdot 10^{-3}$			0.25		
0.02480	200	50.00	2.22			0.165			0.14		
0.02244	181	55.25	3.05			7.59			0.84		
0.02207	178	56.18	9.61			4.20			0.70		
0.02033	164	60.98	4.94			0.140			0.44		
0.01054	85	117.6	2.12			0.423			0.14		
0.005579	45	222.2	1.02			5.59			0.88		
0.001860	15	666.7	6.03			17.9			0.93		
0.001240	10	1000	10.7			24.0			0.94		

Indium Arsenide (InAs) - [Ref. 7]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
25		0.04959				1.139			0.168		
20		0.06199				1.125			0.225		
15		0.08266				0.894			0.336		
10		0.1240				0.835			1.071		
6	48390	0.2066	1.434			2.112			0.45		
5.0	40330	0.2480	1.524			2.871			0.58		

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	n	n_a	n_c	k	k_a	k_c	R	R_a	R_c
4.0	32260	0.3100	3.313			1.799			0.39		
3.5	28230	0.3542	3.008			1.754			0.37		
3.0	24200	0.4133	3.197			2.034			0.41		
2.5	20160	0.4959	4.364			1.786			0.45		
2.44	19680	0.5081	4.489			1.446			0.44		
1.86	15000	0.6666	3.889			0.554			0.36		
1.8	14520	0.6888	3.851			0.530			0.35		
1.7	13710	0.7293	3.798			0.493			0.35		
1.6	12900	0.7749	3.755			0.463			0.34		
1.5	12100	0.8266	3.714			0.432			0.34		
1.2	9679	1.033	3.613						0.32		
1.0	8065	1.240	3.548						0.31		
0.6	4839	2.066				0.161					
0.35	2823	3.542	3.608			$9.58 \cdot 10^{-3}$			0.32		
0.32	2581	3.875	3.512			$1.23 \cdot 10^{-4}$			0.31		
0.20	1613	6.199	3.427						0.30		
0.1240	1000	10.00	3.402						0.30		
0.06199	500	20.00	3.334						0.29		
0.04959	400	25.00	3.264						0.28		
0.04339	350	28.57	3.182			$5.46 \cdot 10^{-3}$			0.27		
0.03720	300	33.33	2.988						0.25		
0.03100	250	40.00	1.970			$6.37 \cdot 10^{-2}$			0.11		
0.02765	222	44.84	5.90			6.53			0.74		
0.02480	200	50.00	6.91			0.30			0.56		
0.01984	160	62.50	5.27			0.41			0.47		
0.01860	150	66.67	5.27			0.51			0.47		
0.01736	140	71.43	3.99			$1.1 \cdot 10^{-2}$			0.36		
0.01488	120	83.33	3.91			$6.6 \cdot 10^{-3}$			0.35		
0.01240	100	100.0	3.85			$4.3 \cdot 10^{-3}$			0.35		
0.009919	80	125.0	3.817						0.34		
0.007439	60	166.7	3.793						0.34		
0.004959	40	250.0	3.778						0.34		
0.002480	20	500	3.769						0.37		
0.001240	10	1000	3.766						0.34		

Indium Phosphide (InP) - [Ref. 8]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	n	n_a	n_c	k	k_a	k_c	R	R_a	R_c
20		0.06199	0.793			0.494					
15		0.08266	0.695			0.574					
10		0.1240	0.806			1.154					
5.5	44360	0.2254	1.426			2.562			0.79		
5.0	40330	0.2480	2.131			3.495			0.61		
4.0	32260	0.3100	3.141			1.730			0.38		
3.0	24200	0.4133	4.395			1.247			0.43		
2.0	16130	0.6199	3.549			0.317			0.32		
1.5	12100	0.8266	3.456			0.203			0.31		
1.25	10085	0.9915	3.324						0.29		
1.00	8068	1.239	3.220						0.28		
0.50	4034	2.479	3.114						0.26		
0.30	2420	4.131	3.089						0.26		
0.10	806.8	12.39	3.012						0.25		
0.075	605.1	16.53	2.932						0.24		
0.060	484.1	20.66	2.780			$1.46 \cdot 10^{-2}$			0.22		
0.050	403.4	24.79	2.429			$3.35 \cdot 10^{-2}$			0.17		
0.03992	322	31.06	0.307			3.57					
0.03496	282	35.46	3.89			0.282			0.35		
0.03100	250	40.00	4.27			$3.0 \cdot 10^{-2}$			0.39		
0.02728	220	45.45	3.93			$1.3 \cdot 10^{-2}$			0.35		

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
0.02480	200	50.0	3.81			$8.7 \cdot 10^{-3}$			0.34		
0.02418	195	51.28	3.19						0.27		
0.02232	180	55.56	3.19						0.27		
0.01860	150	66.67	3.65						0.32		
0.01240	100	100	3.57						0.32		
0.009919	80	125.0	3.551						0.31		
0.007439	60	166.7	3.538						0.31		
0.004959	40	250.0	3.529						0.31		
0.002480	20	500	3.523						0.31		
0.001240	10	1000.0	3.522						0.31		

Lead Selenide (PbSe) - [Ref. 9]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
14.5		0.08551	0.72			0.20					
10		0.1240	0.68			0.50					
5	40330	0.2480	0.54			1.2					
2.0	16130	0.6199	3.65			2.9			0.51		
1.65	13310	0.7514	4.51			1.73			0.46		
1.5	12100	0.8266	4.64			2.64			0.52		
1.0	8065	1.240	4.65			1.1			0.44		
0.75	6049	1.653				0.269					
0.62	5001	2.000	4.59			0.770			0.42		
0.48	3871	2.583	4.90						0.44		
0.40	3226	3.100	4.91						0.44		
0.32	2581	3.875	4.98			0.173			0.44		
0.20	1613	6.199	4.82						0.43		
0.1190	960	10.42	4.74			$1.20 \cdot 10^{-3}$			0.42		
0.09919	800	12.50	4.72			$2.09 \cdot 10^{-3}$			0.42		
0.07935	640	15.63	4.68			$4.12 \cdot 10^{-3}$			0.42		
0.05951	480	20.83	4.59			$1.00 \cdot 10^{-2}$			0.41		
0.04959	400	25.00	4.49			$1.77 \cdot 10^{-2}$			0.40		
0.03968	320	31.25	4.31			$3.62 \cdot 10^{-2}$			0.39		
0.02976	240	41.67	3.89			$9.61 \cdot 10^{-2}$			0.24		
0.01984	160	62.50	2.34			0.56			0.18		
0.009919	80	125.0	1.73			7.38			0.88		
0.007935	64	156.3	2.91			10.1			0.90		
0.004959	40	250.0	11.2			14.6			0.88		
0.002480	20	500.0	12.6			12.2					
0.001736	14	714.3	14.1			16.6					
0.001240	10	1000	17.4			21.1					

Lead Sulfide (PbS) - [Ref. 10]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
150		0.008266				$3.86 \cdot 10^{-3}$					
125		0.009919				$5.59 \cdot 10^{-3}$					
100		0.01240				$1.54 \cdot 10^{-2}$					
80		0.01550				$2.88 \cdot 10^{-2}$					
60		0.02066				$6.17 \cdot 10^{-2}$					
25		0.04959	0.845			0.171					
18.0		0.06888	0.846			0.294					
14.0		0.08856	0.651			0.665					
10.0		0.1240	0.879			1.050					
4.95	39920	0.2505	1.52			2.10			0.43		
4.0	32260	0.3100	1.73			2.83			0.55		
3.00	24200	0.4133	3.88			3.00			0.53		
2.90	23390	0.4275	4.12			2.70			0.51		
2.75	22180	0.4509	4.25			2.33			0.48		
2.55	20570	0.4862	4.35			2.00			0.47		

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
2.00	16130	0.6199	4.29			1.48			0.43		
1.60	12910	0.7749	4.62			0.94			0.43		
1.24	10000	1.00	4.43			0.597			0.41		
1.03	8333	1.2	4.30			0.458			0.39		
0.650	5263	1.9	4.24			0.318			0.39		
0.496	4000	2.5	4.30			0.235			0.39		
0.400	3226	3.1	4.30			$2.27\cdot10^{-2}$			0.39		
0.3100	2500	4.0	4.16			$6.38\cdot10^{-4}$			0.38		
0.2480	2000	5	4.115			$9.25\cdot10^{-4}$			0.37		
0.1240	1000	10	4.01			$6.32\cdot10^{-3}$			0.36		
0.1033	833.3	12	3.90			$1.14\cdot10^{-2}$			0.35		
0.08059	650	15.38	3.90						0.35		
0.06819	550	18.18	3.81						0.34		
0.04959	400	25.00	3.53						0.31		
0.03720	300	33.33	2.99						0.25		
0.02480	200.0	50	0.514			1.59					
0.01378	111.1	90	1.175			8.48			0.94		
0.01240	100.0	100	1.79			10.51			0.94		
0.008856	71.43	140	17.41			17.94			0.89		
0.006199	50.0	200	16.27			2.20			0.79		
0.003100	25.00	400	12.96			0.495			0.73		
0.001653	13.33	750	12.44			0.228			0.72		
0.001240	10.00	1000	12.35			0.167			0.72		
0.0006199	5.000	2000	12.27			0.0815			0.72		

Lead Telluride (PbTe) - [Ref. 11]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
150		0.008266				$2.37\cdot10^{-3}$					
125		0.009919				$9.71\cdot10^{-3}$					
100		0.01240				$4.39\cdot10^{-2}$					
75		0.01653				$6.43\cdot10^{-2}$					
50		0.02480				$6.87\cdot10^{-2}$					
30		0.04133				$7.77\cdot10^{-2}$					
15		0.08266	0.72			0.17					
10		0.1240	0.66			0.60					
7.5		0.1653	0.8			0.92					
5.0	40330	0.2480	0.72			1.0					
3.0	24200	0.4133	1.0			2.2					
2.5	20160	0.4959	1.35			2.86			0.61		
1.5	12100	0.8266	3.8			3.1			0.53		
1.0	8065	1.240	4.55			2.2			0.49		
0.80	6452	1.550	6.25			0.71			0.53		
0.60	4839	2.066	6.10			0.521			0.52		
0.40	3226	3.100	6.075			0.331			0.52		
0.30	2420	4.133	5.95			$3.55\cdot10^{-2}$			0.51		
0.20	1613	6.199	5.77						0.50		
0.15	1210	8.266	5.76						0.50		
0.1017	820	12.20	5.47			$9.16\cdot10^{-3}$			0.48		
0.08927	720	13.89	5.38			$1.37\cdot10^{-2}$			0.47		
0.06943	560	17.86	5.13			$3.06\cdot10^{-2}$			0.45		
0.04959	400	25.00	4.50			$9.6\cdot10^{-2}$			0.40		
0.03968	320	31.25	3.58			0.23			0.32		
0.02976	240	41.67	1.01			1.9					
0.009919	80	125.0	2.95			16.6			0.96		
0.007439	60	166.7	4.9			22.5			0.96		
0.006199	50	200.0	6.9			27.2			0.97		
0.004959	40	250.0	11.6			34.8			0.97		
0.003720	30	333.3	27.7			35.7			0.95		

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
0.002480	20	500.0	27.6			39.1			0.95		
0.001240	10	1000	45.1			57.8			0.97		

Lithium Fluoride (LiF) - [Ref. 12]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
2000		$6.199 \cdot 10^{-4}$	0.9999347			$4.33 \cdot 10^{-6}$					
1496		$8.287 \cdot 10^{-4}$	0.999883			$1.28 \cdot 10^{-5}$					
1016		$1.220 \cdot 10^{-3}$	0.999757			$5.18 \cdot 10^{-5}$					
725		$1.710 \cdot 10^{-3}$	0.999643			$1.62 \cdot 10^{-4}$					
504		$2.460 \cdot 10^{-3}$	0.999162			$4.96 \cdot 10^{-5}$					
303		$4.092 \cdot 10^{-3}$	0.99752			$3.12 \cdot 10^{-4}$					
250		$4.959 \cdot 10^{-3}$	0.99632			$6.17 \cdot 10^{-5}$					
200		$6.199 \cdot 10^{-3}$				$2.12 \cdot 10^{-3}$					
150		$8.265 \cdot 10^{-3}$	0.9899			$3.54 \cdot 10^{-3}$					
100		$1.240 \cdot 10^{-2}$	0.9801			$1.32 \cdot 10^{-2}$					
75		$1.653 \cdot 10^{-2}$				$2.63 \cdot 10^{-2}$					
50		$2.480 \cdot 10^{-2}$				$7.89 \cdot 10^{-2}$					
25		$4.959 \cdot 10^{-2}$	0.558			0.521					
20		$6.199 \cdot 10^{-2}$	1.20			0.58			0.10		
15.1		$8.211 \cdot 10^{-2}$	1.08			0.68			0.10		
13		$9.537 \cdot 10^{-2}$	1.04			1.64					
12.0		0.1033	2.28			0.11			0.15		
11.0		0.1127	1.77			$8.07 \cdot 10^{-7}$			0.08		
10.00		0.12398	1.606			$7.70 \cdot 10^{-7}$			0.05		
9		0.1375	1.53						0.04		
7		0.1771	1.46								
4.959	40000	0.250	1.4189						0.03		
4.000	32260	0.31	1.4073						0.03		
2.952	23810	0.42	1.3978						0.03		
2.000	16130	0.62	1.3915						0.03		
0.9919	8000	1.25	1.3851								
0.7999	6452	1.55	1.3858						0.03		
0.4959	4000	2.5	1.3731						0.02		
0.4000	3226	3.1	1.3650								
0.3100	2500	4.0	1.3493								
0.2480	2000	5.0	1.3266			$1.8 \cdot 10^{-6}$			0.02		
0.2000	1613	6.2	1.2912								
0.1698	1370	7.3	1.2499								
0.1494	1205	8.3	1.2036								
0.1240	1000	10.0	1.1005			$2.6 \cdot 10^{-3}$					
0.1127	909.1	11.0	1.0208			$8.0 \cdot 10^{-3}$					
0.1033	833.3	12.0				$1.9 \cdot 10^{-2}$					
0.09537	769.2	13.0				$3.7 \cdot 10^{-2}$					
0.08679	700	14.29	0.508			$7.74 \cdot 10^{-2}$					
0.07439	600	16.67	0.124			0.804					
0.06199	500	20.00	0.306			1.47			0.68		
0.05579	450	22.22	0.191			1.88			0.85		
0.04959	400	25.00	0.208			2.71			0.91		
0.03720	300	33.33	8.76			3.91			0.68		
0.03100	250	40.00	4.64			0.287			0.42		
0.02480	200	50.00	3.69			0.102			0.33		
0.01240	100.0	100	3.067			0.106			0.26		
0.06199	50.0	200	3.067			$4.0 \cdot 10^{-2}$			0.26		
0.04959	40.00	250	3.067			$2.2 \cdot 10^{-2}$			0.26		
0.02480	20.00	500	3.067			$6.3 \cdot 10^{-3}$					
0.01378	11.11	900				$3.1 \cdot 10^{-3}$					
$4.798 \cdot 10^{-4}$	3.870	2584	3.023			$1.19 \cdot 10^{-3}$			0.25		
$1.464 \cdot 10^{-4}$	1.181	8469	3.023			$6.20 \cdot 10^{-4}$			0.25		

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
$4.053 \cdot 10^{-5}$	0.3269	30590	3.023			$2.63 \cdot 10^{-4}$			0.25		
$1.861 \cdot 10^{-7}$	$1.501 \cdot 10^{-3}$	$6.662 \cdot 10^{6}$	3.018			$1.6 \cdot 10^{-5}$					
$3.718 \cdot 10^{-8}$	$2.999 \cdot 10^{-4}$	$3.335 \cdot 10^{7}$	3.018			$1.6 \cdot 10^{-5}$					
					Potassium Chloride (KCl) - [Ref. 13]						
2860.3		$4.3347 \cdot 10^{-4}$				$3.93 \cdot 10^{-6}$					
2855.3		$4.3423 \cdot 10^{-4}$				$3.39 \cdot 10^{-6}$					
2849.3		$4.3514 \cdot 10^{-4}$				$4.61 \cdot 10^{-6}$					
2835.8		$4.3721 \cdot 10^{-4}$				$5.85 \cdot 10^{-6}$					
2832.3		$4.3775 \cdot 10^{-4}$				$5.85 \cdot 10^{-6}$					
2829.8		$4.3814 \cdot 10^{-4}$				$1.57 \cdot 10^{-6}$					
2828.3		$4.3837 \cdot 10^{-4}$				$4.19 \cdot 10^{-7}$					
219		$5.661 \cdot 10^{-3}$				$1.82 \cdot 10^{-3}$					
215		$5.767 \cdot 10^{-3}$				$1.84 \cdot 10^{-3}$					
212.5		$5.834 \cdot 10^{-3}$				$2.19 \cdot 10^{-3}$					
211		$5.876 \cdot 10^{-3}$				$1.82 \cdot 10^{-3}$					
185.1		$6.7 \cdot 10^{-3}$	0.99874						$1.01 \cdot 10^{-3}$		
109.7		$1.13 \cdot 10^{-2}$	0.99578						$4.22 \cdot 10^{-3}$		
43		0.02883	0.96			$3.0 \cdot 10^{-2}$					
40		0.03179	0.925			$1.8 \cdot 10^{-2}$					
29.9		0.04147	0.756			0.145					
20.1		0.06168	0.910			0.495					
15.1		0.08211	0.965			0.344					
10.0		0.1240	1.16			0.38			0.035		
9.0		0.1378	1.99			0.50			0.13		
8.0		0.1550	1.15			0.46			0.048		
7.0		0.1771	2.0			$8.46 \cdot 10^{-7}$			0.11		
6.199	50000	0.20	1.71739						0.070		
4.959	40000	0.25	1.58972								
3.999	32260	0.31	1.54005								
2.952	23810	0.42	1.50701								
2.695	21740	0.46	1.50115						0.040		
2.616	21100	0.474				$7.6 \cdot 10^{-11}$					
2.384	19230	0.52	1.49501								
2.066	16670	0.60	1.48969						0.039		
1.550	12500	0.80	1.48291						0.038		
1.033	8333	1.2	1.47813						0.037		
0.5166	4167	2.4	1.47464						0.037		
0.2480	2000	5.0	1.47048						0.036		
0.2000	1.613	6.2	1.46796						0.036		
0.1512	1220	8.2	1.46260						0.035		
0.09999	806.5	12.4	1.44611						0.033		
0.07560	609.8	16.4	1.42295						0.030		
0.04959	400.0	25.0	1.34059			$6.57 \cdot 10^{-4}$			0.021		
0.03999	322.6	31.0	1.2431						0.012		
0.02976	240	41.67	0.85			0.16					
0.02728	220	45.45	0.53			0.35					
0.02232	180	55.56	0.31			1.05					
0.01860	150	66.67	0.44			4.0					
0.01612	130	76.92	4.1			0.32			0.37		
0.01240	100	100.0	2.7			0.11			0.21		
0.008679	70	142.9	2.4			$9.2 \cdot 10^{-2}$			0.17		
0.006199	50	200.0	2.2						0.14		
0.001240	10.00	1000				$9.0 \cdot 10^{-3}$					
0.0006199	5.000	2000				$3.7 \cdot 10^{-3}$					
0.0004133	3.333	3000				$2.0 \cdot 10^{-3}$					

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

Silicon Dioxide (Glass) - [Ref. 14]

E/eV	$\bar{\nu}$ /cm⁻¹	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
2000		$6.199 \cdot 10^{-4}$	0.99993			$1.503 \cdot 10^{-5}$					
1860		$6.665 \cdot 10^{-4}$	0.99991			$1.936 \cdot 10^{-5}$					
1609		$7.705 \cdot 10^{-4}$	0.99989			$9.941 \cdot 10^{-6}$					
1496		$8.287 \cdot 10^{-4}$	0.99987			$1.308 \cdot 10^{-5}$					
1204		$1.030 \cdot 10^{-3}$	0.99980			$2.916 \cdot 10^{-5}$					
1093		$1.134 \cdot 10^{-3}$	0.99975			$4.155 \cdot 10^{-5}$					
1016		$1.220 \cdot 10^{-3}$	0.99971			$5.423 \cdot 10^{-5}$					
798		$1.554 \cdot 10^{-3}$	0.99954			$1.289 \cdot 10^{-4}$					
597		$2.077 \cdot 10^{-3}$	0.99917			$3.560 \cdot 10^{-4}$					
396		$3.131 \cdot 10^{-3}$	0.99812			$4.04 \cdot 10^{-4}$					
303		$4.092 \cdot 10^{-3}$	0.99678			$9.91 \cdot 10^{-4}$					
201		$6.168 \cdot 10^{-3}$	0.99269			$3.63 \cdot 10^{-3}$					
151.2		$8.2 \cdot 10^{-3}$	0.9871			$7.3 \cdot 10^{-3}$					
99.99		$1.24 \cdot 10^{-2}$	0.9813			$7.0 \cdot 10^{-3}$					
49.59		$2.50 \cdot 10^{-2}$	0.9164			$6.5 \cdot 10^{-2}$					
40.00		$3.10 \cdot 10^{-2}$	0.907			$9.2 \cdot 10^{-2}$					
31.00		$4.00 \cdot 10^{-2}$	0.851			0.156					
25.00		0.04959	0.733			0.325					
20.00		0.06199	0.859			0.585					
15.00		0.08266	1.168			0.711			0.10		
13.00		0.09537	1.368			0.747			0.11		
11.00		0.1127	1.739			0.569			0.11		
10.00		0.1240	2.330			0.323			0.17		
9.00		0.1378	1.904			$1.89 \cdot 10^{-2}$			0.097		
7.00		0.1771	1.600						0.053		
6.00	48390	0.2066	1.543						0.046		
4.9939	40278.4	0.248272	1.50841						0.041		
4.1034	33096.1	0.302150	1.48719						0.038		
3.0640	24712.3	0.404656	1.46961						0.036		
2.5504	20570.5	0.486133	1.46313						0.035		
2.4379	19662.5	0.508582	1.46187						0.035		
2.2705	18312.5	0.546074	1.46008						0.035		
2.1489	17332.3	0.576959	1.45885						0.035		
2.1411	17269.2	0.579065	1.45877						0.035		
2.1102	17019.5	0.587561	1.45847						0.035		
2.1041	16970.4	0.589262	1.45841						0.035		
1.9257	15531.6	0.643847	1.45671						0.035		
1.8892	15237.6	0.656272	1.45637						0.035		
1.8566	14974.2	0.667815	1.45608						0.034		
1.7549	14153.9	0.706519	1.45515						0.034		
1.4550	11735.6	0.852111	1.45248						0.034		
1.0985	8860.06	1.12866	1.44888						0.034		
0.60243	4858.9	2.0581	1.43722						0.032		
0.35354	2851.4	3.5070	1.40568						0.028		
0.2976	2400	4.176	1.383			$1.07 \cdot 10^{-4}$			0.026		
0.2728	2200	4.545	1.365			$2.56 \cdot 10^{-4}$			0.024		
0.2480	2000	5.000	1.342			$3.98 \cdot 10^{-3}$			0.021		
0.2232	1800	5.556	1.306			$5.63 \cdot 10^{-3}$					
0.1984	1600	6.250	1.239			$6.52 \cdot 10^{-3}$					
0.1736	1400	7.143	1.053			$1.06 \cdot 10^{-2}$					
0.1674	1350	7.407	0.9488			$1.48 \cdot 10^{-2}$					
0.1612	1300	7.692	0.7719			$3.72 \cdot 10^{-2}$					
0.1500	1210	8.265	0.4530			0.704			0.30		
0.1401	1130	8.850	0.3563			1.53			0.66		
0.1302	1050	9.524	2.760			1.65			0.35		
0.1209	975	10.26	2.448			0.231			0.18		

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
0.1091	880	11.36	1.784			$7.75 \cdot 10^{-2}$			0.079		
0.09919	800	12.50	1.753			0.343			0.089		
0.08989	725	13.79	1.698			0.175			0.071		
0.06943	560	17.86	1.337			0.298			0.036		
0.06199	500	20.00	0.6616						0.882		
0.04959	400	25.0	2.739			0.397			0.23		
0.03720	300	33.33	2.210			$6.7 \cdot 10^{-2}$			0.14		
0.01240	100	100.0	1.967			$1.59 \cdot 10^{-2}$			0.11		
0.007439	60	166.7	1.959			$8.62 \cdot 10^{-3}$			0.11		
0.002480	20	500.0	1.955			$7.96 \cdot 10^{-3}$			0.10		

Silicon Monoxide (Noncrystalline) - [Ref. 15]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
25		0.04959	0.8690			0.2717					
20		0.06199	0.8853			0.4919					
17.5		0.07085	0.9825			0.5961					
15		0.08266	1.132			0.6651			0.092		
12.5		0.09919	1.283			0.6523			0.090		
10		0.1240	1.378			0.6843			0.10		
7.5		0.1653	1.593			0.7473			0.12		
5	40330	0.2480	2.001			0.6052			0.15		
4	32260	0.3100	2.141			0.4006			0.15		
3	24200	0.4133	2.116			0.1211			0.13		
2.8	22580	0.4428	2.085			0.08374			0.12		
2.6	20970	0.4769	2.053			0.05544			0.12		
2.4	19360	0.5166	2.021			0.03533			0.11		
2.2	17740	0.5636	1.994			0.02153			0.11		
2	16130	0.6199	1.969			0.01175			0.11		
1.8	14520	0.6888	1.948			0.00523			0.10		
1.6	12900	0.7749	1.929			0.00151			0.10		
1.240	10000	1.000	1.87						0.092		
0.6199	5000	2.000	1.84						0.087		
0.3100	2500	4.000	1.80						0.082		
0.2480	2000	5.000	1.75						0.074		
0.2066	1667	6.000	1.70						0.067		
0.1771	1492	7.000	1.60						0.053		
0.1653	1333	7.500	1.42								
0.1459	1176	8.500	0.90			0.18					
0.1305	1053	9.500	1.20			1.20			0.024		
0.1240	1000	10.00	2.00			1.38			0.27		
0.1181	952.4	10.50	2.85			0.90			0.27		
0.1153	930.2	10.75	2.86			0.58			0.25		
0.1127	909.1	11.00	2.82			0.40			0.24		
0.1078	869.6	11.50	2.50			0.20			0.19		
0.1033	833.3	12.00	2.13			0.14			0.13		
0.09537	769.2	13.00	2.04			0.20			0.12		
0.08856	714.3	14.00	2.01			0.30			0.12		

Noncrystalline Silicon Nitride (Si_3N_4) - [Ref. 16]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
24		0.05166	0.655			0.420			0.28		
23		0.05391	0.625			0.481			0.22		
22		0.05636	0.611			0.560			0.16		
21		0.05904	0.617			0.647			0.19		
20		0.06199	0.635			0.743			0.21		
19		0.06526	0.676			0.841			0.23		
18		0.06888	0.735			0.936			0.26		
17		0.07293	0.810			1.03			0.25		

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	n	n_a	n_c	k	k_a	k_c	R	R_a	R_c
16		0.07749	0.902			1.11			0.26		
15		0.08266	1.001			1.18			0.26		
14		0.08856	1.111			1.26			0.26		
13		0.09537	1.247			1.35			0.27		
12	96790	0.1033	1.417			1.43			0.28		
11	88720	0.1127	1.657			1.52			0.29		
10.5	84690	0.1181	1.827			1.53			0.29		
10	80650	0.1240	2.000			1.49			0.29		
9.5	76620	0.1305	2.162			1.44			0.28		
9	72590	0.1378	2.326			1.32			0.27		
8	64520	0.1550	2.651			0.962			0.26		
7	56460	0.1771	2.752			0.493			0.23		
6	48390	0.2066	2.541			0.102			0.19		
5	40330	0.2480	2.278			$4.9 \cdot 10^{-3}$			0.15		
4.75	38310	0.2610	2.234			$1.2 \cdot 10^{-3}$			0.15		
4.5	36290	0.2755	2.198			$2.2 \cdot 10^{-4}$			0.14		
4	32260	0.3100	2.141						0.13		
3.5	28230	0.3542	2.099						0.13		
3	24200	0.4133	2.066						0.12		
2.5	20160	0.4959	2.041						0.12		
2	16130	0.6199	2.022						0.11		
1.5	12100	0.8266	2.008						0.11		
1	8065	1.240	1.998						0.11		

Sodium Chloride (NaCl) - [Ref. 17]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	n	n_a	n_c	k	k_a	k_c	R	R_a	R_c
209.5		$5.918 \cdot 10^{-3}$				$2.54 \cdot 10^{-3}$					
206		$6.019 \cdot 10^{-3}$				$2.62 \cdot 10^{-3}$					
203		$6.107 \cdot 10^{-3}$				$2.08 \cdot 10^{-3}$					
200		$6.199 \cdot 10^{-3}$				$1.92 \cdot 10^{-3}$					
26.0		0.04769	0.83			0.15			0.015		
25.0		0.04959	0.83			0.18			0.018		
22.0		0.05636	0.83			0.31			0.057		
20.0		0.06199	0.88			0.34			0.036		
18.0		0.06888	0.89			0.33			0.033		
16.1		0.07700	0.74			0.45			0.084		
14.0		0.08856	0.98			0.89			0.17		
12.0		0.1033	1.22			0.79			0.12		
10.0		0.1240	1.55			0.71			0.12		
8.00		0.1550	1.38			1.10			0.20		
6.00	48390	0.2066	1.75						0.074		
5.00	40330	0.2480	1.65						0.060		
2.952	23810	0.42	1.56324						0.048		
2.480	20000	0.50	1.55157						0.047		
2.214	17860	0.56	1.54613						0.046		
2.000	16130	0.62	1.54228						0.045		
1.771	14290	0.70	1.53865						0.045		
1.675	13510	0.74	1.53728						0.045		
1.550	12500	0.80	1.53560						0.045		
1.240	10000	1.00	1.53200						0.044		
1.033	8333	1.2	1.53000						0.044		
0.6888	5556	1.8	1.52712						0.043		
0.4959	4000	2.5	1.52531						0.043		
0.4000	3226	3.1	1.52395						0.043		
0.3263	2632	3.8	1.52226			$(1.8 \pm 0.2) \cdot 10^{-9}$			0.043		
0.2952	2381	4.2	1.52121						0.043		
0.2755	2222	4.5	1.52036						0.043		
0.2480	2000	5.0	1.51883						0.042		

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
0.1240	1000	10.0	1.49473						0.039		
0.1033	833.3	12.0	1.48000						0.037		
0.08856	714.3	14.0	1.46188						0.035		
0.07749	625.0	16.0	1.4399						0.033		
0.06888	555.5	18.0	1.41364						0.029		
0.06199	500.0	20.0	1.3822						0.026		
0.04959	400	25.0	1.27			$3.5\cdot10^{-3}$			0.014		
0.04215	340	29.41	1.12			$1.7\cdot10^{-2}$			0.0032		
0.03720	300	33.33	0.85			0.85			0.18		
0.03410	275	36.36	0.59			0.22			0.084		
0.03286	265	37.74	0.42			0.50			0.26		
0.03224	260	38.46	0.45			0.45			0.22		
0.02480	200	50.00	0.14			1.99			0.89		
0.02108	170	58.82	1.35			6.03			0.87		
0.01984	160	62.50	6.92			2.14			0.59		
0.01922	155	64.52	5.50			0.87			0.49		
0.01860	150	66.67	4.52			0.380			0.41		
0.01736	140	71.43	3.72			0.219			0.33		
0.01612	130	76.92	3.31			0.135			0.29		
0.01488	120	83.33	3.02			0.110			0.25		
0.01240	100	100.0	2.74			0.087			0.22		
0.009919	80	125.0	2.57			0.077			0.19		
0.07439	60	166.7	2.48			0.055			0.18		
0.04959	40	250.00	2.44			0.041			0.18		
0.002480	20	500.0	2.43			0.024			0.17		
0.001240	10	1000	2.43			0.006			0.17		
0.001033	8.333	1200				$8.8\cdot10^{-3}$					
0.0006888	5.556	1800				$5.4\cdot10^{-3}$					
0.0006199	5.000	2000	2.43						0.17		
0.0004959	4.000	2500				$4.4\cdot10^{-3}$					
0.0004797	3.869	2584	2.43			$2.1\cdot10^{-3}$			0.17		
0.0003875	3.125	3200				$3.3\cdot10^{-3}$					
0.0001464	1.181	8469	2.43			$5.8\cdot10^{-4}$			0.17		
0.00004053	0.3269	30590	2.43			$2.5\cdot10^{-4}$					
					Cubic Zinc Sulfide (ZnS) - [Ref. 18]						
2000		$6.199\cdot10^{-4}$	0.999904			$1.76\cdot10^{-5}$					
1204		$1.030\cdot10^{-3}$	0.999777			$1.00\cdot10^{-4}$					
1016		$1.220\cdot10^{-3}$	0.999838			$3.61\cdot10^{-5}$					
901		$1.376\cdot10^{-3}$	0.999647			$5.42\cdot10^{-5}$					
798		$1.554\cdot10^{-3}$	0.999520			$8.28\cdot10^{-5}$					
707		$1.754\cdot10^{-3}$	0.999372			$1.25\cdot10^{-4}$					
597		$2.077\cdot10^{-3}$	0.999160			$2.19\cdot10^{-4}$					
377		$9.50\cdot10^{-3}$	0.99789			$9.50\cdot10^{-4}$					
201		$6.168\cdot10^{-3}$	0.99553			$4.82\cdot10^{-3}$					
100		$1.240\cdot10^{-2}$	0.99061			$1.17\cdot10^{-2}$					
61.99		$2.000\cdot10^{-2}$	0.964			$3.32\cdot10^{-2}$			$6.2\cdot10^{-4}$		
41.33		$3.000\cdot10^{-2}$	0.941			$5.10\cdot10^{-2}$					
31.00		$4.000\cdot10^{-2}$	0.847			$9.95\cdot10^{-2}$					
24.80		$5.000\cdot10^{-2}$	0.796			0.171			$2.2\cdot10^{-2}$		
17.71		$7.000\cdot10^{-2}$	0.747			0.431			$7.7\cdot10^{-2}$		
13.78		$9.000\cdot10^{-2}$	0.758			0.824			0.20		
12.40		0.1000	0.862			0.876			0.19		
9.919		0.125	1.02			1.36			0.31		
8.266		0.150	1.41			1.47			0.29		
6.199		0.200	2.32			1.62			0.32		
6.00	48390	0.2066	2.24			1.65			0.59		

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
4.00	32260	0.3100	2.70			0.44			0.22		
3.00	24200	0.4133	2.54			$4 \cdot 10^{-2}$			0.19		
2.50	20160	0.4959	2.42			$3 \cdot 10^{-2}$			0.17		
2.30	18550	0.5391	2.3950						0.17		
2.00	16130	0.6199	2.3576						0.16		
1.75	14110	0.7085	2.3319						0.16		
1.55	12500	0.7999	2.3146			$3.50 \cdot 10^{-6}$			0.16		
1.40	11290	0.8856	2.3033						0.16		
1.240	10000	1.000	2.2907			$3.02 \cdot 10^{-6}$			0.15		
1.00	8065	1.240	2.2795						0.15		
0.80	6452	1.550	2.2706						0.15		
0.6199	5000	2.000	2.2631			$6.2 \cdot 10^{-6}$			0.15		
0.45	3629	2.755	2.2587						0.15		
0.30	2420	4.133	2.2529						0.15		
0.20	1613	6.199	2.2443						0.15		
0.1550	1250	8.0	2.2213			$4.5 \cdot 10^{-6}$			0.14		
0.1240	1000	10.00	2.1986			$8.8 \cdot 10^{-6}$			0.14		
0.100	806.5	12.4	2.1969						0.14		
0.09	725.9	13.78	2.1793						0.14		
0.07999	645.2	15.5	2.1518			$3.82 \cdot 10^{-3}$			0.14		
0.07	564.6	17.71	2.1040						0.13		
0.06075	490	20.41	2.03			$8.0 \cdot 10^{-3}$			0.12		
0.05	403.3	24.80	1.6866						0.065		
0.03546	286	34.97	3.29			$8.3 \cdot 10^{-2}$			0.28		
0.03472	280	35.71	9.54			$5.2 \cdot 10^{-2}$			0.66		
0.02480	200	50.00	3.48			$3.1 \cdot 10^{-2}$			0.31		
0.01240	100	100.0	3.06			$5.8 \cdot 10^{-3}$			0.26		
0.004955	40	250.0	2.903			$6.2 \cdot 10^{-3}$			0.24		
0.004339	35	285.7	2.899			$7.0 \cdot 10^{-3}$			0.24		
0.003720	30	333.3	2.896						0.24		
0.003100	25	400.0	2.894						0.24		
0.002480	20	500.0	2.892						0.24		
0.001860	15	666.7	2.890						0.24		

Polytetrafluoroethylene (Teflon) - [Ref. 19]

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
4.960	40000	0.250							0.970		
4.769	38462	0.260							0.972		
4.593	37037	0.270							0.975		
4.426	35714	0.280							0.978		
4.276	34483	0.290							0.980		
4.133	33333	0.300							0.983		
4.000	32258	0.310							0.986		
3.875	31250	0.320							0.988		
3.758	30303	0.330							0.990		
3.647	29412	0.340							0.991		
3.543	28571	0.350							0.992		
3.444	27778	0.360							0.992		
3.351	27027	0.370							0.993		
2.255	18182	0.550							0.993		
2.067	16667	0.600							0.992		
1.378	11111	0.900							0.992		
1.305	10526	0.950							0.991		
1.078	8696	1.150							0.991		
1.033	8333	1.200							0.990		
0.9920	8000	1.250							0.990		
0.9538	7692	1.300							0.989		
0.9185	7407	1.350							0.988		

OPTICAL PROPERTIES OF SELECTED INORGANIC AND ORGANIC SOLIDS (continued)

E/eV	$\bar{\nu}$ /cm^{-1}	λ/μm	*n*	n_a	n_c	*k*	k_a	k_c	*R*	R_a	R_c
0.8857	7143	1.400							0.988		
0.8552	6897	1.450							0.989		
0.8267	6667	1.500							0.989		
0.8000	6452	1.550							0.988		
0.7750	6250	1.600							0.988		
0.7515	6061	1.650							0.987		
0.7294	5882	1.700							0.986		
0.7086	5714	1.750							0.986		
0.6889	5556	1.800							0.985		
0.6703	5405	1.850							0.980		
0.6526	5263	1.900							0.978		
0.6359	51282	1.950							0.978		
0.6200	5000	2.000							0.970		
0.6049	4878	2.050							0.959		
0.5905	4762	2.100							0.951		
0.5767	4651	2.150							0.946		
0.5636	4545	2.200							0.966		
0.5511	44444	2.250							0.965		
0.5487	44247	2.260							0.964		
0.5439	4386	2.280							0.963		
0.5415	4367	2.290							0.961		
0.5368	4329	2.310							0.959		
0.5345	4310	2.320							0.957		
0.5322	4292	2.330							0.956		
0.5299	4274	2.340							0.954		
0.5277	4255	2.350							0.951		
0.5232	4219	2.370							0.950		
0.5188	4184	2.390							0.949		
0.5167	4167	2.400							0.947		
0.5061	4082	2.450							0.946		
0.4960	4000	2.500							0.945		

REFERENCES

1. Arsenic Selenide
   D. J. Treacy in *Handbook of Optical Constants of Solids,* E. D. Palik, Editor, Academic Press, 1985, p. 623. (Hereafter abbreviated as *HOCS.*)
   R. Zallen, R. E. Drews, R. L. Emerald, and M. L. Slade, *Phys. Rev. Lett.* 26, 1564 (1971)
   R. Zallen, M. L. Slade, and A. T. Ward, *Phys. Rev.* B 3, 4257 (1971).
   U. Strom and P. C. Taylor, *Phys. Rev.* B 16, 5512 (1977).
   G. Lucovsky, *Phys. Rev.* B 6, 1480 (1972).
   C. T. Moynihan, P. B. Macedo, M. S. Maklad, R. K. Mohr, and R. E. Howard, *J. Non-Cryst. Solids*, 17, 369 (1975).
   Y. Ohmachi, *J. Opt. Soc. Am.* 63, 630 (1973).
2. Arsenic Sulfide
   D. J. Treacy in *HOCS,* 1985, p. 641.
   P. A. Young, *J. Phys.* C 4, 93 (1971).
   W. S. Rodny, I. H. Malitson, and T. A. King, *J. Opt. Soc. Am.* 48, 633 (1958).
   R. Zallen, R.E. Drew, R. L. Emerald, and M.L. Slade, *Phys. Rev. Lett.* 26, 1564 (1971).
   M. S. Maklad, R. K. Mohr, R. E. Howard, P. B. Macedo, and C. T. Moynihan, *Solid State Commun.* 15, 855 (1974).
   P. B. Klein, P. C. Taylor, and D. J. Treacy, *Phys. Rev.* B16, 4511 (1977).
   G. Lucovsky, *Phys. Rev.* B 6, 1480 (1972).
3. Cadmium Telluride
   E. D. Palik in *HOCS,* 1985, p. 409.
   D. T. F. Marple and H. Ehrenreich, *Phys. Lett.* 8, 87 (1962).
   T. H. Myers, S. W. Edwards, and J. F. Schetzina, *J. Appl. Phys.* 52, 4231 (1981).
   D. T. F. Marple, *Phys. Rev.* 150, 728 (1966).
   A. N. Pikhtin and A. D. Yas'kov, *Sov. Phys. Semicond.* 12, 622 (1978).

L. S. Ladd, *Infrared Phys.* 6, 145 (1966).
J. E. Harvey and W. L. Wolfe, *J. Opt. Soc. Am.* 65, 1267 (1975).
A. Manabe, A. Mitsuishi, and H. Yoshinaga, *Jpn. J. Appl. Phys.* 6, 593 (1967).
A. Manabe, A. Mitsuishi, H. Oshinaga, Y. Ueda, and H. Sei, *Technol. Rep. Osaka Univ. Jpn.* 17, 263 (1967).
J. R. Birch and D. K. Murrey, *Infrared Phys.* 18, 283 (1978).

4. Gallium Arsenide
E. D. Palik in *HOCS,* 1985, p. 429.
M. Cardona, W. Gudat, B. Sonntag, and P. Y. Yu, in *Proc. Intl. Conf. Phys. Semicond.,* 10th. Cambridge, 1970, p. 208. US Atom. Energy Commission, Oak Ridge, TN, 1970.
H. R. Philipp and H. Ehrenreich, *Phys. Rev.* 129, 1550 (1963).
J. B. Theeten, D. E. Aspnes, and R. P. H. Chang, *J. Appl. Phys.* 49, 6097 (1978).
H. C. Casey, D. D. Sell, and K. W. Wecht, *J. Appl. Phys.* 46, 250 (1975).
A. H. Kachare, W. G. Spitzer, F. K. Euler, and A. Kahan, *J. Appl. Phys.* 45, 2938 (1974).
R. T. Holm, J. W. Gibson, and E. D. Palik, *J. Appl. Phys.* 48, 212 (1977).
W. Cochran, S. J. Fray, F. A. Johnson, J. E. Quarrington, and N. Williams, *J. Appl. Phys. Suppl.* 32, 2102 (1961).
C. P. Christensen, R. Joiner, S. K. T. Nieh, and W. H. Steier, *J. Appl. Phys.* 45, 4957 (1974).
R. H. Stolen, Phys. Rev. B 11, 767 (1975); *Appl. Phys. Lett.* 15, 74 (1969).

5. Gallium Phosphide
A. Borghesi and G. Guizzetti in *HOCS,* 1985, p. 445.
M. Cardona, W. Gudat, B. Sonntag, and P. Y. Yu, *Proc. Intl. Conf. Phys. Semicond.* Cambridge, 1970, p. 208. US Atom. Energy Commission, Oak Ridge, TN, 1970.
M. Cardona, W. Gudat, E. E. Koch, M. Skibowski, B. Sonntag, and P. Yu. *Phys. Rev. Lett.* 25, 659 (1970).
S. E. Stokowski and D. D. Sell, *Phys. Rev.* B 5, 1636 (1972).
S. A. Abagyan, G. A. Ivanov, Y. E. Shanurin, and V. I. Amosov, *Sov. Phys. Semicond.* 5, 889 (1971).
P. G. Dean, G. Kaminsky, and R. B. Zetterstorm, *J. Appl. Phys.* 38, 3551 (1967).
D. E. Aspnes and A. A. Studna, *Phys. Rev.* B 27, 985 (1983).

6. Indium Antimonide
R. T. Holm in *HOCS,* 1985, p. 491.
M. Cardona, W. Gudat, B. Sonntag, and P. Y. Yu, Proc. *Int. Conf. Phys. Semicond.,* 10th. Cambridge, 1970, p. 208. US Atom. Comm., Oak Ridge, TN, 1970.
H. R. Philipp and H. Ehrenreich, *Phys. Rev.* 129, 1550 (1963).
D. E. Aspnes and A. A. Studna, *Phys. Rev.* B 27, 985 (1983).
T. S. Moss, S. D. Smith, and T. D. F. Hawkins, *Proc. Phys. Soc. London* 70B, 776 (1957).
H. Yoshinaga and R. A. Oetjen, *Phys. Rev.* 101, 526 (1956).
R. B. Sanderson, *J. Phys. Chem. Solids* 26, 803 (1965).

7. Indium Arsenide
E. D. Palick and R. T. Holm in *HOCS,* 1985, p. 479.
H. R. Philipp and H. Ehrenreich, *Phys. Rev.* 129, 1550 (1963).
B. O. Seraphin and H. E. Bennett in *Semiconductors and Semimetals* (R. K. Willardson and A. C. Beer, Eds.), vol. 3, Academic, 1967, p. 499.
D. E. Aspnes and A. A. Studna, *Phys. Rev.* B 27, 985 (1983).
J. R. Dixon and J. M. Ellis, *Phys. Rev.* 123, 1560 (1961).
A. Memon, T. J. Parker, and J. R. Birch, *Proc. SPIE,* 289, 20 (1981).

8. Indium Phosphide
O. J. Glembocki and H. Piller in *HOCS,* 1985, p. 503.
M. Cardona, *J. Appl. Phys.* 32, 958 (1961); 36, 2181 (1965).
D. E. Aspnes and A. A. Studna, *Phys. Rev.* B 27, 985 (1983).
G. D. Pettit and W. J. Turner, *J. Appl. Phys.* 36, 2081 (1965).
R. Newman, *Phys. Rev.* 111, 1518 (1958).
W. N. Reynolds, M. T. Lilburne, and R. M. Dell, *Proc. Phys. Soc. London* 71, 416 (1958).
H. Jamshidi and T. J. Parker, Int. Meet. Infrared Mm. Waves, 7th., Marseilles, 1983.

9. Lead Selenide
G. Bauer and H. Krenn in *HOCS,* 1985, p. 517.
M. Cardona and D. L. Greenaway, *Phys. Rev.* A 133, 1685 (1964).
T. S. Moss, *Optical Properties of Semiconductors,* Butterworth, 1959, p. 189.
J. N. Zemel, J. D. Jensen, and R. B. Schoolar, *Phys. Rev.* A 140, 330 (1965).
W. W. Scanlon, *J. Phys. Chem. Solids*, 8, 423 (1959).
K. V. Vyatkin and A. P. Shotov, *Sov. Phys. Semicond.* 14, 785 (1980); Fiz. Tekh. Poluprovodn. 14, 1331 (1980).

10. Lead Sulfide
G. Guizzetti and A. Borghesi in *HOCS,* 1985, p. 525.
M. Cardona and R. Haensel, *Phys. Rev.* B 1, 2605 (1970).

M. Cardona and D. L. Greenaway, *Phys. Rev.* A 133, 1685 (1964).
M. Cardona, C. M. Penchina, E. E. Koch, and P. Y. Yu, *Phys. Status Solidi* B 53, 327 (1972).
P. R. Wessel, *Phys. Rev.* 153, 836 (1967).
C. E. Rossi and W. Paul, *J. Appl. Phys.* 38, 1803 (1967).
J. N. Zemel, J. D. Jensen, and R. B. Schoolar, *Phys. Rev.* A 140, 330 (1965).

11. Lead Telluride
G. Bauer and H. Krenn in *HOCS,* 1985, p. 535.
M. Cardona and R. Haensel, *Phys. Rev.* B 1, 2605 (1970).
M. Cardona and D. L. Greenaway, *Phys. Rev.* 133, A1685 (1964).
D. M. Korn and R. Braunstein, *Phys. Rev.* B 5, 4837 (1972).
W. W. Scanlon, *J. Phys. Chem. Solids* 8, 423 (1959).
J. N. Zemel, J. D. Jensen, and R. B. Schoolar, *Phys. Rev.* 140, A330 (1965).

12. Lithium Fluoride
E. D. Palik and W. R. Hunter in *HOCS,* 1985, p. 675.
B. L. Henke, P. Lee, T. J. Tanaka, R. L. Shimabukuro, and B. K. Fujikawa, *Low Energy X-ray Diagnostics-1981* (D. T. Attwood and B. L. Henke, Eds.), AIP Conf. Proc. No. 75, 1981.
A. P. Lukirskii, E. P. Savinov, O. A. Ershov, and Y. F. Shepelev, *Opt. Spektrosk.* 16, 168 (1964); 16, 310 (1964).
F. C. Brown, C. Gahwiller, A. B. Kunz, and N. O. Lipari, *Phys. Rev. Lett.* 25, 927 (1970).
A. Milgram and M. P. Givens, *Phys. Rev.* 125, 1506 (1962).
T. Tomiki and T. Miyata, *J. Phys. Soc. Jpn.* 27, 658 (1969).
A. Kachare, G. Andermann, and L. R. Brantley, *J. Phys. Chem. Solids* 33, 467 (1972).

13. Potassium Chloride
E. D. Palik in *HOCS,* 1985, p. 703.
O. Aita, I. Nagakura, and T. Sagawa, *J. Phys. Soc. Jpn.* 30, 1414 (1971).
A. P. Lukirskii, E. P. Savinov, O. A. Ershov, and Y. F. Shepelev, *Opt. Spectrosc.* 16, 168 (1964); Opt. Spektrosk. 16, 310 (1964).
T. Tomika, *J. Phys. Soc. Jpn.* 22, 463 (1967).
M. Antinori, A. Balzarotti, and M. Piacentini, *Phys. Rev.* B 7, 1541 (1973).
H. H. Li, *J. Phys. Chem. Ref. Data* 5, 329 (1976).
S. D. Allen and J. A. Harrington, *Appl. Opt.* 17, 1679 (1978).
K. W. Johnson and E. E. Bell, *Phys. Rev.* 139A, 1295 (1965).

14. Silicon Dioxide
H. R. Philipp in *HOCS,* 1985, p. 749.
J. Rife and J. Osantowski, *J. Opt. Soc. Am.* 70, 1513 (1980).
B. L. Henke, P. Lee, T. J. Tanaka, R. L. Shimabukuro, and B. K. Fujikawa, *Low Energy X-ray Diagnostics-1981* (D. T. Attwood and B. L. Henke, Eds.), AIP Conf. Proc. No. 75, 1981.
H. R. Philipp, *Solid State Commun.* 4, 73 (1966); *J. Phys. Chem. Solids,* 32, 1935 (1971).
P. L. Lamy, *Appl. Opt.* 16, 2212 (1977).
H. R. Philipp, *J. Appl. Phys.* 50 1053 (1979).
D. G. Drummond, *Proc. Roy. Soc. London,* 153, 328 (1935).

15. Silicon Monoxide
H. R. Philipp in *HOCS,* 1985, p. 765.
H. R. Philipp, *J. Phys. Chem. Solids,* 32, 1935 (1971).
G. Hass and C. D. Salzberg, *J. Opt. Soc. Am.* 44, 181 (1954).
E. Cremer, T. Kraus, and E. Ritter, *Zs. Electrochem.* 62, 939 (1958).
A. P. Bradford, G. Hass, M. McFarland, and E. Ritter, *Appl. Opt.* 4, 971 (1965).

16. Silicon Nitride
H. R. Philipp in *HOCS,* 1985, p. 771.
H. R. Philipp, *J. Electrochem. Soc.* 120, 295 (1973).
J. B. Theeten, D. E. Aspnes, F. Simondet, M. Errman, and P. C. Mürau, *J. Appl. Phys.* 52, 6788 (1981).
J. Bauer, *Phys. Status Solidi,* A 39, 411 (1977).

17. Sodium Chloride
J. E. Eldridge and E. D. Palik in *HOCS,* p. 775.
J. A. Harrington, C. J. Duthler, F. W. Patten, and M. Hass, *Solid State Commun.* 18, 1043 (1976).
T. Miyata and T. Tomiki, *J. Phys. Soc. Jpn.* 24, 1286 (1968); ibid., 22, 209 (1967).
D. M. Roessler and W. C. Walker, *J. Opt. Soc. Am.* 58, 279 (1968).
D. M. Roessler and W. C. Walker, *Phys. Rev.* 166, 599 (1968).
S. Allen and J. A. Harrington, *Appl. Opt.* 17, 1679 (1978).
O. Aita, I. Nagakura, and T. Sagawa, *J. Phys. Soc. Jpn.* 30, 1414 (1971).

18. Zinc Sulfide
E. D. Palik and A. Addamiano in *HOCS,* 1985, p. 597.

B. L. Henke, P. L. Lee, T. J. Tanaka, R. L. Shimabukuro, and B. F. Fujikawa, *Low Energy X-ray Diagnostics-1981* (D. T. Attwood and B. L. Henke, Eds.), *AIP Conf. Proc.* No. 75, 1981.
M. Cardona and G. Harbeke, *Phys. Rev.* 137, A1467 (1965).
Eastman Kodak, Publ. No. U-72, Rochester, New York (1981).
C. A. Klein and R. N. Donadio, *J. Appl. Phys.* 51, 797 (1980).
T. Deutsch, *Proc. Int. Conf. Phys. Semicond.,* 6th Exeter 1962, p. 505. The Inst. of Physics and the Physical Soc., London, 1962.
A. Manabe, A. Mitsuishi, and H. Yoshinaga, *Jpn. J. Appl. Phys.* 6, 593 (1967).
W. W. Piper, D. T. F. Marple, and P. D. Johnson, *Phys. Rev.* 110, 323 (1958).

19. Polytetrafluoroethylene
J. W. L. Thomas (NIST), Private communication.
NIST Certificate, STM 2044.
P. Y. Barnes, E. A. Early, and A. C. Parr, *NIST Special Publ. 250-48,* NIST Measurement Services: Spectral Reflectance.
Diffuse Reflectance Coatings and Materials Sections, Labsphere Catalog, 1996.
A. Arecchi and C. Ryder (Labsphere, North Sutten, NJ), private communication.

NOMENCLATURE FOR ORGANIC POLYMERS

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Organic polymers have traditionally been named on the basis of the monomer used, a hypothetical monomer, or a semi-systematic structure. Alternatively, they may be named in the same way as organic compounds, i.e., on the basis of a structure as drawn. The former method, often called "source-based nomenclature" or "monomer-based nomenclature", sometimes results in ambiguity and multiple names for a single material. The latter method, termed "structure-based nomenclature", generates a sometimes cumbersome unique name for a given polymer, independent of its source. Within their limitations, both types of names are acceptable and well-documented.[1] The use of stereochemical descriptors with both types of polymer nomenclature has been published.[2]

Traditional Polymer Names

Monomer-Based Names

"Polystyrene" is the name of a homopolymer made from the single monomer styrene. When the name of a monomer comprises two or more words, the name should be enclosed in parentheses, as in "poly(methyl methacrylate)" or "poly(4-bromostyrene)" to identify the monomer more clearly. This method can result in several names for a given polymer: thus, "poly(ethylene glycol)", "poly(ethylene oxide)", and "poly(oxirane)" describe the same polymer. Sometimes, the name of a hypothetical monomer is used, as in "poly(vinyl alcohol)". Even though a name like "polyethylene" covers a multitude of materials, the system does provide understandable names when a single monomer is involved in the synthesis of a single polymer. When one monomer can yield more than one polymer, e.g. 1,3-butadiene or acrolein, some sort of structural notation must be used to identify the product, and one is not far from a formal structure-based name.

Copolymers, Block Polymers, and Graft Polymers. When more than one monomer is involved, monomer-based names are more complex. Some common polymers have been given names based on an apparent structure, as with "poly(ethylene terephthalate)". A better system has been approved by the IUPAC.[1] With this method, the arrangement of the monomeric units is introduced through use of an italicized connective placed between the names of the monomers. For monomer names represented by A, B, and C, the various types of arrangements are shown in Table 1.

Table 1. IUPAC Source-Based Copolymer Classification

No.	Copolymer Type	Connective	Example
1	Unspecified or unknown	*-co-*	poly(A-*co*-B)
2	Random (obeys Bernoullian distribution)	*-ran-*	poly(A-*ran*-B)
3	Statistical (obeys known statistical laws)	*-stat-*	poly(A-*stat*-B)
4	Alternating (for two monomeric units)	*-alt-*	poly(A-*alt*-B)
5	Periodic (ordered sequence for 2 or more monomeric units)	*-per-*	poly(A-*per*-B-*per*-C)
6	Block (linear block arrangement)	*-block-*	polyA-*block*-polyB
7	Graft (side chains connected to main chains)	*-graft-*	polyA-*graft*-polyB

Table 2 contains examples of common or semi-systematic names of copolymers. The systematic names of comonomers may also be used; thus, the polyacrylonitrile-*block*-polybutadiene-*block*-polystyrene polymer in Table 2 may also be named poly(prop-2-enenitrile)-*block*-polybuta-1,3-diene-*block*-poly(ethenylbenzene). IUPAC does not require alphabetized names of comonomers within a polymer name; many names are thus possible for some copolymers.

These connectives may be used in combination and with small, non-repeating (i.e. non-polymeric) junction units; see, for example, Table 2, line 8. A long dash may be used in place of the connective *-block-*; thus, in Table 2, the polymers of lines 7 and 8 may also be written as shown on lines 9 and 10.

Table 2. Examples of Source-Based Copolymer Nomenclature

No.	Copolymer name
1	poly(propene-*co*-methacrylonitrile)
2	poly[(acrylic acid)-*ran*-(ethyl acrylate)]
3	poly(butene-*stat*-ethylene-*stat*-styrene)
4	poly[(sebacic acid)-*alt*-butanediol]
5	poly[(ethylene oxide)-*per*-(ethylene oxide)-*per*-tetrahydrofuran]
6	polyisoprene-*graft*-poly(methacrylic acid)
7	polyacrylonitrile-*block*-polybutadiene-*block*-polystyrene
8	polystyrene-*block*-dimethylsilylene-*block*-polybutadiene
9	polyacrylonitrile—polybutadiene—polystyrene
10	polystyrene—dimethylsilylene—polybutadiene

IUPAC also recommends an alternative scheme for naming copolymers that comprises use of "copoly" as a prefix followed by the names of the comonomers, a solidus (an oblique stroke) to separate comonomer names, and addition before "copoly" of any applicable connectives listed in Table 2 except *-co-*.

Table 3 gives the same examples shown in Table 2 but with the alternative format. Comonomer names need not be parenthesized.

NOMENCLATURE FOR ORGANIC POLYMERS (continued)

Table 3. Examples of Source-Based Copolymer Nomenclature (Alternative Format)

No.	Polymer name
1	copoly(propene/methacrylonitrile)
2	*ran*-copoly(acrylic acid/ethyl acrylate)
3	*stat*-copoly(butene/ethylene/styrene)
4	*alt*-copoly(sebacic acid/butanediol)
5	*block*-copoly(acrylonitrile/butadiene/styrene)
6	*per*-copoly(ethylene oxide/ethylene oxide/tetrahydrofuran)
7	*graft*-copoly(isoprene/methacrylic acid)

Source-based nomenclature for non-linear macromolecules and macromolecular assemblies is covered by a 1997 IUPAC document.[11] The types of polymers in these classes, together with their connectives, are given in Table 4; the terms shown may be used as connectives, prefixes, or both to designate the features present.

Table 4. Connectives for Non-Linear Macromolecules and Macromolecular Assemblies

No.	Type	Connective
1	Branched (type unspecified)	branch
2	Branched with branch point of functionality f	f-branch
3	Comb	comb
4	Cross-link	ι (Greek iota)
5	Cyclic	cyclo
6	Interpenetrating polymer network	ipn
7	Long-chain branched	l-branch
8	Network	net
9	Polymer blend	blend
10	Polymer-polymer complex	compl
11	Semi-interpenetrating polymer network	sipn
12	Short-chain branched	sh-branch
13	Star	star
14	Star with f arms	f-star

Non-linear polymers are named by using the italicized connective as a *prefix* to the source-based name of the polymer component or components to which the prefix applies; some examples are listed in Table 5.

Table 5. Non-Linear Macromolecules

No.	Polymer Name	Polymer Structural Features
1	poly(methacrylic acid)-*comb*-polyacrylonitrile	Comb polymer with a poly(methacrylic acid) backbone and polyacrylonitrile side chains
2	*comb*-poly[ethylene-*stat*-(vinyl chloride)]	Comb polymer with unspecified backbone composition and statistical ethylene/vinyl chloride copolymer side chains
3	polybutadiene-*comb*-(polyethylene; polypropene)	Comb polymer with butadiene backbone and side chains of polyethylene and polypropene
4	*star*-(polyA; polyB; polyC; polyD; polyE)	Star polymer with arms derived from monomers A, B, C, D, and E, respectively
5	*star*-(polyA-*block*-polyB-*block*-polyC)	Star polymer with every arm comprising a tri-block segment derived from comonomers A, B, and C
6	*star*-poly(propylene oxide)	A star polymer prepared from propylene oxide
7	5-*star*-poly(propylene oxide)	A 5-arm star polymer prepared from propylene oxide
8	*star*-(polyacrylonitrile; polypropylene) (M_r 10000: 25000)	A star polymer containing polyacrylonitrile arms of MW 10000 and polypropylene arms of MW 25000

Macromolecular assemblies held together by forces other than covalent bonds are named by inserting the appropriate italicized connective between names of individual components; Table 6 gives examples.

Table 6. Examples of Polymer Blends and Nets

No.	Polymer Name
1	polyethylene-*blend*-polypropene
2	poly(methacrylic acid)-*blend*-poly(ethyl acrylate)
3	*net*-poly(4-methylstyrene-*ι*-divinylbenzene)
4	*net*-poly[styrene-*alt*-(maleic anhydride)]-*ι*-(polyethylene glycol; polypropylene glycol)
5	*net*-poly(ethyl methacrylate)-*sipn*-polyethylene
6	[*net*-poly(butadiene-*stat*-styrene)]-*ipn*-[*net*-poly(4-methylstyrene-*ι*-divinylbenzene)]

NOMENCLATURE FOR ORGANIC POLYMERS (continued)

Structure-Based Polymer Nomenclature

Regular Single-Strand Polymers

Structure-based nomenclature has been approved by the IUPAC[4] and is currently being updated; it is used by *Chemical Abstracts*.[5] Monomer names are not used. To the extent that a polymer chain can be described by a repeating unit in the chain, it can be named "poly(repeating unit)". For regular single-strand polymers, "repeating unit" is a bivalent group; for regular double-strand (ladder and spiro) polymers, "repeating unit" is usually a tetravalent group.[9]

Since there are usually many possible repeating units in a given chain, it is necessary to select one, called the "constitutional repeating unit" (CRU) to provide a unique and unambiguous name, "poly(CRU)", where "CRU" is a recitation of the names of successive units as one proceeds through the CRU from left to right. For this purpose, a portion of the main chain structure that includes at least two repeating sequences is written out. These sequences will typically be composed of bivalent subunits such as -CH_2-, -O-, and groups from ring systems, each of which can be named by the usual nomenclature rules.[6,7]

Where a chain is simply one long sequence comprising repetition of a single subunit, that subunit is itself the CRU, as in "poly(methylene)" or "poly(1,4-phenylene)". In chains having more than one kind of subunit, a seniority system is used to determine the beginning of the CRU and the direction in which to move along the main chain atoms (following the shortest path in rings) to complete the CRU. Determination of the first, most senior, subunit, is based on a descending order of seniority: (1) heterocyclic rings, (2) hetero atoms, (3) carbocyclic rings, and, lowest, (4) acyclic carbon chains.

Within each of these classes, there is a further order of seniority that follows the usual rules of nomenclature.

Heterocycles: A nitrogen-containing ring system is senior to a ring system not containing nitrogen.[4,9] Further descending order of seniority is determined by:

(i) the highest number of rings in the ring system
(ii) the largest individual ring in the ring system
(iii) the largest number of hetero atoms
(iv) the greatest variety of hetero atoms

Hetero atoms: The senior bivalent subunit is the one nearest the top, right-hand corner of the Periodic Table; the order of seniority is: O, S, Se, Te, N, P, As, Sb, Bi, Si, Ge, Sn, Pb, B, Hg.

Carbocycles: Seniority[4] is determined by:

(i) the highest number of rings in the ring system
(ii) the largest individual ring in the ring system
(iii) degree of ring saturation; an unsaturated ring is senior to a saturated ring of the same size

Carbon chains: Descending order of seniority is determined by:

(i) chain length (longer is senior to shorter)
(ii) highest degree of unsaturation
(iii) number of substituents (higher number is senior to lower number)
(iv) ascending order of locants
(v) alphabetical order of names of substituent groups

Among equivalent ring systems, preference is given to the one having lowest locants for the free valences in the subunit, and among otherwise identical ring systems, the one having least hydrogenation is senior. Lowest locants in unsaturated chains are also given preference. Lowest locants for substituents are the final determinant of seniority.

Direction within the repeating unit depends upon the shortest path, which is determined by counting main chain atoms, both cyclic and acyclic, from the most senior subunit to another subunit of the same kind or to a subunit next lower in seniority. When identification and orientation of the CRU have been accomplished, the CRU is named by writing, in sequence, the names of the largest possible subunits within the CRU from left to right. For example, the main chain of the polymer traditionally named "poly(ethylene terephthalate)" has the structure shown in Figure 1.

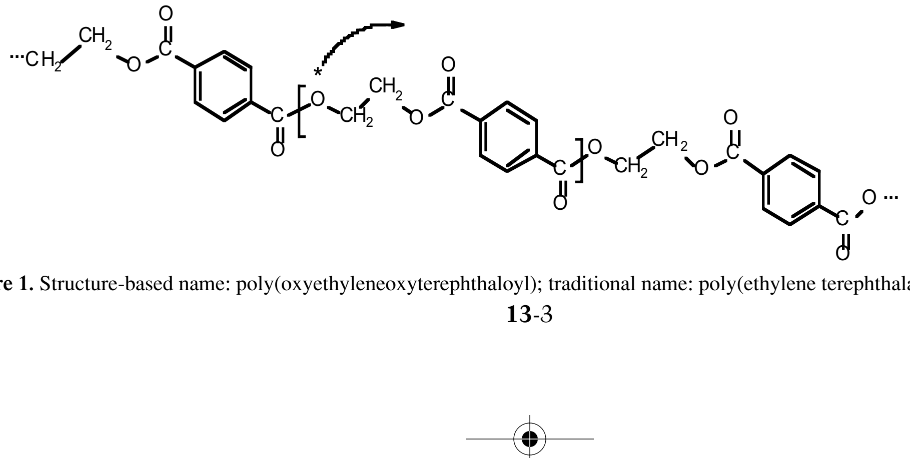

Figure 1. Structure-based name: poly(oxyethyleneoxyterephthaloyl); traditional name: poly(ethylene terephthalate)

NOMENCLATURE FOR ORGANIC POLYMERS (continued)

The CRU in Figure 1 is enclosed in brackets and read from left to right. It is selected because (1) either backbone oxygen atom qualifies as the "most senior subunit", (2) the shortest path length from either -O- to the other -O- is via the ethylene subunit. Orientation of the CRU is thus defined by (1) beginning at the -O- marked with an asterisk, and (2) reading in the direction of the arrow. The structure-based name of this polymer is therefore "poly(oxyethyleneoxyterephthaloyl)", not much longer than the traditional name and much more adaptable to the complexities of substitution. As organic nomenclature evolves, more systematic names may be used for subunits, e.g. "ethane-1,2-diyl" instead of "ethylene". IUPAC still prefers "ethylene" for the $-CH_2-CH_2-$ unit, however, but also accepts "ethane-1,2-diyl".

Structure-based nomenclature can also be used when the CRU backbone has no carbon atoms. An example is the polymer traditionally named "poly(dimethylsiloxane)", which on the basis of structure would be named "poly(oxydimethylsilylene)" or "poly(oxydimethylsilanediyl)". This nomenclature method has also been applied to inorganic and coordination polymers[8] and to double-strand (ladder and spiro) organic polymers.[9]

Irregular Single-Strand Polymers

Polymers that cannot be described by the repetition of a single CRU or comprise units not all connected identically in a directional sense can also be named on a structure basis.[10] These include copolymers, block and graft polymers, and star polymers. They are given names of the type "poly(A/B/C...)", where A, B, C, etc. are the names of the component constitutional units, the number of which are minimized. The constitutional units may include regular or irregular blocks as well as atoms or atomic groupings, and each is named by the method described above or by the rules of organic nomenclature.

The solidus denotes an unspecified arrangement of the units within the main chain.[10] For example, a statistical copolymer derived from styrene and vinyl chloride with the monomeric units joined head-to-tail is named "poly(l-chloroethylene/l-phenylethylene)". A polymer obtained by 1,4- polymerization and both head-to-head and head-to-tail 1,2- polymerization of 1,3-butadiene would be named "poly(but-1-ene-l,4-diyl/l-vinylethylene/2-vinylethylene)".[12] In graphic representations of these polymers, shown in Figure 2, the hyphens or dashes at each end of each CRU depiction are shown *completely within* the enclosing parentheses; this indicates that they are not necessarily the terminal bonds of the macromolecule.

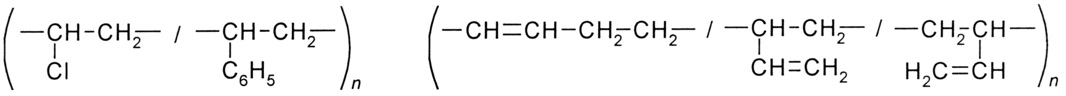

Figure 2. Graphic Representations of Copolymers

A long hyphen is used to separate components in names of block polymers, as in "poly(A)—poly(B)—poly(C)", or "poly(A)—X—poly(B)" in which X is a non-polymeric junction unit, e.g. dimethylsilylene.

In graphic representations of these polymers, the blocks are shown connected when the bonding is known (Figure 3, for example); when the bonding between the blocks is unknown, the blocks are separated by solidi and are shown *completely within* the outer set of enclosing parentheses (Figure 4, for example).[10,13]

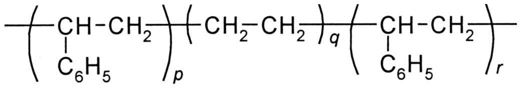

Figure 3. polystyrene—polyethylene—polystyrene

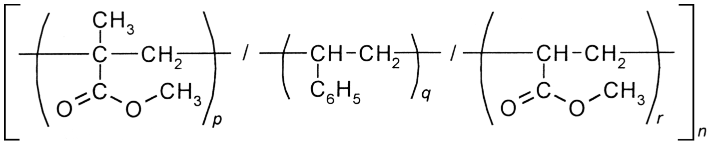

Figure 4. poly[poly(methyl methacrylate)—polystyrene—poly(methyl acrylate)]

Graft polymers are named in the same way as a substituted polymer but without the ending "yl" for the grafted chain; the name of a regular polymer, comprising Z units in which some have grafts of "poly(A)", is "poly[Z/poly(A)Z]". Star polymers are treated as a central unit with substituent blocks, as in "tetrakis(polymethylene)silane".[10,13]

NOMENCLATURE FOR ORGANIC POLYMERS (continued)

Other Nomenclature Articles and Publications

In addition to the *Chemical Abstracts* and IUPAC documents cited above and listed below, other articles on polymer nomenclature are available. A 1999 article lists significant documents on polymer nomenclature published during the last 50 years in books, encyclopedias, and journals by *Chemical Abstracts*, IUPAC, and individual authors.[14] A comprehensive review of source-based and structure-based nomenclature for all of the major classes of polymers,[15] and a short tutorial on the correct identification, orientation, and naming of most commonly encountered constitutional repeating units were both published in 2000.[16]

References and Notes

1. International Union of Pure and Applied Chemistry, *Compendium of Macromolecular Nomenclature,* Blackwell Scientific Publications, Oxford, 1991.
2. International Union of Pure and Applied Chemistry, Stereochemical Definitions and Notations Relating to Polymers (Recommendations 1980), *Pure Appl. Chem.,* **53**, 733-752 (1981).
3. International Union of Pure and Applied Chemistry, Source-Based Nomenclature for Copolymers (Recommendations 1985), *Pure Appl. Chem.,* **57**, 1427-1440 (1985).
4. International Union of Pure and Applied Chemistry, Nomenclature of Regular Single-Strand Organic Polymers (Recommendations 1975), *Pure Appl. Chem.,* **48**, 373-385 (1976).
5. Chemical Abstracts Service, Naming and Indexing of Chemical Substances for Chemical Abstracts, Appendix IV, *Chemical Abstracts 1999 Index Guide*.
6. International Union of Pure and Applied Chemistry, *A Guide to IUPAC Nomenclature of Organic Compounds* (1993), Blackwell Scientific Publications, Oxford, 1993.
7. International Union of Pure and Applied Chemistry, *Nomenclature of Organic Chemistry, Sections A, B, C, D, E, F, and H,* Pergamon Press, Oxford, 1979.
8. International Union of Pure and Applied Chemistry, Nomenclature of Regular Double-Strand and Quasi-Single-Strand Inorganic and Coordination Polymers (Recommendations 1984), *Pure Appl. Chem.,* **57**, 149-168 (1985).
9. International Union of Pure and Applied Chemistry, Nomenclature of Regular Double-Strand (Ladder and Spiro) Organic Polymers (Recommendations 1993), *Pure Appl. Chem.,* **65**, 1561-1580 (1993).
10. International Union of Pure and Applied Chemistry, Structure-Based Nomenclature for Irregular Single-Strand Organic Polymers (Recommendations 1994), *Pure Appl. Chem.,* **66**, 873-889 (1994).
11. International Union of Pure and Applied Chemistry, “Source-Based Nomenclature for Non-Linear Macromolecules and Macromolecular Assemblies (Recommendations 1997).” *Pure Appl. Chem.,* **69**, 2511-2521 (1997).
12. Poly(1,3-butadiene) obtained by polymerization of 1,3-butadiene in the so-called 1,4- mode is frequently drawn incorrectly in publications as $\text{-(CH}_2\text{-CH=CH-CH}_2)_n\text{-}$; the double bond should be assigned the lowest locant possible, i.e. the structure should be drawn as $\text{–(CH=CH-CH}_2\text{-CH}_2)_n\text{-}$.
13. International Union of Pure and Applied Chemistry, “Graphic Representations (Chemical Formulae) of Macromolecules (Recommendations 1994).” *Pure Appl. Chem.,* **66**, 2469-2482 (1994).
14. Wilks, E. S. Macromolecular Nomenclature Note No. 17: “Whither Nomenclature?” *Polym. Prepr.* **40**(2), 6-11 (1999); also available at www.chem.umr.edu/~poly/nomenclature.html.
15. Wilks, E. S. “Polymer Nomenclature: The Controversy Between Source-Based and Structure-Based Representations (A Personal Perspective).” *Prog. Polym. Sci.* **25**, 9-100 (2000).
16. Wilks, E. S. Macromolecular Nomenclature Note No. 18: “SRUs: Using the Rules.” *Polym. Prepr.* **41**(1), 6a-11a (2000); also available at www.chem.umr.edu/~poly/nomenclature.html; a .pdf format version is also available.

SOLVENTS FOR COMMON POLYMERS

Abbreviations: HC: hydrocarbons; MEK: methyl ethyl ketone; THF: tetrahydrofuran; DMF: dimethylformamide; DMSO: dimethylsulfoxide

Polyethylene (HDPE)	HC and halogenated HC
Polypropylene (atactic)	HC and halogenated HC
Polybutadiene	HC, THF, ketones
Polystyrene	ethylbenzene, $CHCl_3$, CCl_4, THF, MEK
Polyacrylates	aromatic HC, chlorinated HC, THF, esters, ketones
Polymethacrylates	aromatic HC, chlorinated HC, THF, esters, MEK
Polyacrylamide	water
Poly(vinyl ethers)	halogenated HC, MEK, butanol
Poly(vinyl alcohol)	glycols (hot), DMF
Poly(vinyl acetate)	aromatic HC, chlorinated HC, THF, esters, DMF
Poly(vinyl chloride)	THF, DMF, DMSO
Poly(vinylidene chloride)	THF (hot), dioxane, DMF
Poly(vinyl fluoride)	DMF, DMSO (hot)
Polyacrylonitrile	DMF, DMSO
Poly(oxyethylene)	aromatic HC, $CHCl_3$, alcohols, esters, DMF
Poly(2,6-dimethylphenylene oxide)	aromatic HC, halogenated HC
Poly(ethylene terephthalate)	phenol, DMSO (hot)
Polyurethanes (linear)	aromatic HC, THF, DMF
Polyureas	phenol, formic acid
Polysiloxanes	HC, THF, DMF
Poly[bis(2,2,2-trifluoroethoxy)-phosphazene]	THF, ketones, ethyl acetate

GLASS TRANSITION TEMPERATURE FOR SELECTED POLYMERS

Robert B. Fox

Polymer names are based on the IUPAC structure-based nomenclature system described in the table “Naming Organic Polymers”. Within each category, names are listed in alphabetical order. Source-based and trivial names are also given (in italics) for the most common polymers. The table does not include polymers for which T_g is not clearly defined because of variability of structure or because of reactions taking place near the glass transition.

All values of T_g cited in this table have been determined by differential scanning calorimetry (DSC) except those values indicated by:

(D) dynamic method
(Dil) dilatometry
(M) mechanical method

Polymer name	**Glass transition temperature (T_g/K)**
ACYCLIC CARBON CHAINS	
Polyalkadienes	
Poly(alkenylene) *Polyalkadiene* –[$CH=CHCH_2CH_2$]–	
Poly(*cis*-1-butenylene)	171
cis-1,3-polybutadiene [PBD]	
Poly(*trans*-1-butenylene)	215
trans-1,3-polybutadiene [PBD]	
Poly(1-chloro-*cis*-1-butenylene)	253
cis-1,3-polychloroprene	
Poly(1-chloro-*trans*-1-butenylene)	233
trans-1,3-polychloroprene	
Poly(1-methyl-*cis*-1-butenylene)	200
cis-1,3-polyisoprene	
Poly(1-methyl-*trans*-1-butenylene)	207
trans-1,3-polyisoprene	
Poly(1,4,4-trifluoro-1-butenylene)	238
Polyalkenes	
Poly(alkylethylene) *Poly(alkylethylene)* -[$RCHCH_2$]-	
Poly(1-benzylethylene)	333
Poly(1-butylethylene)	223
Poly(1-cyclohexylethylene) (atactic)	393
Poly(1-cyclohexylethylene) (isotactic)	406 (D)
Poly(1,1-dimethylethylene)	200
Polyisobutylene [PIB]	
Poly(ethylene)	148
Poly(methylene)	155
Poly(1-phenethylethylene)	283
Poly(propylene) (isotactic)	272
Poly(propylene) (syndiotactic)	ca. 265
Poly[1-(2-pyridyl)ethylene]	377
Poly[1-(4-pyridyl)ethylene]	415
Poly(1-vinylethylene)	273
Polyacrylics	
Poly[1-(alkoxycarbonyl)ethylene] *Poly(alkyl acrylate)* –[$(ROCO)CHCH_2$]–	
Poly[1-(benzyloxycarbonyl)ethylene]	279
Poly[1-(butoxycarbonyl)ethylene]	219 (M)
Poly(butyl acrylate) [PBA]	

Polymer name	Glass transition temperature (T_g/K)
Poly[1-(*sec*-butoxycarbonyl)ethylene]	251
Poly[1-(butoxycarbonyl)-1-cyanoethylene]	358
Poly[1-(butylcarbamoyl)ethylene]	319 (M)
Poly(1-carbamoylethylene)	438
Polyacrylamide [PAM]	
Poly(1-carboxyethylene)	379
Poly(acrylic acid) [PAA]	
Poly[1-(2-chlorophenoxycarbonyl)ethylene]	326
Poly[1-(4-chlorophenoxycarbonyl)ethylene]	331
Poly[1-(4-cyanobenzyloxycarbonyl)ethylene]	317
Poly[1-(2-cyanoethoxycarbonyl)ethylene]	277
Poly[1-(cyanomethoxycarbonyl)ethylene)]	433 Dil
Poly[1-(4-cyanophenoxycarbonyl)ethylene]	363
Poly[1-(cyclohexyloxycarbonyl)ethylene]	292
Poly[1-(2,4-dichlorophenoxycarbonyl)ethylene]	333
Poly[1-(dimethylcarbamoyl)ethylene]	362
Poly[1-(ethoxycarbonyl)ethylene]	249
Poly(ethyl acrylate) [PEA]	
Poly[1-(ethoxycarbonyl)-1-fluoroethylene]	316
Poly[1-(2-ethoxycarbonylphenoxycarbonyl)ethylene]	303
Poly[1-(3-ethoxycarbonylphenoxycarbonyl)ethylene]	297
Poly[1-(4-ethoxycarbonylphenoxycarbonyl)ethylene]	310
Poly[1-(2-ethoxyethoxycarbonyl)ethylene]	223
Poly[1-(3-ethoxypropoxycarbonyl)ethylene]	218
Poly[1-(isopropoxycarbonyl)ethylene]	267-270
Poly[1-(methoxycarbonyl)ethylene]	283
Poly(methyl acrylate) [PMA]	
Poly[1-(2-methoxycarbonylphenoxycarbonyl)ethylene]	319
Poly[1-(3-methoxycarbonylphenoxycarbonyl)ethylene]	311
Poly[1-(4-methoxycarbonylphenoxycarbonyl)ethylene]	340
Poly[1-(2-methoxyethoxycarbonyl)ethylene]	223
Poly[1-(4-methoxyphenoxycarbonyl)ethylene]	324
Poly[1-(3-methoxypropoxycarbonyl)ethylene]	198
Poly[1-(2-naphthyloxycarbonyl)ethylene]	358
Poly[1-(pentachlorophenoxycarbonyl)ethylene]	420
Poly[1-(phenethoxycarbonyl)ethylene]	270
Poly[1-(phenoxycarbonyl)ethylene]	330
Poly[1-(*m*-tolyloxycarbonyl)ethylene]	298
Poly[1-(*o*-tolyloxycarbonyl)ethylene]	325
Poly[1-(*p*-tolyloxycarbonyl)ethylene]	316
Poly[1-(2,2,2-trifluorethoxycarbonyl)ethylene]	263
Polymethacrylics	
Poly[1-(alkoxycarbonyl)-1-methylethylene] *Poly(alkyl methacrylate)* $-[(ROCO)(Me)CCH_2]-$	
Poly[1-(benzyloxycarbonyl)-1-methylethylene]	327
Poly[1-(2-bromoethoxycarbonyl)-1-methylethylene]	325
Poly[(1-(butoxycarbonyl)-1-methylethylene]	293
Poly(butyl methacrylate) [PBMA]	
Poly[1-(*sec*-butoxycarbonyl)-1-methylethylene]	333
Poly[1-(*tert*-butoxycarbonyl)-1-methylethylene)]	391
Poly[1-(2-chloroethoxycarbonyl)-1-methylethylene]	ca 315
Poly[1-(2-cyanoethoxycarbonyl)-1-methylethylene]	364
Poly[1-(4-cyanophenoxycarbonyl)-1-methylethylene]	428
Poly[1-(cyclohexyloxycarbonyl)-1-methylethylene] (atactic)	356
Poly[1-(cyclohexyloxycarbonyl)-1-methylethylene)] (isotactic)	324

GLASS TRANSITION TEMPERATURE FOR SELECTED POLYMERS (continued)

Polymer name	Glass transition temperature (T_g/K)
Poly[1-(dimethylaminoethoxycarbonyl)-1-methylethylene]	292
Poly[1-(ethoxycarbonyl)-1-ethylethylene]	300
Poly[1-(ethoxycarbonyl)-1-methylethylene] (atactic) *Poly(ethyl methacrylate)* [PEMA]	338
Poly[1-(ethoxycarbonyl)-1-methylethylene] (isotactic)	285
Poly[1-(ethoxycarbonyl)-1-methylethylene)] (syndiotactic)	339
Poly[1-(hexyloxycarbonyl)-1-methylethylene]	268
Poly[1-(isobutoxycarbonyl)-1-methylethylene]	326
Poly[1-(isopropoxycarbonyl)-1-methylethylene]	354
Poly[1-(methoxycarbonyl)-1-methylethylene] (atactic) *Poly(methyl methacrylate)* [PMMA]	378
Poly[1-(methoxycarbonyl)-1-methylethylene)] (isotactic)	311
Poly[1-(methoxycarbonyl)-1-methylethylene)] (syndiotactic)	378
Poly[1-(4-methoxycarbonylphenoxy)-1-methylethylene]	379
Poly[1-(methoxycarbonyl)-1-phenylethylene)] (atactic)	391
Poly[1-(methoxycarbonyl)-1-phenylethylene)] (isotactic)	397
Poly[1-methyl-1-(phenethoxycarbonyl)ethylene]	299
Poly[1-methyl-1-(phenoxycarbonyl)ethylene]	383
Polyvinyl ethers, alcohols, and ketones	
Poly(1-alkoxyethylene) *Poly(alkyl vinyl ether)* –[ROCHCH$_2$]–	
Poly(1-hydroxyethylene) *Poly(vinyl alcohol)* –[HOCHCH$_2$]–	
Poly(1-alkanoylethylene) *Poly(alkyl vinyl ketone)* –[RCOCHCH$_2$]–	
Poly(1-butoxyethylene)	218
Poly(1-*sec*-butoxyethylene)	253
Poly(1-*tert*-butoxyethylene)	361
Poly[1-(butylthio)ethylene]	253
Poly(1-ethoxyethylene)	230
Poly[1-(4-ethylbenzoyl)ethylene]	325
Poly(1-hydroxyethylene) *Poly(vinyl alcohol)* [PVA]	358 (D)
Poly(hydroxymethylene)	407
Poly(1-isopropoxyethylene)	270
Poly[1-(4-methoxybenzoyl)ethylene]	319 (M)
Poly(1-methoxyethylene) *Poly(methyl vinyl ether)* [PMVE]	242
Poly[1-(methylthio)ethylene]	272
Poly(1-propoxyethylene)	224
Poly[1-(trifluoromethoxy)trifluoroethylene]	268
Polyvinyl halides and nitriles	
Poly(1-haloethylene) *Poly(vinyl halide)* –[XCHCH$_2$]–	
Poly(1-cyanoethylene) *Poly(acrylonitrile)* –[NCCHCH$_2$]–	
Poly(1-chloroethylene) *Poly(vinyl chloride)* [PVC]	354
Poly(chlorotrifluoroethylene)	373
Poly(1-cyanoethylene) *Polyacrylonitrile* [PAN]	370
Poly(1-cyano-1-methylethylene) *Polymethacrylonitrile*	393
Poly(1,1-dichloroethylene) *Poly(vinylidene chloride)*	255
Poly(1,1-difluoroethylene) *Poly(vinylidene fluoride)*	ca 233
Poly(1-fluoroethylene) *Poly(vinyl fluoride)*	314 (M)

Polymer name	Glass transition temperature (T_g/K)
Poly(1-hexafluoropropylene)	425
Poly[1-(2-iodoethyl)ethylene]	343
Poly(tetrafluoroethylene)	(160)
Poly[1-(trifluoromethyl)ethylene]	300
Polyvinyl esters	
Poly[1-(alkanoyloxy)ethylene] *Poly(vinyl alkanoate)* –[RCOOCHCH$_2$]–	
Poly(1-acetoxyethylene) *Poly(vinyl acetate)* [PVAc]	305
Poly[1-(benzoyloxy)ethylene]	344
Poly[1-(4-bromobenzoyloxy)ethylene]	365
Poly[1-(2-chlorobenzoyloxy)ethylene]	335
Poly[1-(3-chlorobenzoyloxy)ethylene]	338
Poly[1-(4-chlorobenzoyloxy)ethylene]	357
Poly[1-(cyclohexanoyloxy)ethylene]	349 (M)
Poly[1-(4-ethoxybenzoyloxy)ethylene]	343
Poly[1-(4-ethylbenzoyloxy)ethylene]	326
Poly[1-(4-isopropylbenzoyloxy)ethylene]	342
Poly[1-(2-methoxybenzoyloxy)ethylene]	338
Poly[1-(3-methoxybenzoyloxy)ethylene]	ca 317
Poly[1-(4-methoxybenzoyloxy)ethylene]	360
Poly[1-(4-methylbenzoyloxy)ethylene]	343
Poly[1-(4-nitrobenzoyloxy)ethylene]	395
Poly[1-(propionoyloxy)ethylene]	283 (M)
Polystyrenes	
Poly(1-phenylethylene) *Polystyrene* –[C$_6$H$_5$CHCH$_2$]–	
Poly[1-(4-acetylphenyl)ethylene]	389 (M)
Poly[1-(4-benzoylphenyl)ethylene]	371 (M)
Poly[1-(4-bromophenyl)ethylene]	391
Poly[1-(4-butoxyphenyl)ethylene]	ca 320 (M)
Poly[1-(4-butoxycarbonylphenyl)ethylene]	349 (M)
Pol[(1-(4-butylphenyl)ethylene]	279
Poly[1-(4-carboxyphenyl)ethylene]	386 (M)
Poly[1-(2-chlorophenyl)ethylene]	392
Poly[1-(3-chlorophenyl)ethylene]	363
Poly[1-(4-chlorophenyl)ethylene]	383
Poly[1-(2,4-dichlorophenyl)ethylene]	406
Poly[1-(2,5-dichlorophenyl)ethylene]	379
Poly[1-(2,6-dichlorophenyl)ethylene]	440
Poly[1-(3,4-dichlorophenyl)ethylene]	401
Poly[1-(2,4-dimethylphenyl)ethylene]	385
Poly[1-(4-(dimethylamino)phenyl)ethylene]	398 (M)
Poly[1-(4-ethoxyphenyl)ethylene]	ca 359 (M)
Poly[1-(4-ethoxycarbonylphenyl)ethylene]	367 (M)
Poly[1-(4-fluorophenyl)ethylene]	368
Poly[1-(4-iodophenyl)ethylene]	429
Poly[1-(4-methoxyphenyl)ethylene]	386
Poly[1-(4-methoxycarbonylphenyl)ethylene]	386 (M)
Poly(1-methyl-1-phenylethylene) *Poly(α-methylstyrene)*	373
Poly[1-(2-(methylamino)phenyl)ethylene]	462 (M)
Poly(1-phenylethylene) *Polystyrene* [PS]	373

Polymer name	Glass transition temperature (T_g/K)
Poly[1-(4-propoxyphenyl)ethylene]	343 (M)
Poly[1-(4-propoxycarbonylphenyl)ethylene]	365 (M)
Poly(1-*o*-tolylethylene)	409
CHAINS WITH CARBOCYCLIC UNITS	
Poly(arylenealkylene) –[–Ar–$(CH_2)_n$]–	
Poly[1-(2-bromo-1,4-phenylene)ethylene]	353 (M)
Poly[1-(2-chloro-1,4-phenylene)ethylene]	343 (M)
Poly[1-(2-cyano-1,4-phenylene)ethylene]	363 (M)
Poly[1-(2,5-dimethyl-1,4-phenylene)ethylene]	373 (M)
Poly[1-(2-ethyl-1,4-phenylene)ethylene]	298 (M)
Poly[1-(1,4-naphthylene)ethylene]	433 (M)
Poly[1-(1,4-phenylene)ethylene]	ca 353 (M)
CHAINS WITH HETEROATOM UNITS	
Main chain oxide units	
Poly(oxyalkylene) *Poly(alkylene oxide)* –[$O(CH_2)_n$]–	
Poly[oxy(1,1-bis(chloromethyl)trimethylene)]	265
Poly[oxy(1-(bromomethyl)ethylene)]	259
Poly[oxy(1-(butoxymethyl)ethylene)]	194
Poly[oxy(1-butylethylene)]	203
Poly[oxy(1-*tert*-butylethylene)]	308
Poly[oxy(1-(chloromethyl)ethylene)] *Poly(epichlorohydrin)*	251
Poly[oxy(2,6-dimethoxy-1,4-phenylene)]	440
Poly[oxy(1,1-dimethylethylene)]	264
Poly[oxy(2,6-dimethyl-1,4-phenylene)]	482
Poly[oxy(2,6-diphenyl-1,4-phenylene)]	493
Poly[oxy(1-ethylethylene)]	203
Poly(oxyethylidene) *Polyacetaldehyde*	243
Poly[oxy(1-(methoxymethyl)ethylene)]	211
Poly[oxy(2-methyl-6-phenyl-1,4-phenylene)]	428
Poly[oxy(1-methyltrimethylene)]	223 (D)
Poly[oxy(2-methyltrimethylene)]	218
Poly(oxy-1,4-phenylene) *Poly(phenylene oxide)* [PPO]	358
Poly[oxy(1-phenylethylene)]	313
Poly(oxytetramethylene) *Poly(tetrahydrofuran)* [PTMO]	189
Poly(oxytrimethylene)	195
Main-chain ester or anhydride units	
Poly(oxyalkyleneoxyalkanedioyl) *Poly(alkylene alkanedioate)*–[$O(CH_2)_mOCO(CH_2)_nCO$]–	
Poly(oxyadipoyloxydecamethylene)	217
Poly(oxyadipoyloxy-1,4-phenyleneisopropylidene-1,4-phenylene)	341
Poly(oxycarbonyloxy-1,4-phenylene-isopropylidene-1,4-phenylene) *Bisphenol A polycarbonate*	422
Poly(oxycarbonylpentamethylene)	213
Poly(oxycarbonyl-1,4-phenylenemethylene-1,4-phenylene)	395
Poly(oxycarbonyl-1,4-phenyleneisopropylidene-1,4-phenylene)	333

Polymer name	Glass transition temperature (T_g/K)
Poly[oxy(2,6-dimethyl-1,4-phenyleneisopropylidene-3,5-dimethyl-1,4-phenylene)oxysebacoyl]	318
Poly(oxyethylenecarbonyl-1,4-cyclohexylenecarbonyl) (trans)	291
Poly(oxyethyleneoxycarbonyl-1,4-naphthylenecarbonyl)	337
Poly(oxyethyleneoxycarbonyl-1,5-naphthylenecarbonyl)	344
Poly(oxyethyleneoxycarbonyl-2,6-naphthylenecarbonyl)	386
Poly(oxyethyleneoxycarbonyl-2,7-naphthylenecarbonyl)	392
Poly(oxyethyleneoxyterephthaloyl)	342
Poly(ethylene terephthalate) [PET]	
Poly(oxyisophthaloyl)	403 (D)
Poly(oxy(1-oxo-2,2-dimethyltrimethylene))	263
Poly(pivalolactone)	
Poly(oxy-1,4-phenyleneisopropylidene-1,4-phenyleneoxysebacoyl)	280
Poly(oxy-1,4-phenyleneoxy-1,4-phenyleneoxy-carbonyl-1,4-phenylene) [PEEK]	416
Poly(oxypropyleneoxyterephthaloyl)	341
Poly[oxyterephthaloyloxy(2,6-dimethyl-1,4-phenyleneisopropylidene-3,5-dimethyl-1,4-(D)phenylene)]	498
Poly(oxyterephthaloyloxyoctamethylene)	318 (D)
Poly(oxyterephthaloyloxy-1,4-phenyleneisopropylidene-1,4-phenylene)	478
Poly(bisphenol A terephthalate)	
Poly(oxytetramethyleneoxyterephthaloyl)	323
Poly(butylene terephthalate) [PBT]	
Main-chain amide units	
Poly(iminoalkyleneiminoalkanedioyl) *Poly(alkylene alkanediamide)*–[NH(CH_2)$_m$NHCO(CH_2)$_n$CO]–	
Poly(iminoadipoyliminodecamethylene)	313
Nylon 10,6	
Poly(iminoadipoyliminohexamethylene)	ca 323
Nylon 6,6	
Poly(iminoadipoyliminooctamethylene)	318
Nylon 8,6	
Poly[iminoadipoyliminotrimethylene(methylimino)trimethylene]	278
Poly(iminocarbonyl-1,4-cyclohexylenemethylene)	466
Poly[iminocarbonyl-1,4-phenylene(2-oxoethylene)iminohexamethylene]	377
Poly(iminoethylene-1,4-phenyleneethyleneiminosebacoyl)	378 (D)
Poly(iminohexamethyleneiminoazelaoyl)	331
Nylon 6,9	
Poly(iminohexamethyleneiminododecanedioyl)	319
Nylon 6, 12	
Poly(iminohexamethyleneiminopimeloyl)	331
Nylon 6,7	
Poly(iminohexamethyleneiminosebacoyl)	323
Nylon 6,10	
Poly(iminohexamethyleneiminosuberoyl)	330
Nylon 6,8	
Poly(iminoisophthaloylimino-4,4′-biphenylylene)	558
Poly(iminoisophthaloyliminohexamethylene)	390
Poly(iminoisophthaloyliminomethylene-1,4-cyclohexylenemethylene)	481
Poly(iminoisophthaloyliminomethylene-1,3-phenylenemethylene)	438 (M)
Poly[iminomethylene(2,5-dimethyl-1,4-phenylene)methyleneiminosuberoyl]	351
Poly(imino-1,5-naphthyleneiminoisophthaloyl)	598
Poly(imino-1,5-naphthyleneiminoterephthaloyl)	578
Poly(iminooctamethyleneiminodecanedioyl)	333
Nylon 8,10	
Poly(iminooxalyliminohexamethylene)	430
Nylon 6,2	
Poly[imino(1-oxohexamethylene)]	326
Nylon 6	

Polymer name	Glass transition temperature (T_g/K)
Poly[imino(1-oxodecamethylene)]	315
Nylon 10	
Poly[imino(1-oxoheptamethylene)]	325
Nylon 7	
Poly[imino(1-oxo-3-methyltrimethylene]	369
Poly[imino(1-oxononamethylene)]	319
Nylon 9	
Poly[imino(1-oxooctamethylene)]	323
Nylon 8	
Poly[imino(1-oxotrimethylene)]	384
Nylon 3	
Poly(iminopentamethyleneiminoadipoyl)	318
Nylon 5,6	
Poly[iminopentamethyleneiminocarbonyl-1,4-phenylene(2-oxoethylene)]	376
Poly(imino-1,3-phenyleneiminoisophthaloyl)	553 (M)
Poly(imino-1,4-phenyleneiminoterephthaloyl)	618
Poly(iminopimeloyliminoheptamethylene)	328
Nylon 7,7	
Poly(iminoterephthaloylimino-4,4′-biphenylylene)	613
Poly(iminotetramethyleneiminoadipoyl)	316
Nylon 4,6	
Poly[iminotetramethyleneiminocarbonyl-1,4-phenylene(2-oxoethylene)]	357
Poly(iminotrimethyleneiminoadipoyliminotrimethylene)	307
Poly[iminotrimethyleneiminocarbonyl-1,4-phenylene(2-oxoethylene)]	382
Poly(oxy-1,4-phenyleneiminoterephthaloyl-imino-1,4-phenylene)	613
Poly(sulfonylimino-1,4-phenyleneiminoadipoylimino-1,4-phenylene)	467
Main-chain urethane units	
Poly(oxyalkyleneoxycarbonyliminoalkyleneiminocarbonyl)–[O(CH_2)$_m$OCONH(CH_2)$_n$NHCO]–	
Poly(oxyethyleneoxycarbonyliminohexamethyleneiminocarbonyl)	329
Poly[oxyethyleneoxycarbonylimino(6-methyl-1,3-phenylene)iminocarbonyl]	325
Poly(oxyethyleneoxycarbonylimino-1,4-phenylenemethylene-1,4-phenyleneiminocarbonyl)	412
Poly(oxyhexamethyleneoxycarbonyliminohexamethyleneiminocarbonyl)	332
Poly[oxyhexamethyleneoxycarbonylimino(6-methyl-1,3-phenylene)iminocarbonyl]	305
Poly(oxyhexamethyleneoxycarbonylimino-1,4-phenylenemethylene-1,4-phenyleneiminocarbonyl)	364
Poly(oxyoctamethyleneoxycarbonyliminohexamethyleneiminocarbonyl)	331
Poly[oxyoctamethyleneoxycarbonylimino(6-methyl-1,3-phenylene)iminocarbonyl]	337
Poly(oxyoctamethyleneoxycarbonylimino-1,4-phenylenemethylene-1,4-phenyleneiminocarbonyl)	352
Poly(oxytetramethyleneoxycarbonyliminohexamethyleneiminocarbonyl)	332
Poly[oxytetramethyleneoxycarbonylimino(6-methyl-1,3-phenylene)iminocarbonyl]	315
Poly(oxytetramethyleneoxycarbonylimino-1,4-phenylenemethylene-1,4-phenyleneiminocarbonyl)	382
Main-chain siloxanes	
Poly[oxy(dialkylsilylene)] *Poly(dialkylsiloxane)* –[O(R_2Si)]–	
Poly[oxy(dimethylsilylene)]	148
Poly(dimethylsiloxane) [PDMS]	
Poly[oxy(dimethylsilylene)oxy-1,4-phenylene]	363 (M)
Poly[oxy(dimethylsilylene)oxy-1,4-phenyleneisopropylidene-1,4-phenylene]	318 (M)
Poly[oxy(diphenylsilylene)]	238
Poly(diphenylsiloxane)	
Poly[oxy(diphenylsilylene)-1,3-phenylene]	ca 331
Poly[oxy((methyl)phenylsilylene)]	187
Poly[oxy((methyl)-3,3,3-trifluoropropylsilylene]	<193

Polymer name	Glass transition temperature (T_g/K)
Main-chain sulfur-containing units	
Poly(dithioethylene)	223
Poly(dithiomethylene-1,4-phenylenemethylene)	296
Poly(oxy-4,4′-biphenylylene-1,4-phenylenesulfonyl-1,4-phenylene)	503 (M)
Poly(oxycarbonyloxy-1,4-phenylenethio-1,4-phenylene)	ca 383
Poly(oxyethylenedithioethylene)	220 (M)
Poly[oxy(2-hydroxytrimethylene)oxy-1,4-phenylenesulfonyl-1,4-phenylene]	428
Poly(oxymethyleneoxyethylenedithioethylene)	214
Poly(oxy-1,4-phenylenesulfinyl-1,4-phenyleneoxy-1,4-phenylenecarbonyl-1,4-phenylene)	478 (M)
Poly(oxy-1,4-phenylenesulfinyl-1,4-phenyleneoxy-1,4-phenyleneisopropylidene-1,4-phenylene)	438 (M)
Poly(oxy-1,4-phenylenesulfonyl-1,4-phenylene)	487
Poly(oxy-1,4-phenylenesulfonyl-4,4′-biphenylylenesulfonyl-1,4-phenylene)	533
Poly[oxy-1,4-phenylenesulfonyl-1,4-phenyleneoxy(2,6-dimethyl-1,4-phenylene)isopropylidene (3,5-dimethyl-1,4-phenylene)]	508 (M)
Poly(oxy-1,4-phenylenesulfonyl-1,4-phenyleneoxy-1,4-phenylenecarbonyl-1,4-phenylene)	478 (M)
Poly[oxy-1,4-phenylenesulfonyl-1,4-phenyleneoxy-1,4-phenylene(hexafluoroisopropylidene)1,4-phenylene]	478 (M)
Poly(oxy-1,4-phenylenesulfonyl-1,4-phenyleneoxy-1,4-phenyleneisopropylidene-1,4-phenylene)	449
Poly(oxy-1,4-phenylenesulfonyl-1,4-phenyleneoxy-1.4-phenylenemethylene-1,4-phenylene)	453 (M)
Poly(oxy-1,4-phenylenesulfonyl-1,4-phenyleneoxy-1.4-phenylenethio-1,4-phenylene)	448 (M)
Poly(oxy-1,4-phenylenesulfonyl-1,4-phenyleneoxyterephthaloyl)	522
Poly(oxytetramethylenedithiotetramethylene)	197
Poly(sulfonyl-1,2-cyclohexylene)	401
Poly(sulfonyl-1,3-cyclohexylene)	381
Poly(sulfonyl-1,4-phenylenemethylene-1,4-phenylene)	497
Poly(thio-1,3-cyclohexylene)	221
Poly[thio(difluoromethylene)]	155
Poly(thioethylene)	223
Poly[thio(1-ethylethylene]	218
Poly[thio(1-methyl-3-oxotrimethylene)]	285
Poly[thio(1-methyltrimethylene)]	214
Pol[(thio(1-oxohexamethylene)]	292
Poly(thio-1,4-phenylene)	370
Poly(thiopropylene)	226
Main-chain heterocyclic units	
Poly(1,3-dioxa-4,6-cyclohexylenemethylene) *Poly(vinyl formal)*	378
Poly[(2,6-dioxopiperidine-1,4-diyl)trimethylene]	363
Poly[(2-methyl-1,3-dioxa-4,6-cyclohexylene)methylene] *Poly(vinyl acetal)*	355
Poly(1,4-piperazinediylcarbonyloxyethyleneoxycarbonyl)	333
Poly(1,4-piperazinediylisophthaloyl)	465 (M)
Poly[(2-propyl-1,3-dioxa-4,6-cyclohexylene)methylene] *Poly(vinyl butyral)*	322
Poly(3,6-pyridazinediyloxy-1,4-phenyleneisopropylidene-1,4-phenyleneoxy)	453 (M)
Poly(2,5-pyridinediylcarbonyliminohexamethyleneiminocarbonyl)	322

DIELECTRIC CONSTANT OF SELECTED POLYMERS

This table lists typical values of the dielectric constant (more properly called relative permittivity) of some important polymers. Values are given for frequencies of 1 kHz, 1 MHz, and 1 GHz; in most cases the dielectric constant at frequencies below 1 kHz does not differ significantly from the value at 1 kHz. Since the dielectric constant of a polymeric material can vary with density, degree of crystallinity, and other details of a particular sample, the values given here should be regarded only as typical or average values.

REFERENCES

1. Gray, D.E., Ed., *American Institute of Physics Handbook, Third Edition*, p. **5**-132, McGraw Hill, New York, 1972.
2. Anderson, H.L., Editor, *A Physicist's Desk Reference*, American Institute of Physics, New York, 1989.
3. Brandrup, J., and Immergut, E.H., *Polymer Handbook, Third Edition*, John Wiley & Sons, New York, 1989.

Name	*t*/°C	1 kHz	1 MHz	1 GHz
Polyacrylonitrile	25	5.5	4.2	
Polyamides (nylons)	25	3.50	3.14	2.8
	84	11	4.4	2.8
Polybutadiene	25	2.5		
Polycarbonate	23	2.92	2.8	
Polychloroprene (neoprene)	25	6.6	6.3	4.2
Polychlorotrifluoroethylene	23	2.65	2.46	2.39
Polyethylene	23	2.3		
Poly(ethylene terephthalate) (Mylar)	23	3.25	3.0	2.8
Polyisoprene (natural rubber)	27	2.6	2.5	2.4
Poly(methyl methacrylate)	27	3.12	2.76	2.6
	80	3.80	2.7	2.6
Polyoxymethylene (polyformaldehyde)	25	3.8		
Poly(phenylene oxide)	23	2.59	2.59	
Polypropylene	25	2.3	2.3	2.3
Polystyrene	25	2.6	2.6	2.6
Polysulfones	25	3.13	2.10	
Polytetrafluoroethylene (teflon)	25	2.1	2.1	2.1
Poly(vinyl acetate)	50		3.5	
	150		8.3	
Poly(vinyl chloride)	25	3.39	2.9	2.8
	100	5.3	3.3	2.7
Poly(vinylidene chloride)	23	4.6	3.2	2.7
Poly(vinylidene fluoride)	23	12.2	8.9	4.7

PRESSURE-VOLUME-TEMPERATURE RELATIONSHIP FOR POLYMER MELTS

Christian Wohlfarth

Numerous theoretical equations of state for polymer liquids have been developed. These, at the minimum, have to provide accurate fitting functions to experimental data. However, for the purpose of this table, the empirical Tait equation along with a polynomial expression for the zero pressure isobar is used. This equation is able to represent the experimental data for the melt state within the limits of experimental errors, i.e., the maximum deviations between measured and calculated specific volumes are about 0.001-0.002 cm^3/g.

The general form of the Tait equation is:

$$V(P,T) = V(0,T)\{1 - C\ \ln[1 + P/B(T)]\} \quad (1)$$

where the coefficient C is usually taken to be a universal constant equal to 0.0894. T is the absolute temperature in K and P the pressure in MPa. The volume V is the specific volume in cm^3/g. The Tait parameter $B(T)$ has the very simple meaning that it is inversely proportional to the compressibility κ at constant temperature and zero pressure:

$$\kappa(0,T) = -[1/V(0,T)](dV/dP) = C/B(T) \quad (2)$$

The $B(T)$ function is usually given by:

$$B(T) = B_0 \exp[-B_1(T\text{-}273.15)] \quad (3)$$

but, sometimes a polynomial expression is used:

$$B(T) = b_0 + b_1(T\text{-}273.15) + b_2(T\text{-}273.15)^2 \quad (4)$$

The zero-pressure isobar $V(0,T)$ is usually given by:

$$V(0,T) = A_0 + A_1(T\text{-}273.15) + A_2(T\text{-}273.15)^2 \quad (5)$$

where A_0, A_1, A_2 are specific constants for a given polymer (the expression T-273.15 is used because fitting to the zero-pressure isobar is usually done in terms of Celsius temperature). Other forms for $V(0,T)$ are also found in the literature, such as

$$V(0,T) = A_3 \exp[A_4(T\text{-}273.15)] \quad (6)$$

or

$$V(0,T) = A_5 \exp(A_6 T^{1.5}) \quad (7)$$

where A_3 and A_4 or A_5 and A_6 are again specific constants for a given polymer.

The Tait equation is particularly useful to calculate derivative quantities, such as the isothermal compressibility and the thermal expansivity coefficients. The isothermal compressibility $\kappa(P,T)$ is derived from equation (1) as:

$$\kappa(P,T) = -(1/V)(dV/dP) = 1/\{[P + B(T)][1/C - \ln(1 + P/B(T))]\} \quad (8)$$

and the thermal expansivity $\alpha(P,T)$ as:

$$\alpha(P,T) = (1/V)(dV/dT) = \alpha(0,T) - PB_1\kappa(P,T) \quad (9)$$

where $\alpha(0,T)$ represents the thermal expansivity at zero (atmospheric) pressure and is calculated from any suitable fit for the zero-pressure volume, such as equations (5) through (7) above.

Because polymer melt PVT-behavior depends only slightly on polymer molar mass above the oligomeric region, usually no information is given in the original literature for the average molar mass of the polymers.

Table 1 summarizes the polymers or copolymers considered here and the experimental ranges of pressure and temperature over which data are available. In Table 2 the Tait-equation functions, with parameters obtained from the fit, are given for 90 polymer or copolymer melts.

REFERENCES

1. Zoller, P., *J. Appl. Polym. Sci*. 23, 1051-1056, 1979.
2. Starkweather, H. W., Jones, G. A., and Zoller, P., *J. Polym. Sci., Pt. B Polym. Phys*. 26, 257-266,1988.
3. Fakhreddine, Y. A., and Zoller, P., *J. Polym. Sci., Pt. B Polym. Phys*. 29, 1141-1146, 1991.
4. Rodgers, P. A., *J. Appl. Polym. Sci*. 48, 1061-1080, 1993.
5. Rodgers, P. A., *J. Appl. Polym. Sci*. 48, 2075-2083, 1993.
6. Yi, Y. X., and Zoller, P., *J. Polym. Sci., Pt. B Polym. Phys*. 31, 779-788, 1993.
7. Callaghan, T. A., and Paul, D. R., *Macromolecules* 26, 2439–2450, 1993.
8. Wang, Y. Z., Hsieh, K. H., Chen, L. W.,and Tseng, H. C., *J. Appl. Polym. Sci*. 53, 1191-1201, 1994.
9. Privalko, V. P., Arbuzova, A. P., Korskanov, V. V., and Zagdanskaya, N. E., *Polym. Intern*. 35, 161-169, 1994.
10. Sachdev, V. K., Yashi, U., and Jain, R. K., *J. Polym. Sci., Pt. B Polym. Phys*. 36, 841-850, 1998.

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Table 1
Names of the Polymers, Abbreviation Used, and Range of Experimental Data Applied in the Determination of the Equation Constants

Polymer	Symbol	*T*/K	*P*/MPa	Ref.
Ethylene/propylene copolymer (50 wt%)	EP50	413-523	0.1-63	4
Ethylene/vinyl acetate copolymer				
18 wt% vinyl acetate	EVA18	385-491	0.1-177	4
25 wt% vinyl acetate	EVA25	367-506	0.1-177	4
28 wt% vinyl acetate	EVA28	367-508	0.1-177	4
40 wt% vinyl acetate	EVA40	348-508	0.1-177	4
Polyamide-6	PA6	509-569	0.1-196	4
Polyamide-11	PA11	478-542	0.1-200	5
Polyamide-66	PA66	519-571	0.1-196	4
cis-1,4-Polybutadiene	cPBD	277-328	0.1-284	4
Polybutadiene, 8% 1,2-content	PBD-8	298-473	0.1-200	6
Polybutadiene, 24% 1,2-content	PBD-24	298-473	0.1-200	6
Polybutadiene, 40% 1,2-content	PBD-40	298-473	0.1-200	6
Polybutadiene, 50% 1,2-content	PBD-50	298-473	0.1-200	6
Polybutadiene, 87% 1,2-content	PBD-87	298-473	0.1-200	6
Poly(1-butene), isotactic	iPB	406-519	0.1-196	4
Poly(butyl methacrylate)	PnBMA	307-473	0.1-200	4
Poly(butylene terephthalate)	PBT	508-576	0.1-200	3
Poly(ε-caprolactone)	PCL	373-421	0.1-200	4
Polycarbonate-bisphenol-A	PC	424-613	0.1-177	4
Polycarbonate-bisphenol-chloral	BCPC	428-557	0.1-200	4
Polycarbonate-hexafluorobisphenol-A	HFPC	432-553	0.1-200	4
Polycarbonate-tetramethylbisphenol-A	TMPC	491-563	0.1-160	4
Poly(cyclohexyl methacrylate)	PcHMA	396-471	0.1-200	4
Poly(2,5-dimethylphenylene oxide)	PPO	473-593	0.1-177	4
Poly(dimethyl siloxane)	PDMS	298-343	0.1-100	4
Poly(dimethyl siloxane) $M_n = 1000$	PDMS-10	304-420	0.1-250	10
Poly(dimethyl siloxane) $M_n = 4000$	PDMS-40	298-418	0.1-250	10
Poly(dimethyl siloxane) $M_n = 6000$	PDMS-60	291-423	0.1-250	10
Poly(epichlorohydrin)	PECH	333-413	0.1-200	4
Poly(ether ether ketone)	PEEK	619-671	0.1-200	4
Poly(ethyl acrylate)	PEA	310-490	0.1-196	4
Poly(ethyl methacrylate)	PEMA	386-434	0.1-196	4
Polyethylene, high density	HDPE	413-476	0.1-196	4
Polyethylene, linear	LPE	415-473	0.1-200	4
Polyethylene, linear, high MW	HMLPE	410-473	0.1-200	4
Polyethylene, branched	BPE	398-471	0.1-200	4
Polyethylene, low density	LDPE	394-448	0.1-196	4
Polyethylene, low density, type A	LDPE-A	385-498	0.1-196	1
Polyethylene, low density, type B	LDPE-B	385-498	0.1-196	1
Polyethylene, low density, type C	LDPE-C	385-498	0.1-196	1
Poly(ethylene oxide)	PEO	361-497	0.1- 68	4
Poly(ethylene terephthalate)	PET	547-615	0.1-196	4
Poly(4-hexylstyrene)	P4HS	303-403	30-100	4
Polyisobutylene	PIB	326-383	0.1-100	4
Polyisoprene, 8% 3,4-content	PI-8	298-473	0.1-200	6
Polyisoprene, 14% 3,4-content	PI-14	298-473	0.1-200	6
Polyisoprene, 41% 3,4-content	PI-41	298-473	0.1-200	6
Polyisoprene, 56% 3,4-content	PI-56	298-473	0.1-200	6
Poly(methyl acrylate)	PMA	310-493	0.1-196	4

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Table 1
Names of the Polymers, Abbreviation Used, and Range of Experimental Data Applied in the Determination of the Equation Constants

Polymer	Symbol	*T*/K	*P*/MPa	Ref.
Poly(methyl methacrylate)	PMMA	387-432	0.1-200	4
Poly(4-methyl-1-pentene)	P4MP	514-592	0.1-196	4
Poly(α-methylstyrene)	PαMS	473-533	0.1-170	7
Poly(*o*-methylstyrene)	PoMS	412-471	0.1-180	4
Polyoxymethylene	POM	463-493	0.1-196	2
Phenoxy[a]	PH	341-573	0.1-177	4
Polysulfone[b]	PSF	475-644	0.1-196	4
Polyarylate[c]	PAr	450-583	0.1-177	4
Polypropylene, atactic	aPP	353-393	0.1-100	4
Polypropylene, isotactic	iPP	443-570	0.1-196	4
Polystyrene	PS	388-469	0.1-200	4
Poly(tetrafluoroethylene)	PTFE	603-645	0.1- 39	4
Poly(tetrahydrofuran)	PTHF	335-439	0.1- 78	4
Poly(vinyl acetate)	PVAc	308-373	0.1- 80	4
Poly(vinyl chloride)	PVC	373-423	0.1-200	4
Poly(vinyl methyl ether)	PVME	303-471	0.1-200	4
Poly(vinylidene fluoride)	PVdF	451-521	0.1-200	5
Styrene/acrylonitrile copolymer				
2.7 wt% acrylonitrile	SAN3	378-539	0.1-200	4
5.7 wt% acrylonitrile	SAN6	370-540	0.1-200	4
15.3 wt% acrylonitrile	SAN15	405-531	0.1-200	4
18.0 wt% acrylonitrile	SAN18	377-528	0.1-200	4
40 wt% acrylonitrile	SAN40	373-543	0.1-200	4
70 wt% acrylonitrile	SAN70	373-544	0.1-200	4
Styrene/butadiene copolymer				
10 wt% styrene	SBR10	393-533	0.1-196	8
23.5 wt% styrene	SBR23	393-533	0.1-196	8
60 wt% styrene	SBR60	393-533	0.1-196	8
85 wt% styrene	SBR85	393-533	0.1-196	8
Styrene/methyl methacrylate copolymer				
20 wt% methyl methacrylate	SMMA20	383-543	0.1-200	4
60 wt% methyl methacrylate	SMMA60	383-543	0.1-200	4
N-Vinylcarbazole/4-ethylstyrene copolymer				
50 mol% ethylstyrene	VCES50	393-443	30-100	9
N-Vinylcarbazole/4-hexylstyrene copolymer				
80 mol% hexylstyrene	VCHS80	313-423	30-100	9
67 mol% hexylstyrene	VCHS67	333-423	30-100	9
60 mol% hexylstyrene	VCHS60	383-453	30-100	9
50 mol% hexylstyrene	VCHS50	373-443	30-100	9
40 mol% hexylstyrene	VCHS40	423-493	30-100	9
33 mol% hexylstyrene	VCHS33	463-523	30-100	9
20 mol% hexylstyrene	VCHS20	473-523	30-100	9
N-Vinylcarbazole/4-octylstyrene copolymer				
50 mol% octylstyrene	VCOS50	403-453	30-100	9
N-Vinylcarbazole/4-pentylstyrene copolymer				
50 mol% pentylstyrene	VCPS50	383-443	30-100	9

[a]Phenoxy = Poly(oxy-2-hydroxytrimethyleneoxy-1,4-phenyleneisopropylidene-1,4-phenylene)
[b]Polysulfone = Poly(oxy-1,4-phenylenesulfonyl-1,4-phenyleneoxy-1,4-phenyleneisopropylidene-1,4-phenylene)
[c]Polyarylate = Poly(oxyterephthaloyl/isophthaloyl T/I=50/50)oxy-1,4-phenyleneisopropylidene-1,4-phenylene

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Table 2
Tait Equation Parameter Functions for Polymer Melts

Polymer	$V(0,T)$/cm^{3}g^{-1}	$B(T)$/MPa
EP50	$1.2291 + 5.799 \cdot 10^{-5}(T-273.15) + 1.964 \cdot 10^{-6}(T-273.15)^2$	$487.0 \exp[-8.103 \cdot 10^{-3}(T-273.15)]$
EVA18	$1.02391 \exp(2.173 \cdot 10^{-5}T^{1.5})$	$188.2 \exp[-4.537 \cdot 10^{-3}(T-273.15)]$
EVA25	$1.00416 \exp(2.244 \cdot 10^{-5}T^{1.5})$	$184.4 \exp[-4.734 \cdot 10^{-3}(T-273.15)]$
EVA28	$1.00832 \exp(2.241 \cdot 10^{-5}T^{1.5})$	$183.5 \exp[-4.457 \cdot 10^{-3}(T-273.15)]$
EVA40	$1.06332 \exp(2.288 \cdot 10^{-5}T^{1.5})$	$205.1 \exp[-4.989 \cdot 10^{-3}(T-273.15)]$
PA6	$0.7597 \exp[4.701 \cdot 10^{-4}(T-273.15)]$	$376.7 \exp[-4.660 \cdot 10^{-3}(T-273.15)]$
PA11	$0.9581 \exp[6.664 \cdot 10^{-4}(T-273.15)]$	$254.7 \exp[-4.178 \cdot 10^{-3}(T-273.15)]$
PA66	$0.7657 \exp[6.600 \cdot 10^{-4}(T-273.15)]$	$316.4 \exp[-5.040 \cdot 10^{-3}(T-273.15)]$
cPBD	$1.0970 \exp[6.600 \cdot 10^{-4}(T-273.15)]$	$177.7 \exp[-3.593 \cdot 10^{-3}(T-273.15)]$
PBD-8	$1.1004 + 6.718 \cdot 10^{-4}(T-273.15) + 6.584 \cdot 10^{-7}(T-273.15)^2$	$200.0 \exp[-4.606 \cdot 10^{-3}(T-273.15)]$
PBD-24	$1.1049 + 6.489 \cdot 10^{-4}(T-273.15) + 7.099 \cdot 10^{-7}(T-273.15)^2$	$193.0 \exp[-4.519 \cdot 10^{-3}(T-273.15)]$
PBD-40	$1.1013 + 6.593 \cdot 10^{-4}(T-273.15) + 5.776 \cdot 10^{-7}(T-273.15)^2$	$188.0 \exp[-4.437 \cdot 10^{-3}(T-273.15)]$
PBD-50	$1.1037 + 5.955 \cdot 10^{-4}(T-273.15) + 7.789 \cdot 10^{-7}(T-273.15)^2$	$183.0 \exp[-4.425 \cdot 10^{-3}(T-273.15)]$
PBD-87	$1.1094 + 6.729 \cdot 10^{-4}(T-273.15) + 4.470 \cdot 10^{-7}(T-273.15)^2$	$175.0 \exp[-4.538 \cdot 10^{-3}(T-273.15)]$
iPB	$1.1417 \exp[6.751 \cdot 10^{-4}(T-273.15)]$	$167.5 \exp[-4.533 \cdot 10^{-3}(T-273.15)]$
PnBMA	$0.9341 + 5.5254 \cdot 10^{-4}(T-273.15) + 6.5803 \cdot 10^{-6}(T-273.15)^2 + 1.5691 \cdot 10^{-10}(T-273.15)^3$	$226.7 \exp[-5.344 \cdot 10^{-3}(T-273.15)]$
PBT	$0.9640 - 1.017 \cdot 10^{-3}(T-273.15) + 3.065 \cdot 10^{-6}(T-273.15)^2$	$263.0 \exp[-3.444 \cdot 10^{-3}(T-273.15)]$
PCL	$0.9049 \exp[6.392 \cdot 10^{-4}(T-273.15)]$	$189.0 \exp[-3.931 \cdot 10^{-3}(T-273.15)]$
PC	$0.73565 \exp(1.859 \cdot 10^{-5}T^{1.5})$	$310.0 \exp[-4.078 \cdot 10^{-3}(T-273.15)]$
BCPC	$0.6737 + 3.634 \cdot 10^{-4}(T-273.15) + 2.370 \cdot 10^{-7}(T-273.15)^2$	$363.4 \exp[-4.921 \cdot 10^{-3}(T-273.15)]$
HFPC	$0.6111 + 4.898 \cdot 10^{-4}(T-273.15) + 1.730 \cdot 10^{-7}(T-273.15)^2$	$236.6 \exp[-5.156 \cdot 10^{-3}(T-273.15)]$
TMPC	$0.8497 + 5.073 \cdot 10^{-4}(T-273.15) + 3.832 \cdot 10^{-7}(T-273.15)^2$	$231.4 \exp[-4.242 \cdot 10^{-3}(T-273.15)]$
PcHMA	$0.8793 + 4.0504 \cdot 10^{-4}(T-273.15) + 7.774 \cdot 10^{-7}(T-273.15)^2 - 7.7534 \cdot 10^{-10}(T-273.15)^3$	$295.2 \exp[-5.220 \cdot 10^{-3}(T-273.15)]$
PPO	$0.78075 \exp(2.151 \cdot 10^{-5}T^{1.5})$	$227.8 \exp[-4.290 \cdot 10^{-3}(T-273.15)]$
PDMS	$1.0079 \exp[9.121 \cdot 10^{-4}(T-273.15)]$	$89.4 \exp[-5.701 \cdot 10^{-3}(T-273.15)]$
PDMS-10	$0.8343 + 5.991 \cdot 10^{-4}(T-273.15) + 5.734 \cdot 10^{-7}(T-273.15)^2$	$542.63 \exp[-6.69 \cdot 10^{-3}(T-273.15)]$
PDMS-40	$0.8018 + 7.072 \cdot 10^{-4}(T-273.15) + 3.635 \cdot 10^{-7}(T-273.15)^2$	$482.73 \exp[-6.09 \cdot 10^{-3}(T-273.15)]$
PDMS-60	$0.8146 + 5.578 \cdot 10^{-4}(T-273.15) + 5.774 \cdot 10^{-7}(T-273.15)^2$	$482.73 \exp[-6.09 \cdot 10^{-3}(T-273.15)]$
PECH	$0.7216 \exp[5.825 \cdot 10^{-4}(T-273.15)]$	$238.3 \exp[-4.171 \cdot 10^{-3}(T-273.15)]$
PEEK	$0.7158 \exp[6.690 \cdot 10^{-4}(T-273.15)]$	$388.0 \exp[-4.124 \cdot 10^{-3}(T-273.15)]$
PEA	$0.8756 \exp[7.241 \cdot 10^{-4}(T-273.15)]$	$193.2 \exp[-4.839 \cdot 10^{-3}(T-273.15)]$
PEMA	$0.8614 \exp[7.468 \cdot 10^{-4}(T-273.15)]$	$260.9 \exp[-5.356 \cdot 10^{-3}(T-273.15)]$
HDPE	$1.1595 + 8.0394 \cdot 10^{-4}(T-273.15)$	$179.9 \exp[-4.739 \cdot 10^{-3}(T-273.15)]$
LPE	$0.9172 \exp[7.806 \cdot 10^{-4}(T-273.15)]$	$176.7 \exp[-4.661 \cdot 10^{-3}(T-273.15)]$
HMLPE	$0.8992 \exp[8.502 \cdot 10^{-4}(T-273.15)]$	$168.3 \exp[-4.292 \cdot 10^{-3}(T-273.15)]$
BPE	$0.9399 \exp[7.341 \cdot 10^{-4}(T-273.15)]$	$177.1 \exp[-4.699 \cdot 10^{-3}(T-273.15)]$
LDPE	$1.1944 + 2.841 \cdot 10^{-4}(T-273.15) + 1.872 \cdot 10^{-6}(T-273.15)^2$	$202.2 \exp[-5.243 \cdot 10^{-3}(T-273.15)]$
LDPE-A	$1.1484 \exp[6.950 \cdot 10^{-4}(T-273.15)]$	$192.9 \exp[-4.701 \cdot 10^{-3}(T-273.15)]$
LDPE-B	$1.1524 \exp[6.700 \cdot 10^{-4}(T-273.15)]$	$196.6 \exp[-4.601 \cdot 10^{-3}(T-273.15)]$
LDPE-C	$1.1516 \exp[6.730 \cdot 10^{-4}(T-273.15)]$	$186.7 \exp[-4.391 \cdot 10^{-3}(T-273.15)]$
PEO	$0.8766 \exp[7.087 \cdot 10^{-4}(T-273.15)]$	$207.7 \exp[-3.947 \cdot 10^{-3}(T-273.15)]$
PET	$0.6883 + 5.90 \cdot 10^{-4}(T-273.15)$	$369.7 \exp[-4.150 \cdot 10^{-3}(T-273.15)]$
P4HS	$0.8251 + 6.77 \cdot 10^{-4}T$	$103.1 \exp[-2.417 \cdot 10^{-3}(T-273.15)]$
PIB	$1.0750 \exp[5.651 \cdot 10^{-4}(T-273.15)]$	$200.3 \exp[-4.329 \cdot 10^{-3}(T-273.15)]$
PI-8	$1.1030 + 6.488 \cdot 10^{-4}(T-273.15) + 5.125 \cdot 10^{-7}(T-273.15)^2$	$188.0 \exp[-4.541 \cdot 10^{-3}(T-273.15)]$
PI-14	$1.0943 + 6.293 \cdot 10^{-4}(T-273.15) + 6.231 \cdot 10^{-7}(T-273.15)^2$	$202.0 \exp[-4.653 \cdot 10^{-3}(T-273.15)]$
PI-41	$1.0951 + 6.188 \cdot 10^{-4}(T-273.15) + 6.629 \cdot 10^{-7}(T-273.15)^2$	$199.0 \exp[-4.622 \cdot 10^{-3}(T-273.15)]$
PI-56	$1.0957 + 6.655 \cdot 10^{-4}(T-273.15) + 5.661 \cdot 10^{-7}(T-273.15)^2$	$200.0 \exp[-4.644 \cdot 10^{-3}(T-273.15)]$
PMA	$0.8365 \exp[6.795 \cdot 10^{-4}(T-273.15)]$	$235.8 \exp[-4.493 \cdot 10^{-3}(T-273.15)]$
PMMA	$0.8254 + 2.8383 \cdot 10^{-4}(T-273.15) + 7.792 \cdot 10^{-7}(T-273.15)^2$	$287.5 \exp[-4.146 \cdot 10^{-3}(T-273.15)]$
P4MP	$1.4075 - 9.095 \cdot 10^{-4}(T-273.15) + 3.497 \cdot 10^{-6}(T-273.15)^2$	$37.67 + 0.2134(T-273.15)] - 7.0445 \cdot 10^{-4}(T-273.15)^2$
PαMS	$0.89365 + 3.4864 \cdot 10^{-4}(T-273.15) + 5.0184 \cdot 10^{-7}(T-273.15)^2$	$297.7 \exp[-4.074 \cdot 10^{-3}(T-273.15)]$
PoMS	$0.9396 \exp[5.306 \cdot 10^{-4}(T-273.15)]$	$261.9 \exp[-4.114 \cdot 10^{-3}(T-273.15)]$
POM	$0.7484 \exp[6.770 \cdot 10^{-4}(T-273.15)]$	$305.6 \exp[-4.326 \cdot 10^{-3}(T-273.15)]$
PH	$0.76644 \exp(1.921 \cdot 10^{-5}T^{1.5})$	$359.9 \exp[-4.378 \cdot 10^{-3}(T-273.15)]$

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Table 2
Tait Equation Parameter Functions for Polymer Melts

Polymer	$V(0,T)$/cm^{3}g^{-1}	$B(T)$/MPa
PSF	$0.7644 + 3.419\cdot10^{-4}(T\text{-}273.15) + 3.126\cdot10^{-7}(T\text{-}273.15)^2$	$365.9\ \exp[-3.757\cdot10^{-3}(T\text{-}273.15)]$
PAr	$0.73381\ \exp(1.626\cdot10^{-5}T^{1.5})$	$296.9\ \exp[-3.375\cdot10^{-3}(T\text{-}273.15)]$
aPP	$1.1841 - 1.091\cdot10^{-4}(T\text{-}273.15) + 5.286\cdot10^{-6}(T\text{-}273.15)^2$	$162.1\ \exp[-6.604\cdot10^{-3}(T\text{-}273.15)]$
iPP	$1.1606\ \exp[6.700\cdot10^{-4}(T\text{-}273.15)]$	$149.1\ \exp[-4.177\cdot10^{-3}(T\text{-}273.15)]$
PS	$0.9287\ \exp[5.131\cdot10^{-4}(T\text{-}273.15)]$	$216.9\ \exp[-3.319\cdot10^{-3}(T\text{-}273.15)]$
PTFE	$0.3200 + 9.5862\cdot10^{-4}(T\text{-}273.15)$	$425.2\ \exp[-9.380\cdot10^{-3}(T\text{-}273.15)]$
PTHF	$1.0043\ \exp[6.691\cdot10^{-4}(T\text{-}273.15)]$	$178.6\ \exp[-4.223\cdot10^{-3}(T\text{-}273.15)]$
PVAc	$0.82496 + 5.820\cdot10^{-4}(T\text{-}273.15) + 2.940\cdot10^{-7}(T\text{-}273.15)^2$	$204.9\ \exp[-4.346\cdot10^{-3}(T\text{-}273.15)]$
PVC	$0.7196 + 5.581\cdot10^{-5}(T\text{-}273.15) + 1.468\cdot10^{-6}(T\text{-}273.15)^2$	$294.2\ \exp[-5.321\cdot10^{-3}(\mathrm{T}\text{-}273.15)]$
PVME	$0.9585\ \exp[6.653\cdot10^{-4}(T\text{-}273.15)]$	$215.8\ \exp[-4.588\cdot10^{-3}(T\text{-}273.15)]$
PVdF	$0.5790\ \exp[8.051\cdot10^{-4}(T\text{-}273.15)]$	$244.0\ \exp[-5.210\cdot10^{-3}(T\text{-}273.15)]$
SAN3	$0.9233 + 3.936\cdot10^{-4}(T\text{-}273.15) + 5.685\cdot10^{-7}(T\text{-}273.15)^2$	$239.8\ \exp[-4.376\cdot10^{-3}(T\text{-}273.15)]$
SAN6	$0.9211 + 4.370\cdot10^{-4}(T\text{-}273.15) + 5.846\cdot10^{-7}(T\text{-}273.15)^2$	$226.9\ \exp[-4.286\cdot10^{-3}(T\text{-}273.15)]$
SAN15	$0.9044 + 4.207\cdot10^{-4}(T\text{-}273.15) + 4.077\cdot10^{-7}(T\text{-}273.15)^2$	$238.4\ \exp[-3.943\cdot10^{-3}(T\text{-}273.15)]$
SAN18	$0.9016 + 4.036\cdot10^{-4}(T\text{-}273.15) + 4.206\cdot10^{-7}(T\text{-}273.15)^2$	$240.4\ \exp[-3.858\cdot10^{-3}(T\ \text{-}273.15)]$
SAN40	$0.8871 + 3.406\cdot10^{-4}(T\text{-}273.15) + 4.938\cdot10^{-7}(\mathrm{T}\text{-}273.15)^2$	$289.3\ \exp[-4.431\cdot10^{-3}(T\text{-}273.15)]$
SAN70	$0.8528 + 3.616\cdot10^{-4}(T\text{-}273.15) + 2.634\cdot10^{-7}(\mathrm{T}\text{-}273.15)^2$	$335.4\ \exp[-3.923\cdot10^{-3}(T\text{-}273.15)]$
SBR10	$0.9053\ \exp(2.437\cdot10^{-5}T^{1.5})$	$530.3\ \exp[-3.99\cdot10^{-3}(T\text{-}273.15)]$
SBR23	$0.8986\ \exp(2.317\cdot10^{-5}T^{1.5})$	$551.6\ \exp[-4.17\cdot10^{-3}(T\text{-}273.15)]$
SBR60	$0.8812\ \exp(2.031\cdot10^{-5}T^{1.5})$	$486.0\ \exp[-4.34\cdot10^{-3}(T\text{-}273.15)]$
SBR85	$0.8704\ \exp(1.846\cdot10^{-5}T^{1.5})$	$356.7\ \exp[-4.24\cdot10^{-3}(T\text{-}273.15)]$
SMMA20	$0.9063 + 3.570\cdot10^{-4}(T\text{-}273.15) + 6.532\cdot10^{-7}(T\text{-}273.15)^2$	$232.0\ \exp[-4.143\cdot10^{-3}(T\text{-}273.15)]$
SMMA60	$0.8610 + 3.350\cdot10^{-4}(T\text{-}273.15) + 6.980\cdot10^{-7}(T\text{-}273.15)^2$	$261.0\ \exp[-4.611\cdot10^{-3}(T\text{-}273.15)]$
VCES50	$0.6676 + 6.63\cdot10^{-4}T$	$5281.7\ \exp[-9.264\cdot10^{-3}(T\text{-}273.15)]$
VCHS80	$0.7753 + 6.17\cdot10^{-4}T$	$247.6\ \exp[-2.604\cdot10^{-3}(T\text{-}273.15)]$
VCHS67	$0.8028 + 6.50\cdot10^{-4}T$	$581.7\ \exp[-4.553\cdot10^{-3}(T\text{-}273.15)]$
VCHS60	$0.8213 + 6.23\cdot10^{-4}T$	$229.1\ \exp[-2.133\cdot10^{-3}(T\text{-}273.15)]$
VCHS50	$0.7827 + 5.05\cdot10^{-4}T$	$136.0\ \exp[-1.083\cdot10^{-3}(T\text{-}273.15)]$
VCHS40	$0.7805 + 4.92\cdot10^{-4}T$	$155.0\ \exp[-1.605\cdot10^{-3}(T\text{-}273.15)]$
VCHS33	$0.7710 + 4.86\cdot10^{-4}T$	$460.4\ \exp[-3.453\cdot10^{-3}(T\text{-}273.15)]$
VCHS20	$0.6416 + 5.42\cdot10^{-4}T$	$489.8\ \exp[-3.193\cdot10^{-3}(T\text{-}273.15)]$
VCOS50	$0.7081 + 7.40\cdot10^{-4}T$	$666.5\ \exp[-4.503\cdot10^{-3}(T\text{-}273.15)]$
VCPS50	$0.7814 + 4.36\cdot10^{-4}T$	$880.1\ \exp[-4.393\cdot10^{-3}(T\text{-}273.15)]$

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ASTRONOMICAL CONSTANTS

Victor Abalakin

The constants in this table are based primarilarily on the set of constants adopted by the International Astronomical Union (IAU) in 1976. Updates have been made when new data were available. All values are given in SI Units; thus masses are expressed in kilograms and distances in meters.

The astronomical unit of time is a time interval of one day (1 d) equal to 86400 s. An interval of 36525 d is one Julian century (1 cy).

REFERENCES

1. Seidelmann, P. K., *Explanatory Supplement to the Astronomical Almanac*, University Science Books, Mill Valley, CA, 1990.
2. Lang, K. R., *Astrophysical Data: Planets and Stars*, Springer-Verlag, New York, 1992.

Defining constants	
Gaussian gravitational constant	$k = 0.01720209895\ \mathrm{m^3\ kg^{-1}\ s^{-2}}$
Speed of light	$c = 299792458\ \mathrm{m\ s^{-1}}$
Primary constants	
Light-time for unit distance (1 AU)	$\tau_A = 499.004782$ s
Equatorial radius of earth	$a_e = 6378140$ m
Equatorial radius of earth (IUGG value)	$a_e = 6378136$ m
Dynamical form-factor for earth	$J_2 = 0.001082626$
Geocentric gravitational constant	$GE = 3.986005 \times 10^{14}\ \mathrm{m^3s^{-2}}$
Constant of gravitation	$G = 6.672 \times 10^{-11}\ \mathrm{m^3kg^{-1}s^{-2}}$
Ratio of mass of moon to that of earth	$\mu = 0.01230002$
	$1/\mu = 81.300587$
General precession in longitude, per Julian century, at standard epoch J2000	$\rho = 5029''.0966$
Obliquity of the ecliptic at standard epoch J2000	$\varepsilon = 23°26'21''.448$
Derived constants	
Constant of nutation at standard epoch J2000	$N = 9''.2025$
Unit distance (AU = $c\tau_A$)	AU = $1.49597870 \times 10^{11}$ m
Solar parallax (π_0 = arcsin(a_e/AU))	$\pi_0 = 8''.794148$
Constant of aberration for standard epoch J2000	$\kappa = 20''.49552$
Flattening factor for the earth	$f = 1/298.257 = 0.00335281$
Heliocentric gravitational constant ($GS = A^3k^2/D^2$)	$GS = 1.32712438 \times 10^{20}\ \mathrm{m^3\ s^{-2}}$
Ratio of mass of sun to that of the earth (S/E) = (GS)/(GE))	$S/E = 332946.0$
Ratio of mass of sun to that of earth + moon	$(S/E)/(1 + \mu) = 328900.5$
Mass of the sun (S = (GS)/G)	$S = 1.9891 \times 10^{30}$ kg
Ratios of mass of sun to masses of the planets	
Mercury	6023600
Venus	408523.5
Earth + moon	328900.5
Mars	3098710
Jupiter	1047.355
Saturn	3498.5
Uranus	22869
Neptune	19314
Pluto	3000000

PROPERTIES OF THE SOLAR SYSTEM

The following tables give various properties of the planets and characteristics of their orbits in the solar system. Certain properties of the sun and of the earth's moon are also included.

Explanations of the column headings:

- *Den.*: mean density in g/cm^3
- *Radius*: radius at the equator in km
- *Flattening*: degree of oblateness, defined as $(r_e - r_p)/r_e$, where r_e and r_p are the equatorial and polar radii, respectively
- *Potential coefficients*: coefficients in the spherical harmonic representation of the gravitational potential U by the equation

$$U(r,\phi) = (GM/r)\,[1 - \Sigma\, J_n(a/r)^n\, P_n(\sin\phi)]$$

  where G is the gravitational constant, r the distance from the center of the planet, a the radius of the planet, M the mass, ϕ the latitude, and P_n the Legendre polynomial of degree n.
- *Gravity*: acceleration due to gravity at the surface
- *Escape velocity*: velocity needed at the surface of the planet to escape the gravitational pull
- *Dist. to sun*: semi-major axis of the elliptical orbit (1 AU = 1.496×10^8 km)
- ε: eccentricity of the orbit
- *Ecliptic angle*: angle between the planetary orbit and the plane of the earth's orbit around the sun
- *Inclin.*: angle between the equatorial plane and the plane of the planetary orbit
- *Rot. period*: period of rotation of the planet measured in earth days
- *Albedo*: ratio of the light reflected from the planet to the light incident on it
- T_{sur}: mean temperature at the surface
- P_{sur}: pressure of the atmosphere at the surface

The following general information on the solar system is of interest:

Mass of the earth = M_e = 5.9742×10^{24} kg
Total mass of planetary system = 2.669×10^{27} kg = 447 M_e
Total angular momentum of planetary system = 3.148×10^{43} kg m^2/s
Total kinetic energy of the planets = 1.99×10^{35} J
Total rotational energy of planets = 0.7×10^{35} J

Properties of the sun:

Mass = 1.9891×10^{30} kg = 332946.0 M_e
Radius = 6.9599×10^8 m
Surface area = 6.087×10^{18} m^2
Volume = 1.412×10^{27} m^3
Mean density = 1.409 g/cm^3
Gravity at surface = 27398 cm/s^2
Escape velocity at surface = 6.177×10^5 m/s
Effective temperature = 5780 K
Total radiant power emitted (luminosity) = 3.86×10^{26} W
Surface flux of radiant energy = 6.340×10^7 W/m^2
Flux of radiant energy at the earth (Solar Constant) = 1373 W/m^2

REFERENCES

1. Seidelmann, P. K., Editor, *Explanatory Supplement to the Astronomical Almanac*, University Science Books, Mill Valley, CA, 1992.
2. Lang, K. R., *Astrophysical Data: Planets and Stars*, Springer-Verlag, New York, 1992.
3. Allen, C. W., *Astrophysical Quantities, Third Edition*, Athlone Press, London, 1977.

PROPERTIES OF THE SOLAR SYSTEM (continued)

Planet	Mass 10^{24} kg	Den. g/cm^3	Radius km	Flattening	Potential coeffients 10^3 J_2	10^6 J_3	10^6 J_4	Gravity cm/s^2	Escape vel. km/s
Mercury	0.33022	5.43	2439.7	0				370	4.25
Venus	4.8690	5.24	6051.9	0	0.027			887	10.4
Earth	5.9742	5.515	6378.140	0.00335364	1.08263	-2.54	-1.61	980	11.2
(Moon)	0.073483	3.34	1738	0	0.2027			162	2.37
Mars	0.64191	3.94	3397	0.00647630	1.964	36		371	5.02
Jupiter	1898.8	1.33	71492	0.0648744	14.75	-580		2312	59.6
Saturn	568.50	0.70	60268	0.0979624	16.45	-1000		896	35.5
Uranus	86.625	1.30	25559	0.0229273	12			777	21.3
Neptune	102.78	1.76	24764	0.0171	4			1100	23.3
Pluto	0.015	1.1	1151	0				72	1.1

Planet	Dist. to sun AU	ε	Ecliptic angle	Inclin.	Rot. period d	Albedo	No. of satellites
Mercury	0.38710	0.2056	7.00°	0°	58.6462	0.106	0
Venus	0.72333	0.0068	3.39°	177.3°	-243.01	0.65	0
Earth	1.00000	0.0167		23.45°	0.99726968	0.367	1
(Moon)				6.68°	27.321661	0.12	
Mars	1.52369	0.0933	1.85°	25.19°	1.02595675	0.150	2
Jupiter	5.20283	0.048	1.31°	3.12°	0.41354	0.52	16
Saturn	9.53876	0.056	2.49°	26.73°	0.4375	0.47	18
Uranus	19.19139	0.046	0.77°	97.86°	-0.65	0.51	15
Neptune	30.06107	0.010	1.77°	29.56°	0.768	0.41	8
Pluto	39.52940	0.248	17.15°	118°	-6.3867	0.3	1

Planet	T_{sur} K	P_{sur} bar	Atmospheric composition CO_2	N_2	O_2	H_2O	H_2	He	Ar	Ne	CO
Mercury	440	2×10^{-15}					2%	98%			
Venus	730	90	96.4%	3.4%	69 ppm	0.1%			4 ppm		20 ppm
Earth	288	1	0.03%	78.08%	20.95%	0 to 3%			0.93%	18 ppm	1 ppm
Mars	218	0.007	95.32%	2.7%	0.13%	0.03%			1.6%	3 ppm	0.07%
Jupiter	129						86.1%	13.8%			
Saturn	97						92.4%	7.4%			
Uranus	58						89%	11%			
Neptune	56						89%	11%			
Pluto	50	1×10^{-5}									

SATELLITES OF THE PLANETS

This table gives characteristics of the known satellites of the planets. The parameters covered are:

- Orbital period in units of earth days. An R following the value indicates a retrograde motion.
- Distance from the planet, as measured by the semi-major axis of the orbit.
- Eccentricity of the orbit.
- Inclination of the satellite orbit with respect to the equator of the planet.
- Mass of the satellite relative to the planet.
- Radius of the satellite in km.
- Mean density of the satellite.
- Geometric albedo, which is a measure of the fraction of incident sunlight reflected by the satellite.

REFERENCES

1. Seidelmann, P. K., Editor, *Explanatory Supplement to the Astronomical Almanac*, University Science Books, Mill Valley, CA, 1992.
2. Lang, K. R., *Astrophysical Data: Planets and Stars*, Springer-Verlag, New York, 1992.
3. Burns, J. A., and Matthews, M. S., Eds., *Satellites*, University of Arizona Press, Tucson, 1986.

Planet	Satellite		Orb. Period d	Distance 10^3 km	Eccentricity	Inclination	Rel. mass	Radius km	Den. g/cm^3	Albedo
Earth		Moon	27.321661	384.400	0.054900489	18.28-28.58°	0.01230002	1738	3.34	0.12
Mars	I	Phobos	0.31891023	9.378	0.015	1.0°	1.5×10^{-8}	13.5 × 10.8 × 9.4	<2	0.06
	II	Deimos	1.2624407	23.459	0.0005	0.9-2.7°	3×10^{-9}	7.5 × 6.1 × 5.5	<2	0.07
Jupiter	I	Io	1.769137786	422	0.004	0.04°	4.68×10^{-5}	1815	3.55	0.61
	II	Europa	3.551181041	671	0.009	0.47°	2.52×10^{-5}	1569	3.04	0.64
	III	Ganymede	7.15455296	1070	0.002	0.21°	7.80×10^{-5}	2631	1.93	0.42
	IV	Callisto	16.6890184	1883	0.007	0.51°	5.66×10^{-5}	2400	1.83	0.20
	V	Amalthea	0.49817905	181	0.003	0.40°	3.8×10^{-9}	135 × 83 × 75		0.05
	VI	Himalia	250.5662	11480	0.15798	27.63°	5.0×10^{-9}	93		0.03
	VII	Elara	259.6528	11737	0.20719	24.77°	4×10^{-10}	38		0.03
	VIII	Pasiphae	735 R	23500	0.378	145°	1×10^{-10}	25		
	IX	Sinope	758 R	23700	0.275	153°	0.4×10^{-10}	18		
	X	Lysithea	259.22	11720	0.107	29.02°	0.4×10^{-10}	18		
	XI	Carme	692 R	22600	0.20678	164°	0.5×10^{-10}	20		
	XII	Ananke	631 R	21200	0.16870	147°	0.2×10^{-10}	15		
	XIII	Leda	238.72	11094	0.14762	26.07°	0.03×10^{-10}	8		
	XIV	Thebe	0.6745	222	0.015	0.8°	4×10^{-10}	55 × 45		0.05
	XV	Adrastea	0.29826	129			0.1×10^{-10}	12.5 × 10 × 7.5		0.05
	XVI	Metis	0.294780	128			0.5×10^{-10}	20		0.05
Saturn	I	Mimas	0.942421813	185.52	0.0202	1.53°	8.0×10^{-8}	196	1.44	0.5
	II	Enceladus	1.370217855	238.02	0.00452	1.86°	1.3×10^{-7}	250	1.13	1.0
	III	Tethys	1.887802160	294.66	0.00000	1.86°	1.3×10^{-6}	530	1.20	0.9
	IV	Dione	2.736914742	377.40	0.002230	0.02°	1.85×10^{-6}	560	1.41	0.7
	V	Rhea	4.517500436	527.04	0.00100	0.35°	4.4×10^{-6}	765	1.33	0.7
	VI	Titan	15.94542068	1221.83	0.029192	0.33°	2.38×10^{-4}	2575	1.88	0.21
	VII	Hyperion	21.2766088	1481.1	0.104	0.43°	3×10^{-8}	205 × 130 × 110		0.3
	VIII	Iapetus	79.3301825	3561.3	0.02828	14.72°	3.3×10^{-6}	730	1.15	0.2
	IX	Phoebe	550.48 R	12952	0.16326	177°	7×10^{-10}	110		0.06

SATELLITES OF THE PLANETS (continued)

Planet	Satellite		Orb. Period d	Distance 10^3 km	Eccentricity	Inclination	Rel. mass	Radius km	Den. g/cm^3	Albedo
	X	Janus	0.6945	151.472	0.007	0.14°		110 × 100 × 80		0.8
	XI	Epimetheus	0.6942	151.422	0.009	0.34°		70 × 60 × 50		0.8
	XII	Helene	2.7369	377.40	0.005	0.0°		18 × 16 × 15		0.7
	XIII	Telesto	1.8878	294.66				17 × 14 × 13		0.5
	XIV	Calypso	1.8878	294.66				17 × 11 × 11		0.6
	XV	Atlas	0.6019	137.670	0.000	0.3°		20 × 10		0.9
	XVI	Prometheus	0.6130	139.353	0.003	0.0°		70 × 50 × 40		0.6
	XVII	Pandora	0.6285	141.700	0.004	0.0°		55 × 45 × 35		0.9
	XVIII	Pan	0.5750	133.583				10		0.5
Uranus	I	Ariel	2.52037935	191.02	0.0034	0.3°	1.56×10^{-5}	579	1.55	0.34
	II	Umbriel	4.1441772	266.30	0.0050	0.36°	1.35×10^{-5}	586	1.58	0.18
	III	Titania	8.7058717	435.91	0.0022	0.14°	4.06×10^{-5}	790	1.69	0.27
	IV	Oberon	13.4632389	583.52	0.0008	0.10°	3.47×10^{-5}	762	1.64	0.24
	V	Miranda	1.41347925	129.39	0.0027	4.2°	0.08×10^{-5}	240	1.25	0.27
	VI	Cordelia	0.335033	49.77	<0.001	0.1°		13		0.07
	VII	Ophelia	0.376409	53.79	0.010	0.1°		15		0.07
	VIII	Bianca	0.434577	59.17	<0.001	0.2°		21		0.07
	IX	Cressida	0.463570	61.78	<0.001	0.0°		31		0.07
	X	Desdemona	0.473651	62.68	<0.001	0.2°		27		0.07
	XI	Juliet	0.493066	64.35	<0.001	0.1°		42		0.07
	XII	Portia	0.513196	66.09	<0.001	0.1°		54		0.07
	XIII	Rosalind	0.558459	69.94	<0.001	0.3°		27		0.07
	XIV	Belinda	0.623525	75.26	<0.001	0.0°		33		0.07
	XV	Puck	0.761832	86.01	<0.001	0.31°		77		0.07
Neptune	I	Triton	5.8768541 R	354.76	0.000016	157.345°	2.09×10^{-4}	1353	2.05	0.7
	II	Nereid	360.13619	5513.4	0.7512	27.6°	2×10^{-7}	170		0.4
	III	Naiad	0.294396	117.6	<0.001	4.74°		29		0.06
	IV	Thalassa	0.311485	73.6	<0.001	0.21°		40		0.06
	V	Despina	0.334655	52.6	<0.001	0.07°		74		0.06
	VI	Galatea	0.428745	62.0	<0.001	0.05°		79		0.06
	VII	Larissa	0.554654	50.0	<0.0014	0.20°		104 × 89		0.06
	VIII	Proteus	1.122315	48.2	<0.001	0.55°		218 × 208 × 201		0.06
Pluto	I	Charon	6.38725	19.6	<0.001	99°	0.22	593		0.5

MASS, DIMENSIONS, AND OTHER PARAMETERS OF THE EARTH

This table is a collection of data on various properties of the Earth. Most of the values are given in SI units. Note that 1 AU (astronomical unit) = 149,597,870 km.

REFERENCES

1. Seidelmann, P. K., Editor, *Explanatory Supplement to the Astronomical Almanac*, University Science Books, Mill Valley, CA, 1992.
2. Lang, K. R., *Astrophysical Data: Planets and Stars*, Springer-Verlag, New York, 1992.

Quantity	Symbol	Value	Unit
Mass	M	$5.9742 \cdot 10^{27}$	g
Major orbital semi-axis	a_{orb}	1.000000	AU
		$1.4959787 \cdot 10^{8}$	km
Distance from sun at perihelion	r_π	0.9833	AU
Distance from sun at aphelion	r_α	1.0167	AU
Moment of perihelion passage	T_π	Jan. 2, 4 h 52 min	
Moment of aphelion passage	T_α	July 4, 5 h 05 min	
Siderial rotation period around sun	P_{orb}	$31.5581 \cdot 10^{6}$	s
		365.25636	d
Mean rotational velocity	U_{orb}	29.78	km/s
Mean equatorial radius	$\overline{a}$	6378.140	km
Mean polar compression (flattening factor)	α	1/298.257	
Difference in equatorial and polar semi-axes	$a - c$	21.385	km
Compression of meridian of major equatorial axis	α_a	1/295.2	
Compression of meridian of minor equatorial axis	α_b	1/298.0	
Equatorial compression	ε	1/30 000	
Difference in equatorial semi-axes	$a - b$	213	m
Difference in polar semi-axes	$c_N - c_S$	~70	m
Polar asymmetry	η	$\sim 1.10^{-5}$	
Mean acceleration of gravity at equator	g_e	9.78036	m/s^2
Mean acceleration of gravity at poles	g_p	9.83208	m/s^2
Difference in acceleration of gravity at pole and at equator	$g_p - g_e$	5.172	cm/s^2
Mean acceleration of gravity for entire surface of terrestrial ellipsoid	g	9.7978	m/s^2
Mean radius	R	6371.0	km
Area of surface	S	$5.10 \cdot 10^{8}$	km^2
Volume	V	$1.0832 \cdot 10^{12}$	km^3
Mean density	ρ	5.515	g/cm^3
Siderial rotational period	P	86,164.09	s
Rotational angular velocity	ω	$7.292116 \cdot 10^{-5}$	rad/s
Mean equatorial rotational velocity	v	0.46512	km/s
Rotational angular momentum	L	$5.861 \cdot 10^{33}$	J s
Rotational energy	E	$2.137 \cdot 10^{29}$	J
Ratio of centrifugal force to force of gravity at equator	q_c	0.0034677 = 1/288	
Moment of inertia	I	$8.070 \cdot 10^{37}$	kg m^2
Relative braking of earth's rotation due to tidal friction	$\Delta\omega_e/\omega$	$-4.2 \cdot 10^{-8}$	$century^{-1}$
Relative secular acceleration of earth's rotation	$\Delta\omega_i/\omega$	$+1.4 \cdot 10^{-8}$	$century^{-1}$
Not secular braking of earth's rotation	$\Delta\omega/\omega$	$-2.8 \cdot 10^{-8}$	$century^{-1}$
Probable value of total energy of tectonic deformation of earth	E_t	$\sim 1 \cdot 10^{23}$	J/century
Secular loss of heat of earth through radiation into space	$\Delta' E_k$	$1 \cdot 10^{23}$	J/century
Portion of earth's kinetic energy transformed into heat as a result of lunar and solar tides in the hydrosphere	$\Delta'' E_k$	$1.3 \cdot 10^{23}$	J/century

MASS, DIMENSIONS, AND OTHER PARAMETERS OF THE EARTH (continued)

Quantity	Symbol	Value	Unit
Differences in duration of days in March and August	ΔP	0.0025 (March-August)	s
Corresponding relative annual variation in earth's rotational velocity	$\Delta^*\omega/\omega$	$2.9 \cdot 10^{-8}$ (Aug.-March)	
Presumed variation in earth's radius between August and March	$\Delta^* R$	–9.2 (Aug.-March)	cm
Annual variation in level of world ocean	Δh_o	~10 (Sept.-March)	cm
Area of continents	S_C	$1.49 \cdot 10^8$	km^2
		29.2	% of surface
Area of world ocean	S_o	$3.61 \cdot 10^8$	km^2
		70.8	% of surface
Mean height of continents above sea level	h_C	875	m
Mean depth of world ocean	h_o	3794	m
Mean thickness of lithosphere within the limits of the continents	$h_{c.l.}$	35	km
Mean thickness of lithosphere within the limits of the ocean	$h_{o.l.}$	4.7	km
Mean rate of thickening of continental lithosphere	$\Delta h/\Delta t$	10 - 40	m/10^6 y
Mean rate of horizontal extension of continental lithosphere	$\Delta l/\Delta t$	0.75 - 20	km/10^6 y
Mass of crust	m_l	$2.36 \cdot 10^{22}$	kg
Mass of mantle		$4.05 \cdot 10^{24}$	kg
Amount of water released from the mantle and core in the course of geological time		$3.40 \cdot 10^{21}$	kg
Total reserve of water in the mantle		$2 \cdot 10^{23}$	kg
Present content of free and bound water in the earth's lithosphere		$2.4 \cdot 10^{21}$	kg
Mass of hydrosphere	m_h	$1.664 \cdot 10^{21}$	kg
Amount of oxygen bound in the earth's crust		$1.300 \cdot 10^{21}$	kg
Amount of free oxygen		$1.5 \cdot 10^{18}$	kg
Mass of atmosphere	m_a	$5.136 \cdot 10^{18}$	kg
Mass of biosphere	m_b	$1.148 \cdot 10^{16}$	kg
Mass of living matter in the biosphere		$3.6 \cdot 10^{14}$	kg
Density of living matter on dry land		0.1	g/cm^2
Density of living matter in ocean		$15 \cdot 10^{-8}$	g/cm^3
Age of the earth		$4.55 \cdot 10^9$	y
Age of oldest rocks		$4.0 \cdot 10^9$	y
Age of most ancient fossils		$3.4 \cdot 10^9$	y

GEOLOGICAL TIME SCALE

Period or Epoch	Beginning and end, in 10^6 years	Key events
	Cenozoic era	
Quaternian		
Contemporary	0–10,000 y ± 2,000 y	
Pleistocene	10,000–1,000,000 y ± 50,000 y	Homo Erectus breakout
Tertiary		
Pliocene	1.8–5.3	Ape man fossils
Miocene	5–25	Origin of grass
Oligocene	25–37	Rise of cats, dogs, pigs
Eocene	37–55	Debut of hoofed mammals
Paleocene	55–67	Earliest primates
	Mesozoic era	
Cretaceous	67–138	Demise of dinosaurs
Jurassic	138–208	First birds
Triassic	208–245	Appearance of dinosaurs
	Paleozoic era	
Permian	245–290	Flowers, insect pollination
Carboniferous	290–360	First conifers
Devonian	360–410	First vertebrates ashore
Silurian	410–435	Spore-bearing plants
Ordovician	435–520	First animals ashore
Cambrian	520–570	Vertebrates appear
	Pre-Cambrian	
Pre-Cambrian III (Proterozoic)	570–2500	First plants, jellyfish
Pre-Cambrian II (Archean)	2500–3800	Photosynthetic bacteria
Pre-Cambrian I (Hadean)	3800–4450	Earth formed 4600 million years ago

Reference: Calder, N., *Timescale - An Atlas of the Fourth Dimension,* Viking Press, New York, 1983.

ACCELERATION DUE TO GRAVITY

The acceleration due to gravity is tabulated here as a function of latitude and height above the earth's surface. Values were calculated from the expression

$$g/(\mathrm{m/s^2}) = 9.780356\,(1 + 0.0052885 \sin^2\phi - 0.0000059 \sin^2 2\phi) - 0.003086\,H$$

where ϕ is the latitude and H is the height in kilometers.

REFERENCE

Jursa, A. S., Ed., *Handbook of Geophysics and the Space Environment,* 4th ed., Air Force Geophysics Laboratory, 1985, p. 14-17.

ϕ	***H*** **= 0**	***H*** **= 1 km**	***H*** **= 5 km**	***H*** **= 10 km**
0	9.78036	9.77727	9.76493	9.74950
5	9.78075	9.77766	9.76532	9.74989
10	9.78191	9.77882	9.76648	9.75105
15	9.78381	9.78072	9.76838	9.75295
20	9.78638	9.78330	9.77095	9.75552
25	9.78956	9.78647	9.77413	9.75870
30	9.79324	9.79016	9.77781	9.76238
35	9.79732	9.79424	9.78189	9.76646
40	9.80167	9.79858	9.78624	9.77081
45	9.80616	9.80307	9.79073	9.77530
50	9.81065	9.80757	9.79522	9.77979
55	9.81501	9.81193	9.79958	9.78415
60	9.81911	9.81602	9.80368	9.78825
65	9.82281	9.81972	9.80738	9.79195
70	9.82601	9.82292	9.81058	9.79515
75	9.82860	9.82551	9.81317	9.79774
80	9.83051	9.82743	9.81508	9.79965
85	9.83168	9.82860	9.81625	9.80082
90	9.83208	9.82899	9.81665	9.80122

DENSITY, PRESSURE, AND GRAVITY AS A FUNCTION OF DEPTH WITHIN THE EARTH

This table gives the density ρ, pressure *p*, and acceleration due to gravity *g* as a function of depth below the earth's surface, as calculated from the model of the structure of the earth in Reference 1. The model assumes a radius of 6371 km for the earth. The boundary between the crust and mantle (the Mohorovicic discontinuity) is taken as 21 km, while in reality it varies considerable with location.

REFERENCES

1. Anderson, D. L., and Hart, R. S., *J. Geophys. Res.*, 81, 1461, 1976.
2. Carmichael, R. S., *CRC Practical Handbook of Physical Properties of Rocks and Minerals*, p.467, CRC Press, Boca Raton, FL, 1989.

Depth km	ρ g/cm³	*p* kbar	*g* cm/s²
Crust			
0	1.02	0	981
3	1.02	3	982
3	2.80	3	982
21	2.80	5	983
Mantle (solid)			
21	3.49	5	983
41	3.51	12	983
61	3.52	19	984
81	3.48	26	984
101	3.44	33	984
121	3.40	39	985
171	3.37	56	987
221	3.34	73	989
271	3.37	89	991
321	3.47	106	993
371	3.59	124	994
571	3.95	199	999
871	4.54	328	997
1171	4.67	466	992
1471	4.81	607	991
1771	4.96	752	994
2071	5.12	903	1002
2371	5.31	1061	1017
2671	5.45	1227	1042
2886	5.53	1352	1069
Outer core (liquid)			
2886	9.96	1352	1069
2971	10.09	1442	1050
3371	10.63	1858	953
3671	11.00	2154	874
4071	11.36	2520	760
4471	11.69	2844	641
4871	11.99	3116	517
5156	12.12	3281	427
Inner core (solid)			
5156	12.30	3281	427
5371	12.48	3385	355
5771	12.52	3529	218
6071	12.53	3592	122
6371	12.58	3617	0

OCEAN PRESSURE AS A FUNCTION OF DEPTH AND LATITUDE

The following table is based upon an ocean model which takes into account the equation of state of standard seawater and the dependence on latitude of the acceleration of gravity. The tabulated pressure value is the excess pressure over the ambient atmospheric pressure at the surface.

REFERENCES

1. *International Oceanographic Tables, Volume 4*, Unesco Technical Papers in Marine Science No. 40, Unesco, Paris, 1987.
2. Saunders, P.M., and Fofonoff, N.P., *Deep-Sea Res*. 23, 109-111, 1976.

Pressure in MPa at the Specified Latitude

Depth (meters)	**0°**	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
500	5.0338	5.0355	5.0404	5.0471	5.0537	5.0586	5.0605
1000	10.0796	10.0832	10.0930	10.1064	10.1198	10.1296	10.1333
1500	15.1376	15.1431	15.1577	15.1778	15.1980	15.2127	15.2182
2000	20.2076	20.2148	20.2344	20.2613	20.2882	20.3080	20.3153
2500	25.2895	25.2985	25.3231	25.3568	25.3905	25.4153	25.4244
3000	30.3831	30.3940	30.4236	30.4641	30.5047	30.5345	30.5453
3500	35.4886	35.5012	35.5358	35.5832	35.6307	35.6654	35.6782
4000	40.6056	40.6201	40.6598	40.7140	40.7683	40.8082	40.8229
4500	45.7342	45.7505	45.7952	45.8564	45.9176	45.9626	45.9791
5000	50.8742	50.8924	50.9421	51.0102	51.0785	51.1285	51.1469
5500	56.0255	56.0456	56.1004	56.1755	56.2508	56.3059	56.3262
6000	61.1882	61.2100	61.2700	61.3521	61.4344	61.4947	61.5168
6500	66.3619	66.3857	66.4508	66.5399	66.6292	66.6947	66.7187
7000	71.5467	71.5724	71.6427	71.7388	71.8352	71.9059	71.9318
7500	76.7426	76.7701	76.8456	76.9488	77.0523	77.1282	77.1560
8000	81.9493	81.9788	82.0594	82.1697	82.2804	82.3614	82.3911
8500	87.1669	87.1983	87.2841	87.4016	87.5193	87.6057	87.6373
9000	92.3950	92.4284	92.5194	92.6440	92.7689	92.8606	92.8941
9500	97.6346	97.6698	97.7661	97.8978	98.0300	98.1269	98.1624
10000	102.8800	102.9170	103.0185	103.1572	103.2961	103.3981	103.4355

PROPERTIES OF SEAWATER

In addition to the dependence on temperature and pressure, the physical properties of seawater vary with the concentration of the dissolved constituents. A convenient parameter for describing the composition is the salinity, *S*, which is defined in terms of the electrical conductivity of the seawater sample. The defining equation for the practical salinity is:

$$S = a_0 + a_1K^{1/2} + a_2K + a_3K^{3/2} + a_4K^2 + a_5K^{5/2} ,$$

where *K* is the ratio of the conductivity of the seawater sample at 15°C and atmospheric pressure to the conductivity of a potassium chloride solution in which the mass fraction of KCl is 0.0324356, at the same temperature and pressure. The values of the coefficients are:

a_0 = 0.080 a_3 = 14.0941
a_1 = -0.1692 a_4 = -7.0261
a_2 = 25.3851 a_5 = 2.7081
Σa_i = 35.0000

Thus when *K* = 1, *S* = 35 exactly (*S* is normally quoted in units of ‰, i.e., parts per thousand). The value of *S* can be roughly equated with the mass of dissolved material in grams per kilogram of seawater. Salinity values in the oceans at mid latitudes typically fall between 34 and 36.

The freezing point of seawater at normal atmospheric pressure varies with salinity as follows:

S	0	5	10	15	20	25	30	35	40
t_f /°C	0.000	-0.274	-0.542	-0.812	-1.083	-1.358	-1.636	-1.922	-2.212

The first table below gives several properties of seawater as a function of temperature for a salinity of 35. The second gives electrical conductivity as a function of salinity at several temperatures, and the third lists typical concentrations of the main constituents of seawater as a function of salinity.

REFERENCES

1. *The Practical Salinity Scale 1978 and the International Equation of State of Seawater 1980*, Unesco Technical Papers in Marine Science No. 36, Unesco, Paris, 1981; sections No. 37, 38, 39, and 40 in this series give background papers and detailed tables.
2. Kennish, M.J., *CRC Practical Handbook of Marine Science*, CRC Press, Boca Raton, FL, 1989.
3. Poisson, A. *IEEE J. Ocean. Eng*. OE-5, 50, 1981.

Properties of Seawater as a Function of Temperature at Salinity *S*=35 and Normal Atmospheric Pressure (100 kPa)

ρ = density in g/cm^3
β = (1/ρ) (dρ/d*S*) = fractional change in density per unit change in salinity
α = (1/ρ) (dρ/d*t*) = fractional change in density per unit change in temperature (°C^{-1})
κ = electrical conductivity in S/cm
η = viscosity in mPa s (equal to cP)
c_p = specific heat in J/kg
v = speed of sound in m/s

***t*/°C**	**ρ/g cm^{-3}**	**10^7·β**	**10^7·α/°C^{-1}**	**κ/S cm^{-1}**	**η/mPa s**	**c_p/J kg^{-1} °C^{-1}**	***v*/m s^{-1}**
0	1.028106	7854	526	0.029048	1.892	3986.5	1449.1
5	1.027675	7717	1136	0.033468	1.610		
10	1.026952	7606	1668	0.038103	1.388	3986.3	1489.8
15	1.025973	7516	2141	0.042933	1.221		
20	1.024763	7444	2572	0.047934	1.085	3993.9	1521.5
25	1.023343	7385	2970	0.053088	0.966		
30	1.021729	7338	3341	0.058373	0.871	4000.7	1545.6
35	1.019934	7300	3687				
40		7270	4004			4003.5	1563.2

PROPERTIES OF SEAWATER (continued)

Electrical Conductivity of Seawater in S/cm as a Function of Temperature and Salinity

t/°C	S = 5	*S* = 10	*S* = 15	*S* = 20	*S* = 25	*S* = 30	*S* = 35	*S* = 40
0	0.004808	0.009171	0.013357	0.017421	0.021385	0.025257	0.029048	0.032775
5	0.005570	0.010616	0.015441	0.020118	0.024674	0.029120	0.033468	0.037734
10	0.006370	0.012131	0.017627	0.022947	0.028123	0.033171	0.038103	0.042935
15	0.007204	0.013709	0.019905	0.025894	0.031716	0.037391	0.042933	0.048355
20	0.008068	0.015346	0.022267	0.028948	0.035438	0.041762	0.047934	0.053968
25	0.008960	0.017035	0.024703	0.032097	0.039276	0.046267	0.053088	0.059751
30	0.009877	0.018771	0.027204	0.035330	0.043213	0.050888	0.058373	0.065683

Composition of Seawater and Ionic Strength at Various Salinities

Concentration of major constituents expressed as molality (moles per kilogram of H_2O)

Constituent	*S* = 30	*S* = 35	*S* = 40
Cl^-	0.482	0.562	0.650
Br^-	0.00074	0.00087	0.00100
F^-		0.00007	
SO_4^{2-}	0.0104	0.0114	0.0122
HCO_3^-	0.00131	0.00143	0.00100
$NaSO_4^-$	0.0085	0.0108	0.0139
KSO_4^-	0.00010	0.00012	0.00015
Na^+	0.405	0.472	0.544
K^+	0.00892	0.01039	0.01200
Mg^{2+}	0.0413	0.0483	0.0561
Ca^{2+}	0.00131	0.00143	0.00154
Sr^+	0.00008	0.00009	0.00011
$MgHCO_3^+$	0.00028	0.00036	0.00045
$MgSO_4$	0.00498	0.00561	0.00614
$CaSO_4$	0.00102	0.00115	0.00126
$NaHCO_3$	0.00015	0.00020	0.00024
H_3BO_3	0.00032	0.00037	0.00042
Ionic strength (mol/kg)	0.5736	0.6675	0.7701

ABUNDANCE OF ELEMENTS IN THE EARTH'S CRUST AND IN THE SEA

This table gives the estimated abundance of the elements in the continental crust (in mg/kg, equivalent to parts per million by mass) and in seawater near the surface (in mg/L). Values represent the median of reported measurements. The concentrations of the less abundant elements may vary with location by several orders of magnitude.

REFERENCES

1. Carmichael, R. S., Ed., *CRC Practical Handbook of Physical Properties of Rocks and Minerals,* CRC Press, Boca Raton, FL, 1989.
2. Bodek,I., et al., *Environmental Inorganic Chemistry*, Pergamon Press, New York, 1988.
3. Ronov, A. B., and Yaroshevsky, A. A.,"Earth's Crust Geochemistry", in *Encyclopedia of Geochemistry and Environmental Sciences,* Fairbridge, R. W.,Ed., Van Nostrand, New York, 1969.

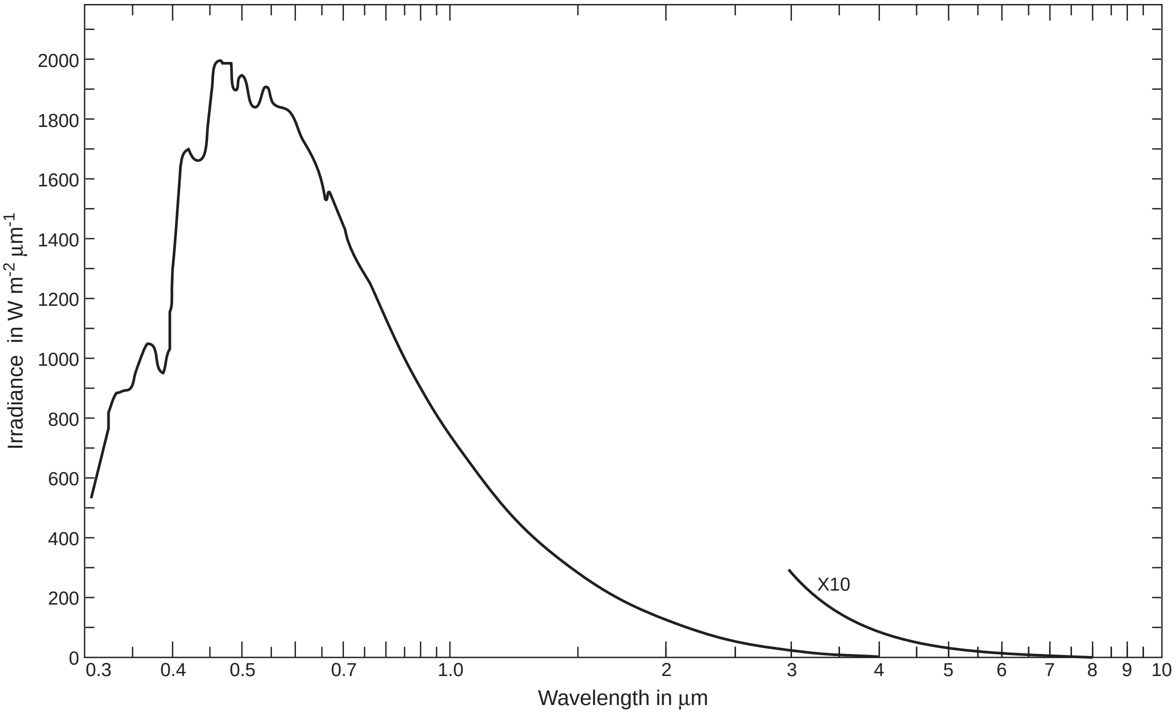
	Abundance	
Element	**Crust mg/kg**	**Sea mg/L**
Ac	5.5×10^{-10}	
Ag	7.5×10^{-2}	4×10^{-5}
Al	8.23×10^{4}	2×10^{-3}
Ar	3.5	4.5×10^{-1}
As	1.8	3.7×10^{-3}
Au	4×10^{-3}	4×10^{-6}
B	1.0×10^{1}	4.44
Ba	4.25×10^{2}	1.3×10^{-2}
Be	2.8	5.6×10^{-6}
Bi	8.5×10^{-3}	2×10^{-5}
Br	2.4	6.73×10^{1}
C	2.00×10^{2}	2.8×10^{1}
Ca	4.15×10^{4}	4.12×10^{2}
Cd	1.5×10^{-1}	1.1×10^{-4}
Ce	6.65×10^{1}	1.2×10^{-6}
Cl	1.45×10^{2}	1.94×10^{4}
Co	2.5×10^{1}	2×10^{-5}
Cr	1.02×10^{2}	3×10^{-4}
Cs	3	3×10^{-4}
Cu	6.0×10^{1}	2.5×10^{-4}
Dy	5.2	9.1×10^{-7}
Er	3.5	8.7×10^{-7}
Eu	2.0	1.3×10^{-7}
F	5.85×10^{2}	1.3
Fe	5.63×10^{4}	2×10^{-3}
Ga	1.9×10^{1}	3×10^{-5}
Gd	6.2	7×10^{-7}
Ge	1.5	5×10^{-5}
H	1.40×10^{3}	1.08×10^{5}
He	8×10^{-3}	7×10^{-6}
Hf	3.0	7×10^{-6}
Hg	8.5×10^{-2}	3×10^{-5}
Ho	1.3	2.2×10^{-7}
I	4.5×10^{-1}	6×10^{-2}
In	2.5×10^{-1}	2×10^{-2}
Ir	1×10^{-3}	
K	2.09×10^{4}	3.99×10^{2}
Kr	1×10^{-4}	2.1×10^{-4}
La	3.9×10^{1}	3.4×10^{-6}
Li	2.0×10^{1}	1.8×10^{-1}
Lu	8×10^{-1}	1.5×10^{-7}
Mg	2.33×10^{4}	1.29×10^{3}
Mn	9.50×10^{2}	2×10^{-4}
Mo	1.2	1×10^{-2}
N	1.9×10^{1}	5×10^{-1}
Na	2.36×10^{4}	1.08×10^{4}
Nb	2.0×10^{1}	1×10^{-5}
Nd	4.15×10^{1}	2.8×10^{-6}
Ne	5×10^{-3}	1.2×10^{-4}
Ni	8.4×10^{1}	5.6×10^{-4}
O	4.61×10^{5}	8.57×10^{5}
Os	1.5×10^{-3}	
P	1.05×10^{3}	6×10^{-2}
Pa	1.4×10^{-6}	5×10^{-11}
Pb	1.4×10^{1}	3×10^{-5}
Pd	1.5×10^{-2}	
Po	2×10^{-10}	1.5×10^{-14}
Pr	9.2	6.4×10^{-7}
Pt	5×10^{-3}	
Ra	9×10^{-7}	8.9×10^{-11}
Rb	9.0×10^{1}	1.2×10^{-1}
Re	7×10^{-4}	4×10^{-6}
Rh	1×10^{-3}	
Rn	4×10^{-13}	6×10^{-16}
Ru	1×10^{-3}	7×10^{-7}
S	3.50×10^{2}	9.05×10^{2}
Sb	2×10^{-1}	2.4×10^{-4}
Sc	2.2×10^{1}	6×10^{-7}
Se	5×10^{-2}	2×10^{-4}
Si	2.82×10^{5}	2.2
Sm	7.05	4.5×10^{-7}
Sn	2.3	4×10^{-6}
Sr	3.70×10^{2}	7.9
Ta	2.0	2×10^{-6}
Tb	1.2	1.4×10^{-7}
Te	1×10^{-3}	
Th	9.6	1×10^{-6}
Ti	5.65×10^{3}	1×10^{-3}
Tl	8.5×10^{-1}	1.9×10^{-5}
Tm	5.2×10^{-1}	1.7×10^{-7}
U	2.7	3.2×10^{-3}
V	1.20×10^{2}	2.5×10^{-3}
W	1.25	1×10^{-4}
Xe	3×10^{-5}	5×10^{-5}
Y	3.3×10^{1}	1.3×10^{-5}
Yb	3.2	8.2×10^{-7}
Zn	7.0×10^{1}	4.9×10^{-3}
Zr	1.65×10^{2}	3×10^{-5}

SOLAR SPECTRAL IRRADIANCE

The solar luminosity (total radiant power emitted) is $3.86 \cdot 10^{26}$ W, of which 1373 W/m^2 reaches the top of the earth's atmosphere. To a zeroth approximation the sun can be considered a black body with an effective temperature of 5780 K, which implies a peak in the radiation at around 0.520 µm (5200 Å). The actual solar spectral emission is more complex, especially at ultraviolet and shorter wavelengths. The graph below, which was taken from Reference 1, summarizes the solar irradiance at the top of the atmosphere in the range 0.3 to 10 µm.

REFERENCES

1. Jursa, A.S., ed., *Handbook of Geophysics and the Space Environment*, Air Force Geophysics Laboratory, 1985.
2. Pierce, A.K., and Allen, R.G., "The Solar Spectrum between 0.3 and 10 µm", in *The Solar Output and its Variation*, White, O.R., Ed., Colorado Associated University Press, Boulder, CO, 1977.
3. Lang, K.R., *Astrophysical Data. Planets and Stars*, Springer-Verlag, New York, 1992.



U.S. STANDARD ATMOSPHERE (1976)

A Standard Atmosphere is a hypothetical vertical distribution of atmospheric temperature, pressure, and density which is roughly representative of year-round, midlatitude conditions. Typical uses are to serve as a basis for pressure altimeter calibrations, aircraft performance calculations, aircraft and rocket design, ballistic tables, meteorological diagrams, and various types of atmospheric modeling. The air is assumed to be dry and to obey the perfect gas law and the hydrostatic equation which, taken together, relate temperature, pressure, and density with vertical position. The atmosphere is considered to rotate with the earth and to be an average over the diurnal cycle, the semiannual variation, and the range from active to quiet geomagnetic and sunspot conditions.

The U.S. Standard Atmosphere, 1976 is an idealized, steady-state representation of mean annual conditions of the earth's atmosphere from the surface to 1000 km at latitude 45°N, as it is assumed to exist during a period with moderate solar activity. The defining meteorological elements are sea-level temperature and pressure and a temperature-height profile to 1000 km. The 1976 Standard Atmosphere uses the following sea-level values which have been standard for many decades:

Temperature — 288.15 K (15°C)
Pressure — 101325 Pa (1013.25 mbar, 760 mm of Hg, or 29.92 in. of Hg)
Density — 1225 g/m^3 (1.225 g/L)
Mean molar mass — 28.964 g/mol

The parameters included in this condensed version of the U.S. Standard Atmosphere are:

Z — Height (geometric) above mean sea level in meters
T — Temperature in kelvins
P — Pressure in pascals (1 Pa = 0.01 millibars)
ρ — Density in kilograms per cubic meter (1 kg/m^3 = 1 g/L)
n — Number density in molecules per cubic meter
ν — Mean collision frequency in collisions per second
l — Mean free path in meters
η — Absolute viscosity in pascal seconds (1 Pa s = 1000 cP)
k — Thermal conductivity in joules per meter second kilogram (W/m K)
v_s — Speed of sound in meters per second
g — Acceleration of gravity in meters per second square

The sea-level composition (percent by volume) is taken to be:

N_2 — 78.084%	He — 0.000524
O_2 — 20.9476	Kr — 0.000114
Ar — 0.934	Xe — 0.0000087
CO_2 — 0.0314	CH_4 — 0.0002
Ne — 0.001818	H_2 — 0.00005

The T and P columns for the troposphere and lower stratosphere were generated from the following formulas:

	***T*/K**	***P*/Pa**
$H \leq 1100$ m	$288.15 - 0.0065\,H$	$101325(288.15/T)^{-5.25577}$
11000 m $< H \leq$ 20000 m	216.65	$22632\ e^{-0.00015768832(H-11000)}$
20000 m $< H \leq$ 32000 m	$216.65 + 0.0010(H-20000)$	$5474.87(216.65/T)^{34.16319}$

where $H = rZ/(r + Z)$ is the geopotential height in meters and r is the mean earth radius at 45° N latitude, taken as 6356766 m. For altitudes up to 32 km, $\rho = 0.003483677(P/T)$ in the units used here. Formulas for the other quantities may be found in the references.

REFERENCES

1. COESA, U.S. Standard Atmosphere, 1976, U.S. Government Printing Office, Washington, D.C., 1976.
2. Jursa, A.S., ed., *Handbook of Geophysics and the Space Environment*, Air Force Geophysics Laboratory, 1985.

Z/m	*T*/K	*P*/Pa	ρ/kg m^{-3}	*n*/m^{-3}	ν/s^{-1}	*l*/m	η/Pa s	*k*/J m^{-1}s^{-1}K^{-1}	v_s/m s^{-1}	*g*/m s^{-2}
-5000	320.68	1.778E+05	1.931	4.015E+25	1.151E+10	4.208E-08	1.942E-05	0.02788	359.0	9.822
-4500	317.42	1.685E+05	1.849	3.845E+25	1.096E+10	4.395E-08	1.927E-05	0.02763	357.2	9.830
-4000	314.17	1.596E+05	1.770	3.680E+25	1.044E+10	4.592E-08	1.912E-05	0.02738	355.3	9.819
-3500	310.91	1.511E+05	1.693	3.520E+25	9.933E+09	4.800E-08	1.897E-05	0.02713	353.5	9.818
-3000	307.66	1.430E+05	1.619	3.366E+25	9.448E+09	5.019E-08	1.882E-05	0.02688	351.6	9.816
-2500	304.41	1.352E+05	1.547	3.217E+25	8.982E+09	5.252E-08	1.867E-05	0.02663	349.8	9.814
-2000	301.15	1.278E+05	1.478	3.102E+25	8.623E+09	5.447E-08	1.852E-05	0.02638	347.9	9.813
-1500	297.90	1.207E+05	1.411	2.935E+25	8.106E+09	5.757E-08	1.836E-05	0.02613	346.0	9.811
-1000	294.65	1.139E+05	1.347	2.801E+25	7.693E+09	6.032E-08	1.821E-05	0.02587	344.1	9.810
-500	291.40	1.075E+05	1.285	2.672E+25	7.298E+09	6.324E-08	1.805E-05	0.02562	342.2	9.808
0	288.15	1.013E+05	1.225	2.547E+25	6.919E+09	6.633E-08	1.789E-05	0.02533	340.3	9.807
500	284.90	9.546E+04	1.167	2.427E+25	6.556E+09	6.961E-08	1.774E-05	0.02511	338.4	9.805
1000	281.65	8.988E+04	1.112	2.311E+25	6.208E+09	7.310E-08	1.758E-05	0.02485	336.4	9.804
1500	278.40	8.456E+04	1.058	2.200E+25	5.874E+09	7.680E-08	1.742E-05	0.02459	334.5	9.802
2000	275.15	7.950E+04	1.007	2.093E+25	5.555E+09	8.073E-08	1.726E-05	0.02433	332.5	9.801
2500	271.91	7.469E+04	0.957	1.990E+25	5.250E+09	8.491E-08	1.710E-05	0.02407	330.6	9.799
3000	268.66	7.012E+04	0.909	1.891E+25	4.959E+09	8.937E-08	1.694E-05	0.02381	328.6	9.797
3500	265.41	6.579E+04	0.863	1.795E+25	4.680E+09	9.411E-08	1.678E-05	0.02355	326.6	9.796
4000	262.17	6.166E+04	0.819	1.704E+25	4.414E+09	9.917E-08	1.661E-05	0.02329	324.6	9.794
4500	258.92	5.775E+04	0.777	1.616E+25	4.160E+09	1.046E-07	1.645E-05	0.02303	322.6	9.793
5000	255.68	5.405E+04	0.736	1.531E+25	3.918E+09	1.103E-07	1.628E-05	0.02277	320.6	9.791
5500	252.43	5.054E+04	0.697	1.450E+25	3.687E+09	1.165E-07	1.612E-05	0.02250	318.5	9.790
6000	249.19	4.722E+04	0.660	1.373E+25	3.467E+09	1.231E-07	1.595E-05	0.02224	316.5	9.788
6500	245.94	4.408E+04	0.664	1.299E+25	3.258E+09	1.302E-07	1.578E-05	0.02197	314.4	9.787
7000	242.70	4.111E+04	0.590	1.227E+25	3.058E+09	1.377E-07	1.561E-05	0.02170	312.3	9.785
7500	239.46	3.830E+04	0.557	1.159E+25	2.869E+09	1.458E-07	1.544E-05	0.02144	310.2	9.784
8000	236.22	3.565E+04	0.526	1.093E+25	2.689E+09	1.545E-07	1.527E-05	0.02117	308.1	9.782
8500	232.97	3.315E+04	0.496	1.031E+25	2.518E+09	1.639E-07	1.510E-05	0.02090	306.0	9.781
9000	229.73	3.080E+04	0.467	9.711E+24	2.356E+09	1.740E-07	1.493E-05	0.02063	303.9	9.779
9500	226.49	2.858E+04	0.440	9.141E+24	2.202E+09	1.848E-07	1.475E-05	0.02036	301.7	9.777
10000	223.25	2.650E+04	0.414	8.598E+24	2.056E+09	1.965E-07	1.458E-05	0.02009	299.5	9.776
10500	220.01	2.454E+04	0.389	8.079E+24	1.918E+09	2.091E-07	1.440E-05	0.01982	297.4	9.774
11000	216.77	2.270E+04	0.365	7.585E+24	1.787E+09	2.227E-07	1.422E-05	0.01954	295.2	9.773
11500	216.65	2.098E+04	0.337	7.016E+24	1.653E+09	2.408E-07	1.422E-05	0.01953	295.1	9.771
12000	216.65	1.940E+04	0.312	6.486E+24	1.528E+09	2.605E-07	1.422E-05	0.01953	295.1	9.770
12500	216.65	1.793E+04	0.288	5.996E+24	1.412E+09	2.818E-07	1.422E-05	0.01953	295.1	9.768
13000	216.65	1.658E+04	0.267	5.543E+24	1.306E+09	3.048E-07	1.422E-05	0.01953	295.1	9.767
13500	216.65	1.533E+04	0.246	5.124E+24	1.207E+09	3.297E-07	1.422E-05	0.01953	295.1	9.765
14000	216.65	1.417E+04	0.228	4.738E+24	1.116E+09	3.566E-07	1.422E-05	0.01953	295.1	9.764
14500	216.65	1.310E+04	0.211	4.380E+24	1.032E+09	3.857E-07	1.422E-05	0.01953	295.1	9.762
15000	216.65	1.211E+04	0.195	4.049E+24	9.538E+08	4.172E-07	1.422E-05	0.01953	295.1	9.761
16000	216.65	1.035E+04	0.166	3.461E+24	8.153E+08	4.881E-07	1.422E-05	0.01953	295.1	9.758
17000	216.65	8.850E+03	0.142	2.959E+24	6.969E+08	5.710E-07	1.422E-05	0.01953	295.1	9.754
18000	216.65	7.565E+03	0.122	2.529E+24	5.958E+08	6.680E-07	1.422E-05	0.01953	295.1	9.751
19000	216.65	6.467E+03	0.104	2.162E+24	5.093E+08	7.814E-07	1.422E-05	0.01953	295.1	9.748

Z/m	T/K	P/Pa	ρ/kg m^{-3}	n/m^{-3}	ν/s^{-1}	l/m	η/Pa s	k/J m^{-1}s^{-1}K^{-1}	v_s/m s^{-1}	g/m s^{-2}
20000	216.65	5.529E+03	8.891E-02	1.849E+24	4.354E+08	9.139E-07	1.422E-05	0.01953	295.1	9.745
21000	217.58	4.729E+03	7.572E-02	1.574E+24	3.716E+08	1.073E-06	1.427E-05	0.01961	295.1	9.742
22000	218.57	4.048E+03	6.451E-02	1.341E+24	3.173E+08	1.260E-06	1.432E-05	0.01970	296.4	9.739
23000	219.57	3.467E+03	5.501E-02	1.144E+24	2.712E+08	1.477E-06	1.438E-05	0.01978	297.1	9.736
24000	220.56	2.972E+03	4.694E-02	9.759E+23	2.319E+08	1.731E-06	1.443E-05	0.01986	297.7	9.733
25000	221.55	2.549E+03	4.008E-02	8.334E+23	1.985E+08	2.027E-06	1.448E-05	0.01995	298.4	9.730
26000	222.54	2.188E+03	3.426E-02	7.123E+23	1.700E+08	2.372E-06	1.454E-05	0.02003	299.1	9.727
27000	223.54	1.880E+03	2.930E-02	6.092E+23	1.458E+08	2.773E-06	1.459E-05	0.02011	299.7	9.724
28000	224.53	1.610E+03	2.508E-02	5.214E+23	1.250E+08	3.240E-06	1.465E-05	0.02020	300.4	9.721
29000	225.52	1.390E+03	2.148E-02	4.466E+23	1.073E+08	3.783E-06	1.470E-05	0.02028	301.1	9.718
30000	226.51	1.197E+03	1.841E-02	3.828E+23	9.219E+07	4.414E-06	1.475E-05	0.02036	301.7	9.715
31000	227.50	1.031E+03	1.579E-02	3.283E+23	7.925E+07	5.146E-06	1.481E-05	0.02044	302.4	9.712
32000	228.49	8.891E+02	1.356E-02	2.813E+23	6.818E+07	5.995E-06	1.486E-05	0.02053	303.0	9.709
33000	230.97	7.673E+02	1.157E-02	2.406E+23	5.852E+07	7.021E-06	1.499E-05	0.02073	304.7	9.706
34000	233.74	6.634E+02	9.887E-03	2.056E+23	5.030E+07	8.218E-06	1.514E-05	0.02096	306.5	9.703
35000	236.51	5.746E+02	8.463E-03	1.760E+23	4.331E+07	9.601E-06	1.529E-05	0.02119	308.3	9.700
36000	239.28	4.985E+02	7.258E-03	1.509E+23	3.736E+07	1.120E-05	1.543E-05	0.02142	310.1	9.697
38000	244.82	3.771E+02	5.367E-03	1.116E+23	2.794E+07	1.514E-05	1.572E-05	0.02188	313.7	9.690
40000	250.35	2.871E+02	3.996E-03	8.308E+22	2.104E+07	2.034E-05	1.601E-05	0.02233	317.2	9.684
42000	255.88	2.200E+02	2.995E-03	6.227E+22	1.594E+07	2.713E-05	1.629E-05	0.02278	320.7	9.678
44000	261.40	1.695E+02	2.259E-03	4.697E+22	1.215E+07	3.597E-05	1.657E-05	0.02323	324.1	9.672
46000	266.93	1.313E+02	1.714E-03	3.564E+22	9.318E+06	4.740E-05	1.685E-05	0.02376	327.5	9.666
48000	270.65	1.023E+02	1.317E-03	2.738E+22	7.208E+06	6.171E-05	1.704E-05	0.02397	329.8	9.660
50000	270.65	7.978E+01	1.027E-03	2.135E+22	5.620E+06	7.913E-05	1.703E-05	0.02397	329.8	9.654
52000	269.03	6.221E+01	8.056E-04	1.675E+22	4.397E+06	1.009E-04	1.696E-05	0.02384	328.8	9.648
54000	263.52	4.834E+01	6.390E-04	1.329E+22	3.452E+06	1.272E-04	1.660E-05	0.02340	325.4	9.642
56000	258.02	3.736E+01	5.045E-04	1.049E+22	2.696E+06	1.611E-04	1.640E-05	0.02296	322.0	9.636
58000	252.52	2.872E+01	3.963E-04	8.239E+21	2.095E+06	2.051E-04	1.612E-05	0.02251	318.6	9.632
60000	247.02	2.196E+01	3.097E-04	6.439E+21	1.620E+06	2.624E-04	1.584E-05	0.02206	315.1	9.624
65000	233.29	1.093E+01	1.632E-04	3.393E+21	8.294E+05	4.979E-04	1.512E-05	0.02093	306.2	9.609
70000	219.59	5.221	8.283E-05	1.722E+21	4.084E+05	9.810E-04	1.438E-05	0.01978	297.1	9.594
75000	208.40	2.388	3.992E-05	8.300E+20	1.918E+05	2.035E-03	1.376E-05	0.01883	289.4	9.579
80000	198.64	1.052	1.846E-05	3.838E+20	8.656E+04	4.402E-03	1.321E-05	0.01800	282.5	9.564
85000	188.89	4.457E-01	8.220E-06	1.709E+20	3.766E+04	9.886E-03	1.265E-05	0.01716	275.5	9.550
90000	186.87	1.836E-01	3.416E-06	7.116E+19	1.560E+04	2.370E-02				9.535
95000	188.42	7.597E-02	1.393E-06	2.920E+19	6.440E+03	5.790E-02				9.520
100000	195.08	3.201E-02	5.604E-07	1.189E+19	2.680E+03	1.420E-01				9.505
110000	240.00	7.104E-03	9.708E-08	2.144E+18	5.480E+02	7.880E-01				9.476
120000	360.00	2.538E-03	2.222E-08	5.107E+17	1.630E+02	3.310				9.447
130000	469.27	1.251E-03	8.152E-09	1.930E+17	7.100E+01	8.800				9.418
140000	559.63	7.203E-04	3.831E-09	9.322E+16	3.800E+01	1.800E+01				9.389
150000	634.39	4.542E-04	2.076E-09	5.186E+16	2.300E+01	3.300E+01				9.360
160000	696.29	3.040E-04	1.233E-09	3.162E+16	1.500E+01	5.300E+01				9.331
170000	747.57	2.121E-04	7.815E-10	2.055E+16	1.000E+01	8.200E+01				9.302
180000	790.07	1.527E-04	5.194E-10	1.400E+16	7.200	1.200E+02				9.274

Z/m	T/K	P/Pa	ρ/kg m^{-3}	n/m^{-3}	ν/s^{-1}	l/m	η/Pa s	k/J m^{-1}s^{-1}K^{-1}	v_s/m s^{-1}	g/m s^{-2}
190000	825.16	1.127E-04	3.581E-10	9.887E+15	5.200	1.700E+02				9.246
200000	854.56	8.474E-05	2.541E-10	7.182E+15	3.900	2.400E+02				9.218
220000	899.01	5.015E-05	1.367E-10	4.040E+15	2.300	4.200E+02				9.162
240000	929.73	3.106E-05	7.858E-11	2.420E+15	1.400	7.000E+02				9.106
260000	950.99	1.989E-05	4.742E-11	1.515E+15	9.300E-01	1.100E+03				9.051
280000	965.75	1.308E-05	2.971E-11	9.807E+14	6.100E-01	1.700E+03				8.997
300000	976.01	8.770E-06	1.916E-11	6.509E+14	4.200E-01	2.600E+03				8.943
320000	983.16	5.980E-06	1.264E-11	4.405E+14	2.900E-01	3.800E+03				8.889
340000	988.15	4.132E-06	8.503E-12	3.029E+14	2.000E-01	5.600E+03				8.836
360000	991.65	2.888E-06	5.805E-12	2.109E+14	1.400E-01	8.000E+03				8.784
380000	994.10	2.038E-06	4.013E-12	1.485E+14	1.000E-01	1.100E+04				8.732
400000	995.83	1.452E-06	2.803E-12	1.056E+14	7.200E-02	1.600E+04				8.680
450000	998.22	6.447E-07	1.184E-12	4.678E+13	3.300E-02	3.600E+04				8.553
500000	999.24	3.024E-07	5.215E-13	2.192E+13	1.600E-02	7.700E+04				8.429
550000	999.67	1.514E-07	2.384E-13	1.097E+13	8.400E-03	1.500E+05				8.307
600000	999.85	8.213E-08	1.137E-13	5.950E+12	4.800E-03	2.800E+05				8.188
650000	999.93	4.887E-08	5.712E-14	3.540E+12	3.100E-03	4.800E+05				8.072
700000	999.97	3.191E-08	3.070E-14	2.311E+12	2.200E-03	7.300E+05				7.958
750000	999.98	2.260E-08	1.788E-14	1.637E+12	1.700E-03	1.000E+06				7.846
800000	999.99	1.704E-08	1.136E-14	1.234E+12	1.400E-03	1.400E+06				7.737
850000	1000.00	1.342E-08	7.824E-15	9.717E+11	1.200E-03	1.700E+06				7.630
900000	1000.00	1.087E-08	5.759E-15	7.876E+11	1.000E-03	2.100E+06				7.525
950000	1000.00	8.982E-09	4.453E-15	6.505E+11	8.700E-04	2.600E+06				7.422
1000000	1000.00	7.514E-09	3.561E-15	5.442E+11	7.500E-04	3.100E+06				7.322

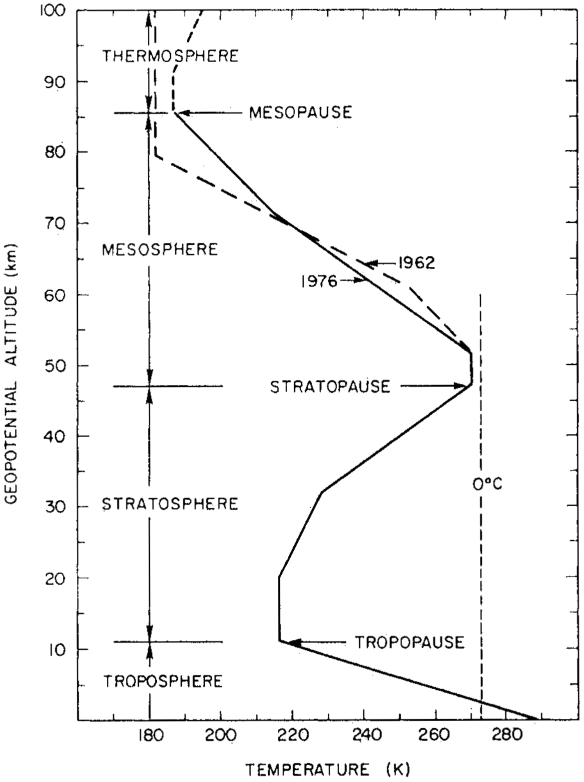


FIGURE 1. Temperature-height profile for U.S. Standard Atmosphere.

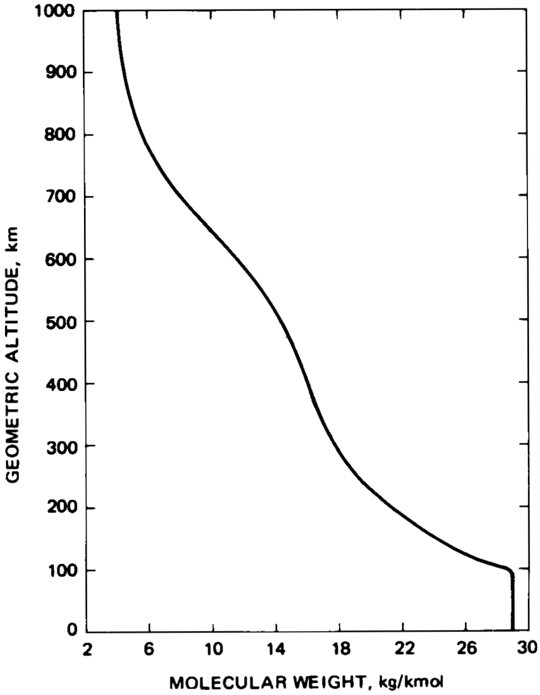


FIGURE 3. Mean molecular weight as a function of geometric altitude.

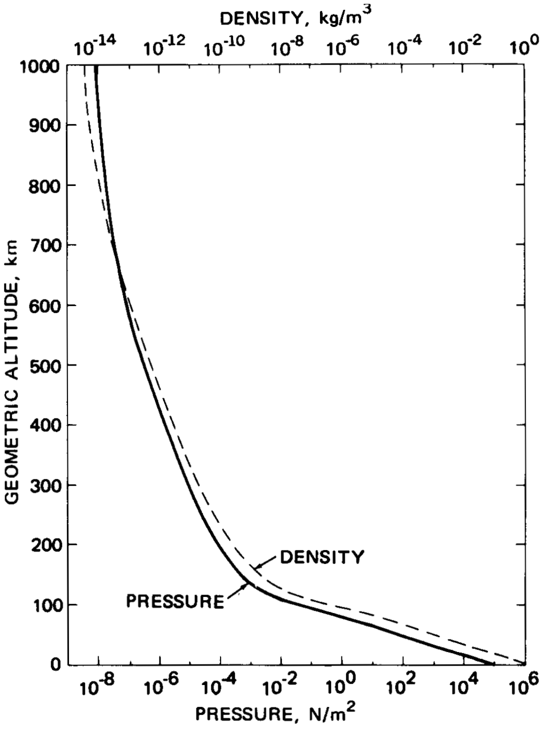


FIGURE 2. Total pressure and mass density as a function of geometric altitude.

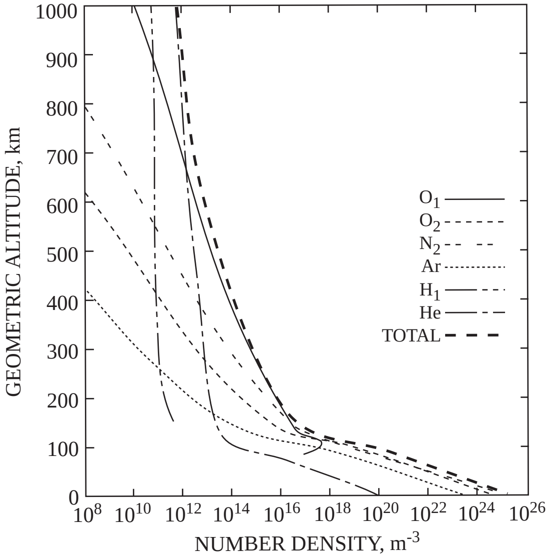


FIGURE 4. Number density of individual species and total number density as a function of geometric altitude.

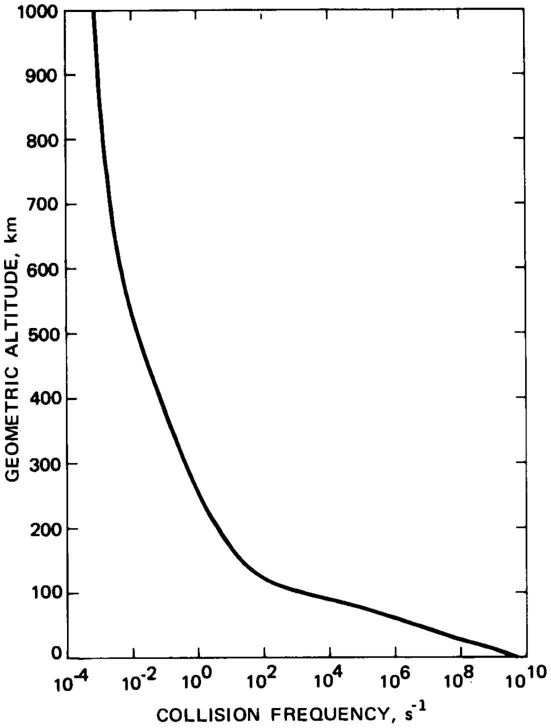


FIGURE 5. Collision frequency as a function of geometric altitude.

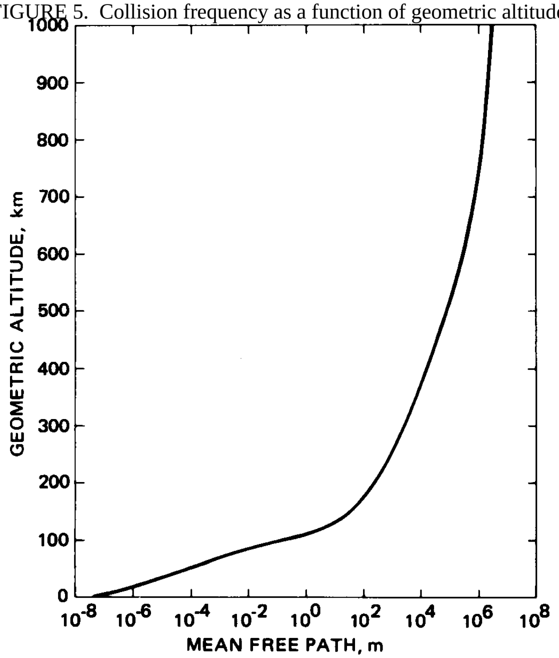


FIGURE 6. Mean free path as a function of geometric altitude.

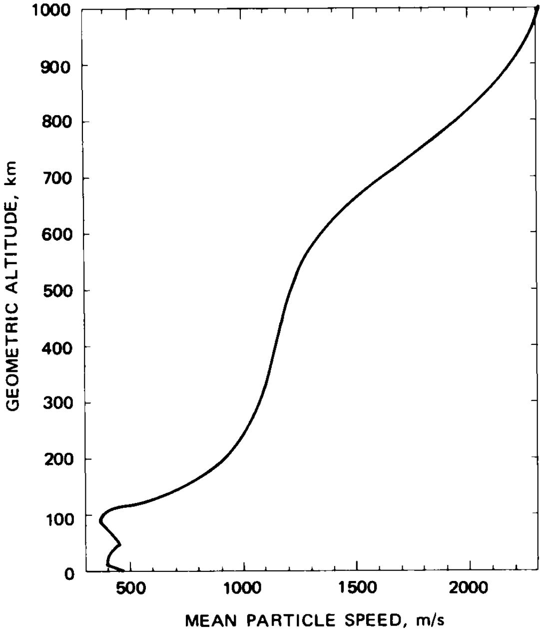


FIGURE 7. Mean air-particle speed as a function of geometric altitude.

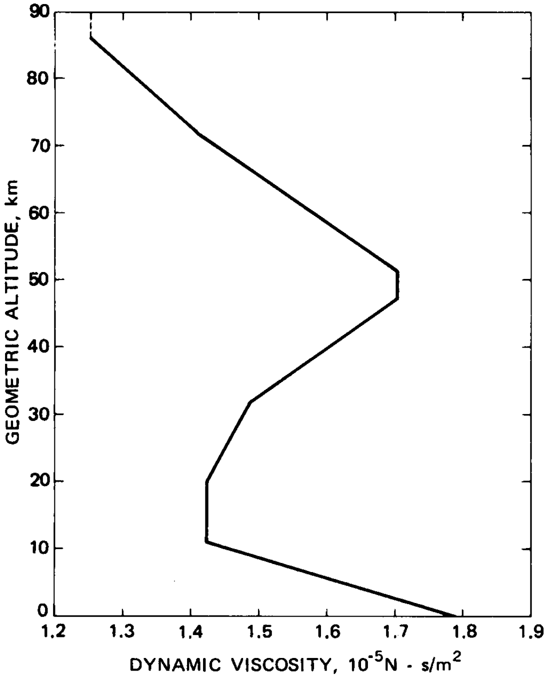


FIGURE 8. Dynamic viscosity as a function of geometric altitude.

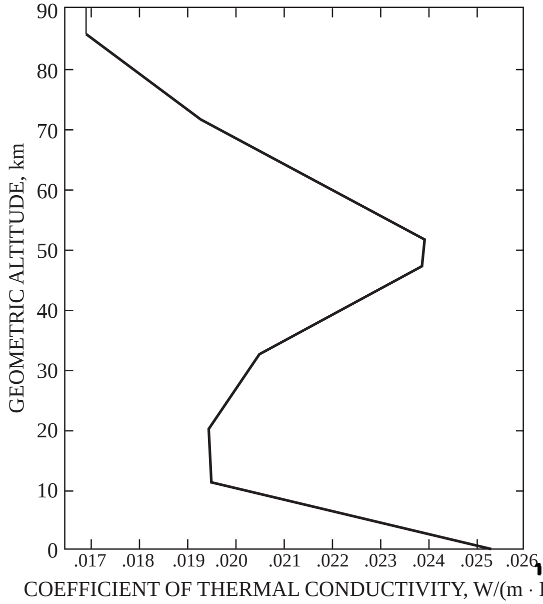


FIGURE 9. Coefficient of thermal conductivity as a function of geometric altitude.

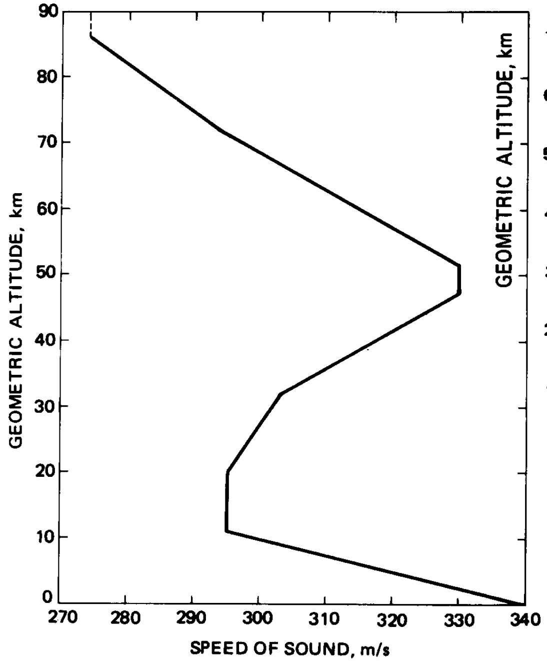


FIGURE 10. Speed of sound as a function of geometric altitude.

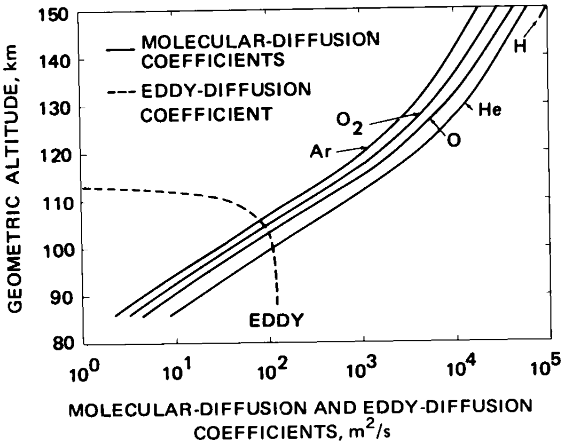


FIGURE 11. Molecular-diffusion and eddy-diffusion coefficients as a function of geometric altitude.

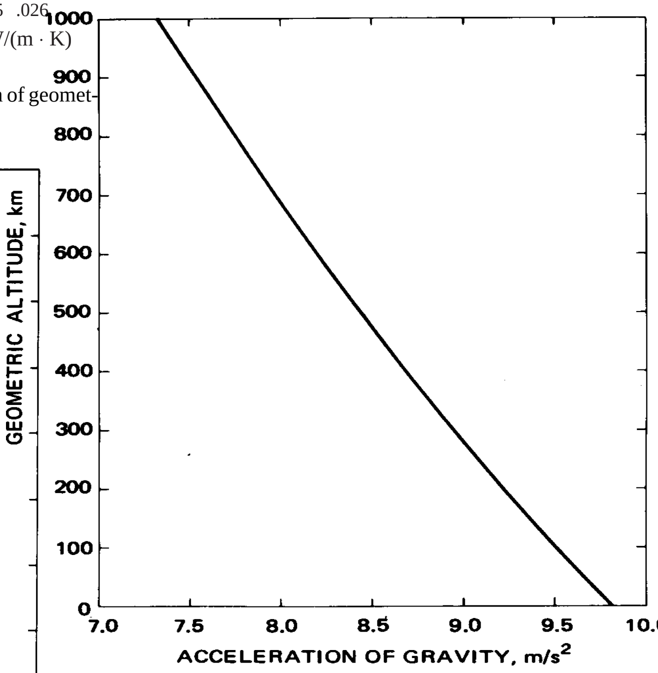


FIGURE 12. Acceleration of gravity as a function of geometric altitude.

GEOGRAPHICAL AND SEASONAL VARIATION IN SOLAR RADIATION

This table gives the amount of solar radiation reaching a unit area at the top of the earth's atmosphere per day as a function of latitude and approximate date. It is based upon a solar constant (total energy per unit area at the earth's average orbital distance) of 1373 W/m^2. Absorption of radiation by the atmosphere is not taken into consideration.

REFERENCE

List, R.J., *Smithsonian Meteorological Tables, Seventh Edition*, Smithsonian Institution Press, Washington, D.C., 1962.

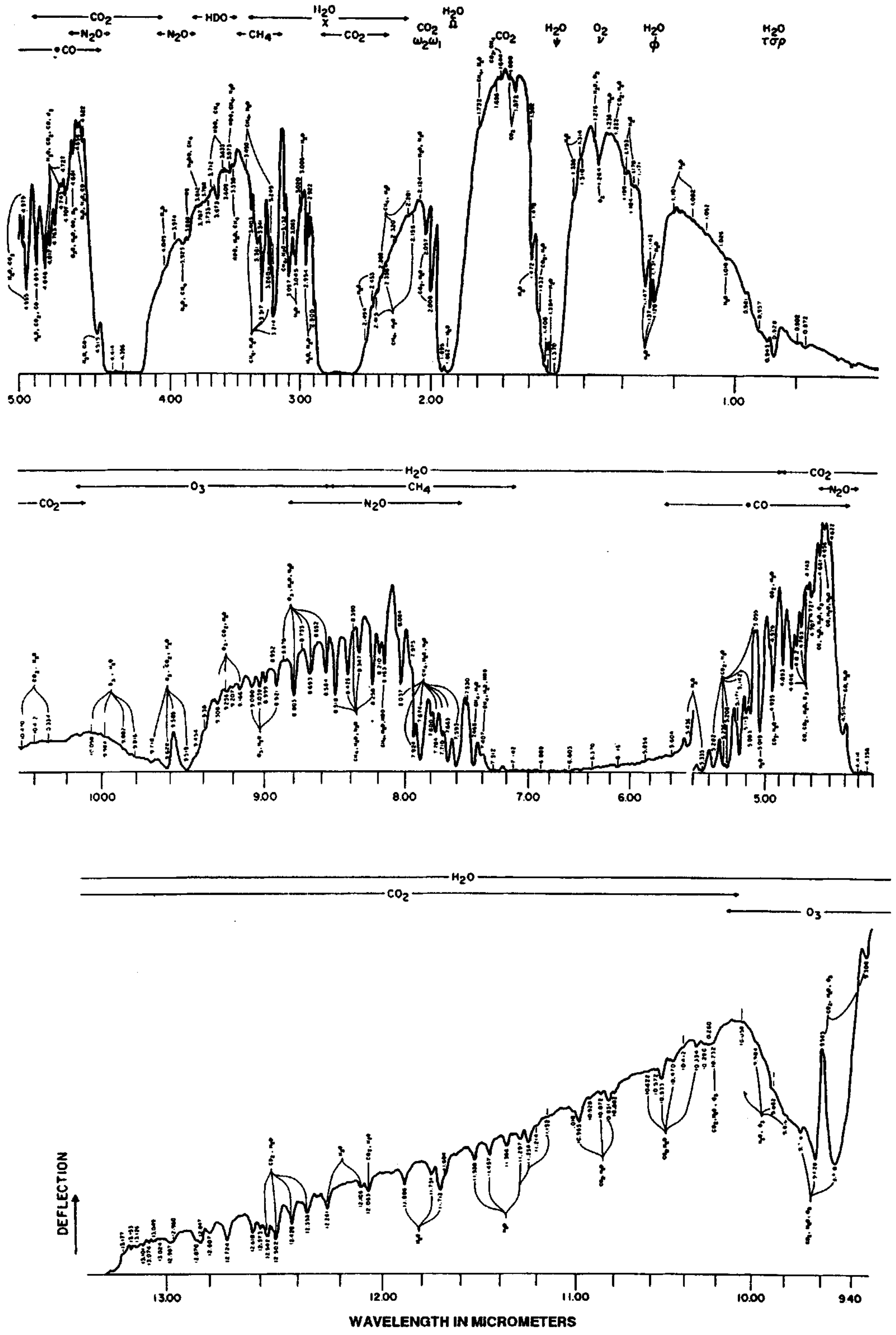
Daily Solar Radiation in MJ/m^2

Lat.	Mar. 21	Apr. 13	May 6	May 29	Jun. 2	Jul. 15	Aug. 8	Aug. 31
90°		18.0	32.8	42.4	45.7	42.2	32.5	17.7
80	6.6	18.0	32.3	41.8	45.0	41.6	32.0	17.7
70	13.0	22.3	31.8	39.9	43.0	39.7	31.5	22.0
60	19.0	27.0	34.4	39.7	41.6	39.4	34.0	26.7
50	24.4	31.1	36.8	40.7	42.0	40.5	36.5	30.8
40	29.1	34.3	38.6	41.3	42.1	41.1	38.3	33.9
30	32.9	36.7	39.4	41.1	41.4	40.8	39.1	36.3
20	35.7	38.0	39.2	39.7	39.7	39.5	38.9	37.5
10	37.4	38.1	37.9	37.4	37.1	37.2	37.6	37.7
0	38.0	37.1	35.5	34.1	33.5	34.0	35.2	36.6
–10	37.4	35.0	32.3	30.0	29.2	29.9	32.0	34.6
–20	35.7	31.8	28.0	25.2	24.1	25.1	27.8	31.5
–30	32.9	27.8	23.1	19.7	18.5	19.7	22.8	27.4
–40	29.1	22.8	17.5	14.0	12.6	13.9	17.4	22.6
–50	24.4	17.3	11.7	8.2	7.0	8.2	11.6	17.2
–60	19.0	11.4	5.9	2.9	2.0	2.9	5.9	11.3
–70	13.0	5.4	1.0				1.0	5.3
–80	6.6	0.3						0.3
–90								

Lat.	Sep. 23	Oct. 16	Nov. 8	Nov. 30	Dec. 22	Jan. 13	Feb. 4	Feb. 26
90°								
80	6.5	0.3						0.3
70	12.9	5.5	1.0				1.0	5.6
60	18.8	11.6	6.2	3.1	2.1	3.1	6.2	11.7
50	24.1	17.6	12.1	8.7	7.5	8.7	12.3	17.8
40	28.7	23.1	18.2	14.8	13.5	14.9	18.4	23.5
30	32.5	28.2	23.9	20.9	19.8	21.0	24.1	28.4
20	35.3	32.3	29.1	26.6	25.7	26.7	29.3	32.7
10	37.0	35.5	33.5	31.8	31.1	31.9	33.8	35.9
0	37.6	37.6	36.9	36.1	35.8	36.3	37.3	38.0
–10	37.0	38.6	39.4	39.5	39.6	39.7	39.7	39.1
–20	35.3	38.5	40.7	42.0	42.4	42.2	41.1	39.0
–30	32.5	37.2	40.9	43.3	44.2	43.5	41.3	37.7
–40	28.7	34.8	40.1	43.6	45.0	43.8	40.5	35.2
–50	24.1	31.5	38.3	43.1	44.8	43.2	38.6	31.9
–60	18.8	27.3	35.7	41.9	44.4	42.1	36.0	27.7
–70	12.9	22.6	33.0	42.2	45.9	42.4	33.3	22.9
–80	6.5	18.2	33.5	44.2	48.1	44.4	33.8	18.4
–90		18.2	34.0	44.8	48.8	45.1	34.4	18.4

INFRARED ABSORPTION BY THE EARTH'S ATMOSPHERE

This graph summarizes the absorption by various atmospheric constituents in the wavelength range from 1 to 13 μm (wavenumber range 10,000 to 770 cm^{-1}). The vertical scale is in arbitrary units and does not take into account the wavelength variation of either the solar background radiation or the infrared detector response. Thus the intensities of the absorption bands have only qualitative significance.



ATMOSPHERIC CONCENTRATION OF CARBON DIOXIDE, 1958-1996

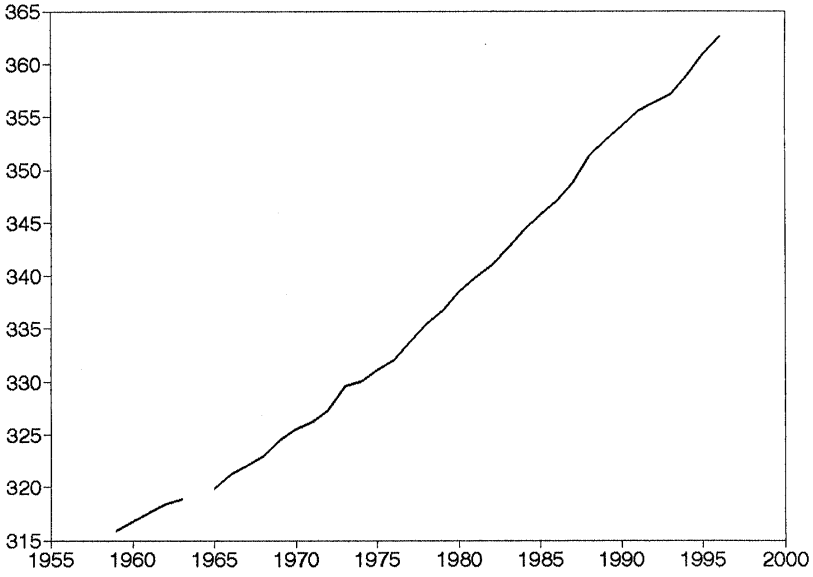
The data in this table were taken at Mauna Loa Observatory in Hawaii and represent averages adjusted to the 15th of each month. The concentration of CO_2 is given in parts per million by volume. Data from other measurement sites may be found in the references.

REFERENCES

1. Keeling, C. D., and Whorf, T. P., Carbon Dioxide Information Analysis Center WWW site <http://cdiac.esd.ornl.gov/trends_html/trends/co2>, August 1997.
2. Keeling, C. D., and Whorf, T. P., in *Trends ’93: A Compendium of Data on Global Change*, p.16, Boden, T. A., Kaiser, D. P., Sepanski, R. J., and Stoss, F. W., Editors, ORNL/CDIAC-65, Oak Ridge National Laboratory, Oak Ridge, TN, 1994.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1958	N/A	N/A	315.56	317.29	317.34	N/A	315.69	314.78	313.05	N/A	313.18	314.50	N/A
1959	315.42	316.31	316.50	317.56	318.13	318.00	316.39	314.65	313.68	313.18	314.66	315.43	315.83
1960	316.27	316.81	317.42	318.87	319.87	319.43	318.01	315.74	314.00	313.68	314.84	316.03	316.75
1961	316.73	317.54	318.38	319.31	320.42	319.61	318.42	316.63	314.84	315.16	315.94	316.85	317.49
1962	317.78	318.40	319.53	320.42	320.85	320.45	319.45	317.25	316.11	315.27	316.53	317.53	318.30
1963	318.58	318.93	319.70	321.22	322.08	321.31	319.58	317.61	316.05	315.83	316.91	318.20	318.83
1964	319.41	N/A	N/A	N/A	322.05	321.73	320.27	318.53	316.54	316.72	317.53	318.55	N/A
1965	319.27	320.28	320.73	321.97	322.00	321.71	321.05	318.71	317.66	317.14	318.70	319.25	319.87
1966	320.46	321.43	322.23	323.54	323.91	323.59	322.24	320.20	318.48	317.94	319.63	320.87	321.21
1967	322.17	322.34	322.88	324.25	324.83	323.93	322.38	320.76	319.10	319.24	320.56	321.80	322.02
1968	322.40	322.99	323.73	324.86	325.40	325.20	323.98	321.95	320.18	320.09	321.16	322.74	322.89
1969	323.83	324.27	325.47	326.50	327.21	326.54	325.72	323.50	322.22	321.62	322.69	323.95	324.46
1970	324.89	325.82	326.77	327.97	327.90	327.50	326.18	324.53	322.93	322.90	323.85	324.96	325.52
1971	326.01	326.51	327.02	327.62	328.76	328.40	327.20	325.27	323.20	323.40	324.63	325.85	326.16
1972	326.60	327.47	327.58	329.56	329.90	328.92	327.88	326.16	324.68	325.04	326.34	327.39	327.29
1973	328.37	329.40	330.14	331.33	332.31	331.90	330.70	329.15	327.35	327.02	327.99	328.48	329.51
1974	329.18	330.55	331.32	332.48	332.92	332.08	331.01	329.23	327.27	327.21	328.29	329.41	330.08
1975	330.23	331.25	331.87	333.14	333.80	333.43	331.73	329.90	328.40	328.17	329.32	330.59	330.99
1976	331.58	332.39	333.33	334.41	334.71	334.17	332.89	330.77	329.14	328.78	330.14	331.52	331.98
1977	332.75	333.24	334.53	335.90	336.57	336.10	334.76	332.59	331.42	330.98	332.24	333.68	333.73
1978	334.80	335.22	336.47	337.59	337.84	337.72	336.37	334.51	332.60	332.38	333.75	334.78	335.34
1979	336.05	336.59	337.79	338.71	339.30	339.12	337.56	335.92	333.75	333.70	335.12	336.56	336.68
1980	337.84	338.19	339.91	340.60	341.29	341.00	339.39	337.43	335.72	335.84	336.93	338.04	338.52
1981	339.06	340.30	341.21	342.33	342.74	342.08	340.32	338.26	336.52	336.68	338.19	339.44	339.76
1982	340.57	341.44	342.53	343.39	343.96	343.18	341.88	339.65	337.81	337.69	339.09	340.32	340.96
1983	341.20	342.35	342.93	344.77	345.58	345.14	343.81	342.21	339.69	339.82	340.98	342.82	342.61
1984	343.52	344.33	345.11	346.89	347.25	346.62	345.22	343.11	340.90	341.18	342.80	344.04	344.25
1985	344.79	345.82	347.25	348.17	348.74	348.07	346.38	344.52	342.92	342.62	344.06	345.38	345.73
1986	346.11	346.78	347.68	349.37	350.03	349.37	347.76	345.73	344.68	343.99	345.48	346.72	346.97
1987	347.84	348.29	349.24	350.80	351.66	351.08	349.33	347.92	346.27	346.18	347.64	348.78	348.75
1988	350.25	351.54	352.05	353.41	354.04	353.63	352.22	350.27	348.55	348.72	349.91	351.18	351.31
1989	352.60	352.92	353.53	355.26	355.52	354.97	353.75	351.52	349.64	349.83	351.14	352.37	352.75
1990	353.50	354.55	355.23	356.04	357.00	356.07	354.67	352.76	350.82	351.04	352.70	354.07	354.04
1991	354.59	355.63	357.03	358.48	359.22	358.12	356.06	353.92	352.05	352.11	353.64	354.89	355.48
1992	355.88	356.63	357.72	359.07	359.58	359.17	356.94	354.92	352.94	353.23	354.09	355.33	356.29
1993	356.63	357.10	358.32	359.41	360.23	359.55	357.53	355.48	353.67	353.95	355.30	356.78	356.99
1994	358.34	358.89	359.95	361.25	361.67	360.94	359.55	357.49	355.84	356.00	357.59	359.05	358.88
1995	359.98	361.03	361.66	363.48	363.82	363.30	361.93	359.49	358.08	357.77	359.57	360.69	360.90
1996	362.03	363.22	363.99	364.66	365.36	364.91	363.58	361.41	359.37	359.50	360.65	362.21	362.57

CO_2 Concentration in Parts per Million (Annual Average)



MEAN TEMPERATURES IN THE UNITED STATES, 1900-1992

Historical records of atmospheric temperatures have been analyzed to obtain mean temperatures in °C for 23 climatically distinct regions of the United States. The table below gives the average over these 23 regions, which cover completely the contiguous 48 states. Data for the individual regions and for other parts of the world may be found in the references.

The data are presented as temperature anomalies, i.e., as deviations (in °C) from the average temperature at each individual recording station over a 1961-1990 reference period. The trend in the temperature anomaly thus gives an indication of the long-term variation in average temperatures.

CY Mean: Calendar year mean (January-December)
Winter: December-February
Spring: March-May
Summer: June-August
Fall: September-November

REFERENCES

1. Karl, T. R., Easterling, D. R., Knight, R. W., and Hughes, P. Y., in *Trends '93: A Compendium of Data on Global Change*, p. 686, Boden, T. A., Kaiser, D. P., Sepanski, R. J., and Stoss, F. W., Editors, ORNL/CDIAC-65, Oak Ridge National Laboratory, Oak Ridge, TN, 1994.
2. Carbon Dioxide Information Analysis Center, WWW site <http://cdiac.esd.ornl.gov/ftp/trends93>.

Year	CY Mean	Winter	Spring	Summer	Fall
1900	0.46		0.21	0.27	0.85
1901	-0.21	0.07	-0.46	0.48	-0.28
1902	-0.14	-0.69	0.48	-0.58	0.12
1903	-0.77	-0.84	0.10	-0.83	-1.02
1904	-0.72	-1.86	-0.39	-0.92	-0.21
1905	-0.45	-1.86	0.67	-0.32	-0.25
1906	-0.04	0.23	-0.69	-0.42	-0.10
1907	-0.23	1.09	-0.61	-0.85	-0.39
1908	-0.11	0.73	0.36	-0.64	-0.59
1909	-0.36	0.82	-1.06	0.06	0.01
1910	-0.14	-2.08	0.95	-0.55	0.13
1911	0.02	0.52	0.20	-0.19	-0.62
1912	-0.88	-1.50	-0.75	-0.76	-0.51
1913	-0.23	-0.74	-0.65	-0.07	0.22
1914	-0.05	0.48	0.04	0.14	0.32
1915	-0.11	-0.37	-0.18	-1.16	0.31
1916	-0.77	-0.29	-0.36	-0.30	-1.23
1917	-1.34	-1.93	-1.75	-0.73	-1.04
1918	-0.14	-2.02	0.30	0.03	-0.09
1919	-0.16	0.69	0.00	0.12	-0.13
1920	-0.37	-0.83	-0.96	-0.67	0.02
1921	0.87	1.56	0.83	0.52	0.32
1922	0.01	-0.44	0.15	0.16	0.41
1923	-0.10	0.23	-1.02	-0.07	-0.09
1924	-1.01	0.13	-1.27	-0.64	-0.53
1925	0.20	-0.44	0.57	0.05	-0.41
1926	-0.01	0.97	-0.58	-0.27	0.02
1927	0.20	1.11	0.41	-0.83	0.83
1928	-0.08	-0.40	-0.28	-0.43	-0.08
1929	-0.68	-1.94	0.30	-0.39	-0.78
1930	-0.12	0.07	0.09	-0.07	-0.25
1931	0.81	1.16	-0.71	0.51	1.41
1932	-0.14	1.75	-0.58	0.26	-0.78
1933	0.35	-0.60	-0.08	0.45	0.54
1934	0.86	1.45	0.77	0.86	0.82
1935	0.12	0.84	0.12	0.31	-0.47
1936	-0.10	-2.23	0.48	1.00	-0.32
1937	-0.13	-0.65	-0.24	0.66	-0.03
1938	0.71	1.31	0.98	0.39	0.08
1939	0.38	0.36	0.34	0.18	0.15
1940	0.06	0.03	-0.10	0.18	0.12

MEAN TEMPERATURES IN THE UNITED STATES, 1901-1992 (continued)

Year	CY Mean	Winter	Spring	Summer	Fall
1941	0.79	1.56	0.44	0.28	0.85
1942	0.01	0.35	0.22	0.08	0.06
1943	-0.17	0.20	-0.46	0.54	-0.79
1944	0.04	0.61	-0.38	-0.20	0.43
1945	-0.02	0.30	0.25	-0.47	0.08
1946	0.53	-0.26	1.21	-0.21	0.18
1947	0.10	0.47	-0.42	0.03	0.85
1948	-0.22	-0.67	-0.01	0.02	-0.15
1949	0.05	-0.77	0.39	0.33	0.23
1950	-0.37	0.39	-1.02	-0.86	0.13
1951	-0.45	0.05	-0.69	-0.30	-0.70
1952	0.03	0.68	-0.40	0.49	-1.22
1953	0.61	1.91	0.03	0.31	0.31
1954	0.57	1.47	-0.22	0.36	0.70
1955	-0.25	-0.33	0.12	0.19	-0.60
1956	-0.05	-0.16	-0.42	0.01	-0.37
1957	0.45	1.02	0.44	0.25	-0.13
1958	0.14	0.93	0.06	0.11	0.45
1959	0.12	-0.60	0.16	0.50	-0.52
1960	-0.27	0.43	-0.98	0.01	0.56
1961	-0.01	-0.02	-0.17	0.18	-0.29
1962	-0.04	-0.52	-0.09	-0.41	0.65
1963	-0.06	-1.35	0.61	0.12	1.38
1964	-0.27	-1.30	-0.24	-0.08	-0.40
1965	-0.03	-0.07	-0.56	-0.42	0.28
1966	-0.34	-0.31	-0.25	-0.07	-0.13
1967	-0.13	0.23	-0.05	-0.37	-0.32
1968	-0.28	-0.31	-0.16	-0.12	0.01
1969	-0.06	-0.36	-0.54	0.12	-0.16
1970	-0.12	-0.17	-0.44	0.32	-0.07
1971	-0.04	-0.08	-0.99	0.01	0.56
1972	-0.13	0.20	0.26	-0.19	0.05
1973	0.48	-0.23	0.47	0.22	0.90
1974	0.16	0.52	0.74	-0.32	-0.39
1975	-0.09	0.63	-0.79	0.03	-0.20
1976	-0.62	0.88	-0.09	-0.54	-1.72
1977	0.32	-1.95	1.07	0.60	0.68
1978	-0.37	-1.31	0.23	0.09	0.21
1979	-0.53	-2.92	0.09	-0.21	-0.07
1980	0.18	0.72	-0.25	0.43	-0.04
1981	0.64	0.90	0.80	0.57	0.36
1982	-0.08	-0.86	0.03	-0.11	0.06
1983	0.40	2.33	-0.36	0.58	0.94
1984	0.21	-0.78	-0.30	0.31	0.07
1985	-0.26	-0.78	1.24	-0.23	0.05
1986	0.93	0.22	1.22	0.45	0.49
1987	0.67	1.52	0.97	0.33	-0.17
1988	-0.07	-0.26	-0.06	0.57	0.04
1989	-0.30	-0.28	0.36	0.12	-0.27
1990	0.72	0.41	0.72	0.41	0.66
1991	0.77	0.32	1.36	0.56	-0.31
1992		2.48	0.82	-0.70	

GLOBAL TEMPERATURE TREND, 1866-1996

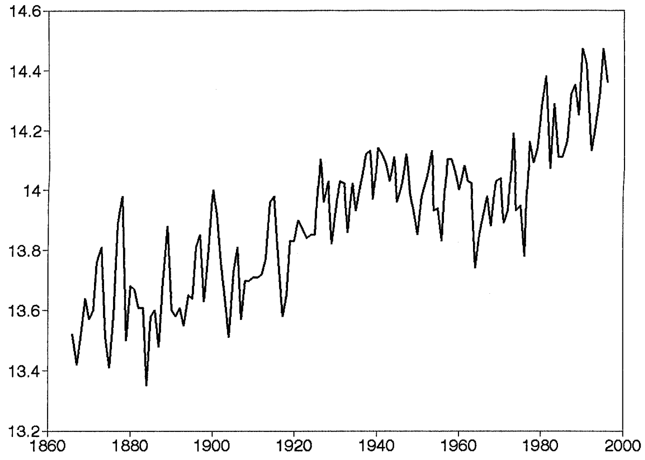
This table and graph summarize the trend in annual mean global temperature from 1886 to 1996. The temperatures were calculated from mean temperature anomalies by assuming an absolute global mean of 14.00 °C (which is the best estimate for the 1951-1980 period). The estimated uncertainty in the year-to-year change in the recent years is about 0.07 °C.

REFERENCES

1. NASA Goddard Institute for Space Studies, World Wide Web site, www.giss.nasa.gov/data/gistemp/
2. Hansen, J., and Wilson, H., *Climatic Change,* 25, 285, 1993.

Year	*t*/°C	Year	*t*/°C	Year	*t*/°C	Year	*t*/°C	Year	*t*/°C
1866	13.52	1897	13.85	1928	14.03	1959	14.05	1990	14.47
1867	13.42	1898	13.63	1929	13.82	1960	14.00	1991	14.42
1868	13.52	1899	13.78	1930	13.93	1961	14.08	1992	14.13
1869	13.64	1900	14.00	1931	14.03	1962	14.03	1993	14.21
1870	13.57	1901	13.92	1932	14.02	1963	14.02	1994	14.31
1871	13.60	1902	13.76	1933	13.86	1964	13.74	1995	14.47
1872	13.76	1903	13.64	1934	14.02	1965	13.85	1996	14.36
1873	13.81	1904	13.51	1935	13.93	1966	13.91		
1874	13.51	1905	13.73	1936	14.02	1967	13.98		
1875	13.41	1906	13.81	1937	14.12	1968	13.88		
1876	13.58	1907	13.57	1938	14.13	1969	14.03		
1877	13.89	1908	13.70	1939	13.97	1970	14.04		
1878	13.98	1909	13.70	1940	14.14	1971	13.89		
1879	13.50	1910	13.71	1941	14.12	1972	13.93		
1880	13.68	1911	13.71	1942	14.09	1973	14.19		
1881	13.67	1912	13.72	1943	14.03	1974	13.93		
1882	13.61	1913	13.77	1944	14.11	1975	13.95		
1883	13.61	1914	13.96	1945	13.96	1976	13.78		
1884	13.35	1915	13.98	1946	14.01	1977	14.16		
1885	13.58	1916	13.76	1947	14.12	1978	14.09		
1886	13.60	1917	13.58	1948	13.99	1979	14.14		
1887	13.48	1918	13.65	1949	13.93	1980	14.28		
1888	13.70	1919	13.83	1950	13.85	1981	14.38		
1889	13.88	1920	13.83	1951	13.98	1982	14.07		
1890	13.60	1921	13.90	1952	14.04	1983	14.29		
1891	13.58	1922	13.87	1953	14.13	1984	14.11		
1892	13.61	1923	13.84	1954	13.93	1985	14.11		
1893	13.55	1924	13.85	1955	13.94	1986	14.16		
1894	13.65	1925	13.85	1956	13.83	1987	14.32		
1895	13.64	1926	14.10	1957	14.10	1988	14.35		
1896	13.81	1927	13.96	1958	14.10	1989	14.25		

Annual Mean Global Temperature in °C



ATMOSPHERIC ELECTRICITY

Hans Dolezalek, Hannes Tammet, John Latham, and Martin A. Uman

I. SURVEY AND GLOBAL CIRCUIT

Hans Dolezalek

The science of atmospheric electricity originated in 1752 by an experimental proof of a related earlier hypothesis (that lightning is an electrical event). In spite of a large effort, in part by such eminent physicists as Coulomb, Lord Kelvin, and many others, an overall, proven theory able to generate models with sufficient resolution is not yet available. Generally accepted and encompassing text books are now more than 20 years old. The voluminous proceedings of the, so far, nine international atmospheric electricity conferences (1954 to 1992) give much valuable detail and demonstrate impressive progress, as do a number of less comprehensive textbooks published in the last 20 years, but a general theory as indicated above is not yet created. Only now, certain related measuring techniques and mathematical possibilities are emerging.

Applications to practical purposes do exist in the field of lightning research (including the electromagnetic radiation emanating from lightning) by the establishment of lightning-location networks and by the now developing possibility to detect electrified clouds which pose hazards to aircraft. Application of atmospheric electricity to other parts of meteorology seems to be promising but so far has seldom been instituted. Because some atmospheric electric signals propagate around the earth and because of the existence of a global circuit, applications for the monitoring of global change processes and conditions are now being proposed. Significant secular changes in the global circuit would indicate a change in the global climate; the availability of many old data (about a span of 100 years) could help detect a long term trend.

The concept of the "global circuit" is based on the theory of the global spherical capacitor: both, the solid (and liquid) earth as one electrode, and the high atmospheric layers (about the ionosphere) as the other, are by orders of magnitude more electrically conductive than the atmosphere between them. According to the "classical picture of atmospheric electricity", this capacitor is continuously charged by the common action of all thunderstorms to a d.c. voltage difference of several hundred kilovolts, the earth being negative. The much smaller but still existing conductivity of the atmosphere allows a current flowing from the ionosphere to the ground, integrated for all sink areas of the whole earth, of the order of 1.5 kA. In this way, a global circuit is created with many generators and sink-areas both interspaced and distributed over the whole globe, all connected to two nodes: ionosphere and ground. Within the scope of the global circuit, for each location, the current density (order of several pA/m^2) is determined by the voltage difference between ionosphere and ground (which is the same for all locations but varying in time) and the columnar resistance reaching from the ground up to the ionosphere (in the order of $10^{17}\ \Omega\ m^2$).

Natural processes, especially meteorological processes and some human activity, which produce or move electric charges ("space charges") or affect the ion distribution, constitute local generators and thereby "local circuits", horziontally and/or in parallel or antiparallel to the local part of the global circuit. In many cases, the local currents are much stronger than the global ones, making the measurement of the global current at a given location and/or during a period of time very difficult or, often, impossible. The strongest local circuits usually occur with certain weather conditions (precipitation, fog, high wind, blown-up dust or snow, heavy cloudiness) which make measurement of the global circuit impossible everywhere; but even in their absence local generators exist in varying magnitudes and of different characters. The separation of the local and global shares in the measured values of current density is a central problem of the science of atmospheric electricity. Aerological measurements are of high value in this regard.

The above description is within the "classical picture" of atmospheric electricity, a group of hypotheses to explain the electricifation of the atmosphere. It is probably fundamentally correct but certainly not complete; it has not yet been confirmed by systems of measurements resulting in no inner contradictions. In particular, extraterrestrial influences must be permitted; their general significance is still under debate.

Within this "classical picture" a kind of electric standard atmosphere may be constructed as shown in Table 1.

Values with a star, *, are rough average values from measurement. A star in parentheses, (*), points to a typical value from one or a few measurements. All other values have been calculated from starred values, under the assumption that at 2 km 50% and at 12 km 90% of the columnar resistance is reached. Voltage drop along one of the partial columns can be calculated by subtracting the value for the lower column from that of the upper one. Columnar resistances, conductances, and capacitances are valid for that particular part of the column which is indicated at the left. Capacitances are calculated with the formula for plate capacitors, and this fact must be considered also for the time constants for columns.

According to measurements, U, the potential difference between 0 m and 65 km may vary by a factor of approximately 2. The total columnar resistance, R_c, is estimated to vary up to a factor of 3, the variation being due to either reduction of conductivity in the exchange layer (about lowest 2 km of this table) or to the presence of high mountains; in both cases the variation is caused in the troposphere. Smaller variations in the stratosphere and mesosphere are being discussed because of aerosols there. The air-earth current density in fair weather varies by a factor of 3 to 6 accordingly. Conductivity near the ground varies by a factor of about 3 but only decreasing; increase of conductivity due to extraordinary radioactivity is a singular event. The field strength near the ground varies as a consequence of variations of air-earth current density and conductivity from about 1/3 to about 10 times of the value quoted in the table. Conductivity near the ground shows a diurnal and an annual variation which depends strongly on the locality: air-earth current density shows a diurnal and annual variation because the earth-ionosphere potential difference undergoes such variations, and also because the columnar resistance is supposed to have a diurnal and probably an annual variation.

Conductivities and air-earth current densities on high mountains are greater than at sea level by factors of up to 10. Conductivity decreases when atmospheric humidity increases. Values for space charges are not quoted because measurements are too few to allow calculation of average values. Values of parameters over the oceans are still rather uncertain.

Theoretically, in fair-weather conditions, Ohm's law must be fulfilled for the electric field, the conduction current density, and the electrical conductivity of the atmosphere. Deviations point to shortcomings in the applied measuring techniques. Data which are representative for a large area (in the extreme, "globally representative data", i.e. data on the global circuit), can on the ground be obtained only by stations on an open plane and only if local generators are either small or constant or are independently measured. Certain measurements with instrumented aircraft provide globally representative information valid for the period of the actual measurement.

TABLE 1
Electrical Parameters of the Clear (Fair-Weather) Atmosphere, Pertinent to the Classical Picture of Atm. Electricity (Electric Standard Atmosphere)

Part of atmosphere for which the values are calculated (elements are in free, cloudless atmosphere)	Currents, I, in A; and current densities, i, in A/m^2	Potential differences, U, in V; field strength E in V/m; U = 0 at sea level	Resistances, R, in Ω; columnar resistances, R_c, in Ω m^2 and resistivities, ρ, in Ω m	Conductances, G, in Ω^{-1}; columnar conductances G_c, in Ω^{-1} m^{-2}; total conductivities, γ, in Ω^{-1} m^{-1}	Capacitances, C, in F; columnar capacitances, C_c, in F m^{-2} and capacitivities, ε, in F m^{-1}	Time constants τ, in seconds
Volume element at about sea level, 1 m^3	$i = 3 \times 10^{-12*}$	$E_0 = 1.2 \times 10^{2*}$	$\rho_0 = 4 \times 10^{13}$	$\gamma_0 = 2.5 \times 10^{-14}$	$\varepsilon_0 = 8.9 \times 10^{-12*}$	$\tau_0 = 3.6 \times 10^2$
Lower column of 1 m^2 cross section from sea level to 2 km height	$i = 3 \times 10^{-12}$	At upper end: $U_1 = 1.8 \times 10^5$	$R_{c1} = 6 \times 10^{16}$	$G_{c1} = 1.7 \times 10^{-17}$	$C_{c1} = 4.4 \times 10^{-15}$	$\tau_{c1} = 2.6 \times 10^2$
Volume element at about 2 km height, 1 m^3	$i = 3 \times 10^{-12}$	$E_2 = 6.6 \times 10^1$	$\rho_2 = 2.2 \times 10^{13(*)}$	$\gamma_2 = 4.5 \times 10^{-14}$	$\varepsilon_2 = 8.9 \times 10^{-12}$	$\tau_2 = = 2 \times 10^2$
Center column of 1 m^2 cross section from 2 to 12 km	$i = 3 \times 10^{-12}$	At upper end: $U_m = 3.15 \times 10^5$	$R_{cm} = 4.5 \times 10^{16}$	$G_{cm} = 5 \times 10^{-17}$	$C_{cm} = 8.8 \times 10^{-16}$	$\tau_{cm} = 1.8 \times 10^1$
Volume element at about 12 km height, 1 m^3	$i = 3 \times 10^{-12}$	$E_{12} = 3.9 \times 10^0$	$\rho_{12} = 1.3 \times 10^{12(*)}$	$\gamma_{12} = 7.7 \times 10^{-13}$	$\varepsilon_{12} = 8.9 \times 10^{-12}$	$\tau_{12} = 1.2 \times 10^1$
Upper column of 1 m^2 cross section from 12 to 65 km height	$i = 3 \times 10^{-12}$	At upper end: $U_u = 3.5 \times 10^5$	$R_{cu} = 1.5 \times 10^{16}$	$G_{cu} = 2.5 \times 10^{-17}$	$C_{cu} = 1.67 \times 10^{-16}$	$\tau_{cm} = 6.7 \times 10^0$
Whole column of 1 m^2 cross section from 0 to 65 km height	$i = 3 \times 10^{-12}$	At upper end: $U = 3.5 \times 10^5$	$R_c = 1.2 \times 10^{17}$	$G_c = 8.3 \times 10^{-18}$	$C_c = 1.36 \times 10^{-16}$	$\tau_c = 1.64 \times 10^1$
Total spherical capacitor area: 5×10^{14} m^2	$1 = 1.5 \times 10^3$	$U = 3.5 \times 10^{5*}$	$R = 2.4 \times 10^2$	$G = 4.2 \times 10^{-3}$	$C = 6.8 \times 10^{-2}$	$\tau = 1.64 \times 10^1$

Note: All currents and fields listed are part of the global circuit, i.e., circuits of local generators are not included. Values are subject to variations due to latitude and altitude of the point of observation above sea level, locality with respect to sources of disturbances, meteorological and climatological factors, and man-made changes. For more explanations, see text.

II. AIR IONS

Hannes Tammet

The term " air ions" signifies all airborne particles which are the carriers of the electrical current in the air and have drift velocities determined by the electric field.

The probability of electrical dissociation of molecules in the atmospheric air under thermodynamic equilibrium is near to zero. The average ionization at the ground level over the ocean is $2 \cdot 10^6$ ion pairs $m^{-3}s^{-1}$. This ionization is produced mainly by cosmic rays. Over the continents the ionizing radiation from soil and from radioactive substances in the air each add about $4 \cdot 10^6$ $m^{-3}s^{-1}$. The total average ionization rate of 10^7 $m^{-3}s^{-1}$ is equivalent to 17 μR/h which is a customary expression of the background level of the ionizing radiations. The ionization rate over the ground varies in space due to the radioactivity of soil, and in time depending on the exchange of air between the atmosphere and radon-containing soil. Radioactive pollution increases the ionization rate. A temporary increase of about 10 times was registered in Sweden after the Chernobyl accident in 1986. The emission of Kr^{85} from nuclear power plants can noticeably increase the global ionization rate in the next century. The ionization rate decreases with altitude near the ground and increases at higher altitudes up to 15 km, where it has a maximum about $5 \cdot 10^7$ $m^{-3}s^{-1}$. Solar X-ray and extreme UV radiation cause a new increase at altitudes over 60 km.

Local sources of air ions are point discharges in strong electric fields, fluidization of charged drops from waves, etc.

The enhanced chemical activity of an ion results in a chain of ion-molecule reactions with the colliding neutrals, and, in the first microsecond of the life of an air ion, a charged molecular cluster called the *cluster ion* is formed. According to theoretical calculations in the air free from exotic trace gases the following cluster ions should be dominant:

$$NO_3^- \cdot (HNO_3) \cdot H_2O,\ NO_2^- \cdot (H_2O)_2,\ NO_3^- \cdot H_2O,\ O_2^- \cdot (H_2O)_4,\ O_2^- \cdot (H_2O)_5,$$
$$H_3O^+ \cdot (H_2O)_6,\ NH_4^+ \cdot (H_2O)_2,\ NH_4^+ \cdot (H_2O),\ H_3O^+ \cdot (H_2O)_5,\ NH_4^+ \cdot NH_3$$

A measurable parameter of air ions is the electrical mobility *k*, characterizing the drift velocity in the unit electric field. The mobility is inversely proportional to the density of air, and the results of measurements are as a rule reduced to normal conditions. According to mobility the air ions are called: fast or small or light ions with mobility $k > 5 \cdot 10^{-5}$ $m^2V^{-1}s^{-1}$, intermediate ions, and slow or large or heavy ions with mobility $k < 10^{-6}$ $m^2V^{-1}s^{-1}$. The boundary between intermediate and slow ions is conventional.

Cluster ions are fast ions. The masses of cluster ions may be measured with mass spectrometers, but the possible ion-molecule reactions during the passage of the air through nozzles to the vacuum chamber complicate the measurement. Mass and mobility of cluster ions are highly correlated. The experimental results[5] can be expressed by the empirical formula

$$m \approx \frac{850\ \mathrm{u}}{\left[0.3 + k/\left(10^{-4}\mathrm{m}^2\mathrm{V}^{-1}\mathrm{s}^{-1}\right)\right]^3}$$

where u is the unified atomic mass unit.

The value of the transport cross-section of a cluster ion is needed to calculate its mobility according to the kinetic theory of Chapman and Enskog. The theoretical estimation of transport cross-sections is rough and cannot be used to identify the chemical structures of cluster ions. Mass spectrometry is the main technique of identification of cluster ions.[2]

Märk and Castleman (1986) presented an overview of over 1000 publications on the experimental studies of cluster ions. Most of them present information about ions of millisecond age range. The low concentration makes it difficult to get detailed information about masses and mobilities of the natural atmospheric ions at ground level. The results of a 1-year continuous measurement[6] are as follows:

	+ ions	- ions	unit
Average mobility	1.36	1.56	10^{-4} $m^2V^{-1}s^{-1}$
The corresponding mass	190	130	u
The corresponding diameter	0.69	0.61	nm
The average concentration	400	360	10^6 m^{-3}
The corresponding conductivity	8.7	9.0	fS

The distribution of tropospheric cluster ions according to the mobility and estimated mass is depicted in Figure 1.

The problems and results of direct mass spectrometry of natural cluster ions are analysed by Eisele (1986) for ground level and by Meyerott, Reagan and Joiner (1980) for stratospheric measurements. Air ions in the high atmosphere are a subject of ionospheric physics.

During its lifetime (about 1 min), a cluster ion at ground level collides with nearly 10^{12} molecules. Thus the cluster ions are able to concentrate trace gases of very low concentration if they have an extra high electron or proton affinity. For example, Eisele (1986) demonstrated that a considerable fraction of positive atmospheric cluster ions in the unpolluted atmosphere at ground level probably consist of a molecule derived from pyridine. The concentration of these constituents is estimated to be about 10^{-12}. Therefore, air-ion mass and mobility spectrometry is considered as a promising technique for trace analysis in the air. Mass and mobility spectrometry of millisecond-age air ions has been developed as a technique of chemical analysis known as "plasma chromatography" (Carr, 1984). The sensitivity of the detection grows with the age of the cluster ions measured.

The mechanisms of annihilation of cluster ions are ion-ion recombination (on the average 3%) and sedimentation on aerosol particles (on the average 97% of cluster ions at ground level). The result of the combination of a cluster ion and neutral particle is a charged particle called an *aerosol ion*. In conditions of detailed thermodynamic equilibrium the probability that a spherical particle of diameter *d* carries *q* elementary charges is calculated from the Boltzmann distribution:

$$p_q(d) = (2\pi d/d_0)^{1/2} \exp(-q^2 d_0/2d)$$

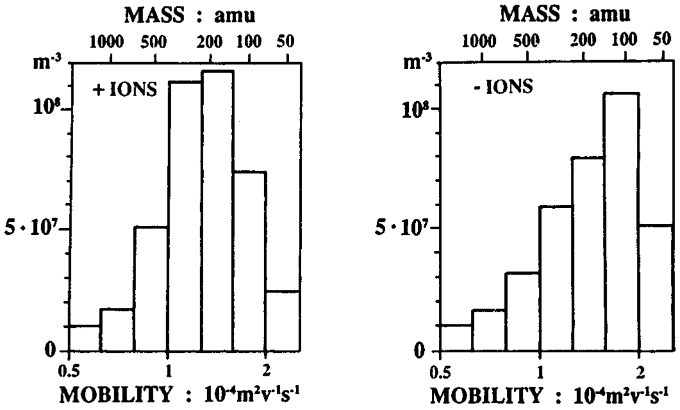


Figure 1. Average mobility and mass spectra of natural tropospheric cluster ions. Concentrations of the mobility fractions were measured in a rural site every 5 min over 1 year.[6] Ion mass is estimated according to the above empirical formula.

where d_0 = 115 nm (at 18°C). The supposition about the detailed equilibrium is an approximation and the formula is not valid for particles less than d_0. On the basis of numerical calculations by Hoppel and Frick (1990) the following charge probabilities can be derived:

d	3	10	30	100	300	1000	3000	nm
p_0	98	90	70	42	24	14	8	%
$p_{-1}+p_1$	2	10	30	48	41	25	15	%
$p_{-2}+p_2$	0	0	0	10	23	21	14	%
$p_{q>2}$	0	0	0	0	12	40	63	%
k_1	15000	1900	250	28	5.1	1.11	0.33	$10^{-9}m^2V^{-1}s^{-1}$

The last line of the table presents the mobility of a particle carrying one elementary charge. The distribution of the atmospheric aerosol ions over mobility is demonstrated in Figure 2.

Although the concentration of aerosol in continental air at ground level is an order of magnitude higher than the concentration of cluster ions, the mobilities of aerosol ions are so small that their percentage in air conductivity is less than 1%.

A specific class of aerosol ions are condensed aerosol ions produced as a result of the condensation of gaseous matter on the cluster ions. In aerosol physics the process is called ion-induced nucleation; it is considered as one among the processes of gas-to-particle conversion. The condensed aerosol ions have an inherent charge. Their sizes and mobilities are between the sizes and mobilities of cluster ions and of ordinary aerosol ions. Water and standard constituents of atmospheric air are not able to condense on the cluster ions in the real atmosphere. Thus the concentration of condensed aerosol ions depends on the trace constituents in the air and is very low in unpolluted air. Knowledge about condensed aerosol ions is poor because of measurement difficulties.

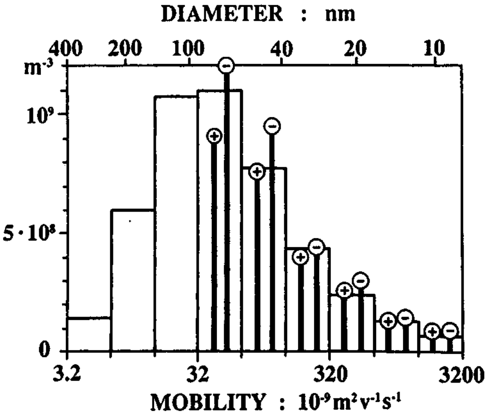


Figure 2. Mobility and size spectra of tropospheric aerosol ions.[6] The wide bars mark the fraction concentrations theoretically estimated on the basis of the standard size distribution of tropospheric aerosol. The pin bars with head + and - mark average values of positive and negative aerosol ion fraction concentrations measured in a rural site every 5 min during 4 months.

REFERENCES

1. Carr, T. W., Ed., *Plasma Chromatography*, Plenum Press, New York and London, XII + 259 pp., 1984.
2. Eisele, F. L., Identification of Tropospheric Ions, *J. Geophys. Res.*, vol. 91, no. D7, pp. 7897-7906, 1986.

3. Hoppel, W. A., and Frick, G. M., The Nonequilibrium Character of the Aerosol Charge Distributions Produced by Neutralizers, *Aerosol Sci. Technol.*, vol. 12, no. 3, pp. 471-496, 1990.
4. Mark, T. D., and Castleman, A. W., Experimental Studies on Cluster Ions, in *Advances in Atomic and Molecular Physics*, vol. 20, pp. 65.-172, Academic Press, 1985.
5. Meyerott, R. E., Reagan, J. B., and Joiner, R. G., The Mobility and Concentration of Ions and the Ionic Conductivity in the Lower Stratosphere, *J. Geophys. Res.*, vol. 85, no. A3, pp. 1273-1278, 1980.
6. Salm, J., Tammet, H., Iher, H., and Hörrak, U., Atmospheric Electrical Measurements in Tahkuse, Estonia (in Russian), in *Voprosy Atmosfernogo Elektrichestva*, pp. 168-175, Gidrometeoizdat, Leningrad, 1990.

III. THUNDERSTORM ELECTRICITY

John Latham

The development of improved radar techniques and instruments for in-cloud electrical and physical measurements, coupled with a much clearer recognition by the research community that establishment of the mechanism or mechanisms responsible for electric field development in thunderclouds, culminating in lightning, is inextricably linked to the concomitant dynamical and microphysical evolution of the clouds, has led to significant progress over the past decade.

Field studies indicate that in most thunderclouds the electrical development is associated with the process of glaciation, which can occur in a variety of incompletely understood ways. In the absence of ice, field growth is slow, individual hydrometeor charges are low, and lightning is produced only rarely. Precipitation — in the solid form, as graupel — also appears to be a necessary ingredient for significant electrification, as does significant convective activity and mixing between the clouds and their environments, via entrainment.

Increasingly, the view is being accepted that charge transfer leading to field-growth is largely a consequence of rebounding collisions between graupel pellets and smaller vapor-grown ice crystals, followed by the separation under gravity of these two types of hydrometeor. These collisions occur predominantly within the temperature range -15 to -30°C, and for significant charge transfer need to occur in the presence of supercooled cloud droplets.

The field evidence is inconsistent with an inductive mechanism, and extensive laboratory studies indicate that the principal charging mechanism is non-inductive and associated — in ways yet to be identified — with differences in surface characteristics of the interacting hydrometeors.

Laboratory studies indicate that the two most favored sites for corona emission leading to the lightning discharge are the tips of ephemeral liquid filaments, produced during the glancing collisions of supercooled raindrops, and protuberances on large ice crystals or graupel pellets. The relative importance of these alternatives will depend on the hydrometeor characteristics and the temperature in the regions of strongest fields; these features are themselves dependent on air-mass characteristics and climatological considerations.

A recently identified but unresolved question is why, in continental Northern Hemisphere thunderclouds at least, the sign of the charge brought to ground by lightning is predominantly negative in summer but more evenly balanced in winter.

IV. LIGHTNING

Martin A. Uman

From both ground-based weather-station data and satellite measurements, it has been estimated that there are about 100 lightning discharges, both cloud and ground flashes, over the whole earth each second; representing an average global lightning flash density of about 6 $km^{-2}yr^{-1}$. Most of this lightning occurs over the earth's land masses. For example, in central Florida, where thunderstorms occur about 90 days/yr, the flash density for discharges to earth is about 15 $km^{-2}yr^{-1}$. Some tropical areas of the earth have thunderstorms up to 300 days/yr.

Lightning can be defined as a transient, high-current electric discharge whose path length is measured in kilometers and whose most common source is the electric charge separated in the ordinary thunderstorm or cumulonimbus cloud. Well over half of all lightning discharges occur totally within individual thunderstorm clouds and are referred to as intracloud discharges. Cloud-to-ground lightning, however, has been studied more extensively than any other lightning form because of its visibility and its more practical interest. Cloud-to-cloud and cloud-to-air discharges are less common than intracloud or cloud-to-ground lightning.

Lightning between the cloud and earth can be categorized in terms of the direction of motion, upward or downward, and the sign of the charge, positive or negative, of the developing discharge (called a *leader*) which initiates the overall event. Over 90% of the worldwide cloud-to-ground discharges is initiated in the thundercloud by downward-moving negatively-charged leaders and subsequently results in the lowering of negative charge to earth. Cloud-to-ground lightning can also be initiated by downward-moving positive leaders, less than 10% of the worldwide cloud-to-ground lightning being of this type although the exact percentage is a function of season and latitude. Lightning between cloud and ground can also be initiated by leaders which develop upward from the earth. These upward-initiated discharges are relatively rare, may be of either polarity, and generally occur from mountaintops and tall man-made structures.

We discuss next the most common type of cloud-to-ground lightning. A negative cloud-to-ground discharge or *flash* has an overall duration of some tenths of a second and is made up of various components, among which are typically three or four high-current pulses called *strokes*. Each stroke lasts about a millisecond, the separation time between strokes being typically several tens of milliseconds. Such lightning often appears to "flicker" because the human eye can just resolve the individual light pulse associated with each stroke. A drawing of the components of a negative cloud-to-ground flash is found in Figure 3. Some values for salient parameters are found in Table 1. The negatively-charged *stepped leader* initiates the first stroke in a flash by propagating from cloud to ground through virgin air in a series of discrete steps. Photographically observed leader steps in clear

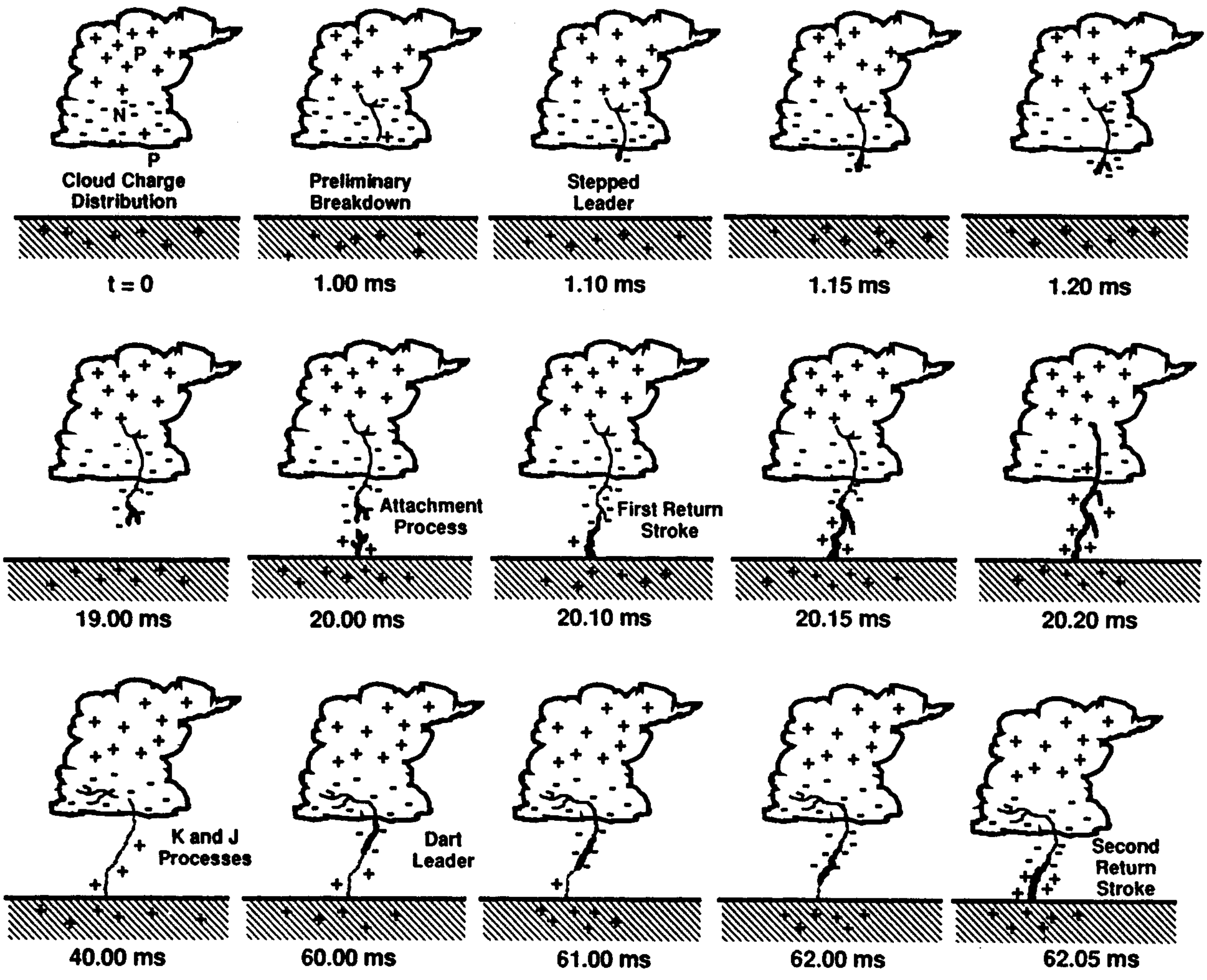


Figure 3. Sequence of steps in cloud-to-ground lightning.

air are typically 1 μs in duration and tens of meters in length, with a pause time between steps of about 50 μs. A fully developed stepped leader lowers up to 10 or more coulombs of negative cloud charge toward ground in tens of milliseconds with an average downward speed of about 2×10^5 m/s. The average leader current is in the 100 to 1000 A range. The steps have pulse currents of at least 1 kA. Associated with these currents are electric- and magnetic-field pulses with widths of about 1 μs or less and risetimes of about 0.1 μs or less. The stepped leader, during its trip toward ground, branches in a downward direction, resulting in the characteristic downward-branched geometrical structure commonly observed. The electric potential of the bottom of the negatively-charged leader channel with respect to ground has a magnitude in excess of 10^7 V. As the leader tip nears ground, the electric field at sharp objects on the ground or at irregularities of the ground itself exceeds the breakdown value of air, and one or more upward-moving discharges (often called upward leaders) are initiated from those points, thus beginning the *attachment process*. An understanding of the physics of the attachment process is central to an understanding of the operation of lightning protection of ground-based objects and the effects of lightning on humans and animals, since it is the attachment process that determines where the lightning connects to objects on the ground and the value of the early currents which flow. When one of the upward-moving discharges from the ground (or from a lightning rod or an individual) contacts the tip of the downward-moving stepped leader, typically some tens of meters above the ground, the leader tip is effectively connected to ground potential. The negatively-charged leader channel is then discharged to earth when a ground potential wave, referred to as the first *return stroke*, propagates continuously up the leader path. The upward speed of a return stroke near the ground is typically near one third the speed of light, and the speed decreases with height. The first return stroke produces a peak current near ground of typically 30 kA, with a time from zero to peak of a few microseconds. Currents measured at the ground fall to half of the peak value in about 50 μs, and currents of the order of hundreds of amperes may flow for times of a few milliseconds up to several hundred milliseconds. The longer-lasting currents are known as *continuing currents*. The rapid release of return stroke energy heats the leader channel to a temperature near 30,000 K and creates a high-pressure channel which expands and generates the shock waves that eventually become thunder, as further discussed later. The return stroke effectively lowers to ground the charge originally deposited onto the stepped-

leader channel and additionally initiates the lowering of other charge which may be available to the top of its channel. First return-stroke electric fields exhibit a microsecond scale rise to peak with a typical peak value of 5 V/m, normalized to a distance of 100 km by an inverse distance relationship. Roughly half of the field rise to peak, the so-called "fast transition", takes place in tenths of a microsecond, an observation that can only be made if the field propagation is over a highly conducting surface such as salt water.

After the first return-stroke current has ceased to flow, the flash, including charge motion in the cloud, may end. The lightning is then called a single-stroke flash. On the other hand, if additional charge is made available to the top of the channel, a continuous or *dart leader* may propagate down the residual first-stroke channel at a typical speed of about 1×10^7 m/s. The dart leader lowers a charge of the order of 1 C by virtue of a current of about 1 kA. The dart leader then initiates the second (or any subsequent) return stroke. Subsequent return-stroke currents generally have faster zero-to-peak rise times than do first-stroke currents, but similar maximum rates of change, about 100 kA/μs. Some leaders begin as dart leaders, but toward the end of their trip toward ground become stepped leaders. These leaders are known as *dart-stepped leaders* and may have different ground termination points (and separate upward leaders) from the first stroke. Most often the dart-stepped leaders are associated with the second stroke of the flash. Nearly half of all flashes exhibit more than one termination point on ground with the distance between separate terminations being up to several kilometers. Subsequent return-stroke radiated electric and magnetic fields are similar to, but usually a factor of two or so smaller, than first return-stroke fields. About one third of all multiple-stroke flashes has at least one subsequent stroke which is larger than the first stroke.

Cloud-to-ground flashes that lower positive charge, though not common, are of considerable practical interest because their peak currents and total charge transfer can be much larger than for the more common negative ground flash. The largest recorded peak currents, those in the 200- to 300-kA range, are due to the return strokes of positive lightning. Such positive flashes to ground are initiated by downward-moving leaders which do not exhibit the distinct steps of their negative counterparts. Rather, they show a luminosity which is more or less continuous but modulated in intensity. Positive flashes are generally composed of a single stroke followed by a period of continuing current. Positive flashes are probably initiated from the upper positive charge in the thundercloud charge dipole when that cloud charge is horizontally separated from the negative charge beneath it, the source of the usual negative cloud-to-ground lightning. Positive flashes are relatively common in winter thunderstorms (snow storms), which produce few flashes overall, and are relatively uncommon in summer thunderstorms. The fraction of positive lightning in summer thunderstorms apparently increases with increasing latitude and with increasing height of the ground above sea level.

Distant lightning return stroke fields are often referred to as sferics (called "atmospherics" in the older literature). The peak in the sferics frequency spectrum is near 5 kHz due to the bipolar or ringing nature of the distant return-stroke electromagnetic signal and to the effects of propagation.

Thunder, the acoustic radiation associated with lightning, is sometimes divided into the categories "audible", sounds that one can hear, and "infrasonic", below a few tens of hertz, a frequency range that is inaudible. This division is made because it is thought that the mechanisms that produce audible and infrasonic thunder are different. Audible thunder is thought to be due to the expansion of a rapidly heated return stroke channel, as noted earlier, whereas infrasonic thunder is thought to be associated with the conversion to sound of the energy stored in the electrostatic field of the thundercloud when lightning rapidly reduces that cloud field.

The technology of artificially initiating lightning by firing upward small rocket trailing grounded wire of a few hundred meters length has been well-developed during the past decade. Such "triggered" flashes are similar to natural upward-initiated discharges from tall structure. They often contain subsequent strokes which, when they occur, are similar to the subsequent strokes in natural lightning. These triggered subsequent strokes have been the subject of considerable recent research.

Also in the past 10 years or so sophisticated lightning locating equipment has been installed throughout the world. For example, all ground flashes in the U.S. are now centrally monitored for research, for better overall weather prediction, and for hazard warning for aviation, electric utilities and other lightning-sensitive facilities.

Information on lightning physics can be found in M. A. Uman, *The Lightning Discharge*, Academic Press, San Diego, 1987; on lightning death and injury in *Medical Aspects of Lightning Injury*, editors C. Andrews, M. A. Cooper, M. Darveniza, and D. Mackerras, CRC Press, 1992. Ground flash location information for the U.S., in real time or archived, is available from Geomet Data Service of Tucson, AZ, which is also a source of the names of providers of those data in other countries.

Table 2 has data for cloud-to-ground lightning discharges bringing negative charge to earth. The values listed are intended to convey a rough feeling for the various physical parameters of lightning. No great accuracy is claimed since the results of different investigators are often not in good agreement. These values may, in fact, depend on the particular environment in which the lightning discharge is generated. The choice of some of the entries in the table is arbitrary.

TABLE 2
Data for Cloud-to-Ground Lightning Discharges

	Minimum[a]	Representative values	Maximum[a]
Stepped leader			
Length of step, m	3	50	200
Time interval between steps, μs	30	50	125
Average speed of propagation of stepped leader, m/s[b]	1.0×10^5	2.0×10^5	3.0×10^6
Charged deposited on stepped-leader channel, coulombs	3	5	20
Dart leader			
Speed of propagation, m/s[b]	1.0×10^6	1.0×10^7	2.4×10^7
Charged deposited on dart-leader channel, coulombs	0.2	1	6
Return stroke[c]			
Speed of propagation, m/s[b]	2.0×10^7	1.0×10^8	2.0×10^8
Maximum current rate of increase, kA/μs	<1	100	400
Time to peak current, μs	<1	2	30
Peak current, kA	2	30	200
Time to half of peak current, μs	10	50	250
Charge transferred excluding continuing current, coulombs	0.02	3	20
Channel length, km	2	5	15
Lightning flash			
Number of strokes per flash	1	4	26
Time interval between strokes in absence of continuing current, ms	3	60	100
Time duration of flash, s	10^{-2}	0.5	2
Charge transferred including continuing current, coulombs	3	30	200

[a] The words maximum and minimum are used in the sense that most measured values fall between these limits.

[b] Speeds of propagation are generally determined from photographic data and are "two-dimensional". Since many lightning flashes are not vertical, values stated are probably slight underestimates of actual values.

[c] First return strokes have longer times to current peak and generally larger charge transfer than do subsequent return strokes.

Adapted from Uman, M. A., *Lightning*, Dover Paperbook, New York, 1986, and Uman, M. A., *The Lightning Discharge*, Academic Press, San Diego, 1987.

SPEED OF SOUND IN VARIOUS MEDIA

The speed of sound in various solids, liquids, and gases is given in these tables. While only a single parameter v is needed for liquids and gases, sound propagation in isotropic solids is characterized by three velocity parameters. For a solid of infinite extent (or of finite extent if all dimensions are much larger than a wavelength, there are two relevant quantities,

v_1: velocity of longitudinal waves
v_s: velocity of shear waves.

For a cylindrical rod with diameter much smaller than a wavelength,

v_{ext}: velocity of extensional waves along the rod. (Torsional waves in the rod are propagated at the same speed as sheer waves in an infinite solid.)

Table 1 lists values for a variety of solid materials. Table 2 covers gases liquids and gases; values for cryogenic liquids are given at the normal boiling point. Table 3 gives the speed of sound in pure water and in seawater of salinity $S = 3.5\%$ as a function of temperature. All values are in meters per second and are given for normal atmospheric pressure.

REFERENCES

1. Gray, D.E., Ed., *American Institute of Physics Handbook, Third Edition*, McGraw Hill, New York, 1972.
2. Anderson, H.L., Ed., *A Physicist's Desk Reference*, American Institute of Physics, New York, 1989.
3. Younglove, B.A., *Thermophysical Proeprties of Fluids. Part I, J. Phys. Chem. Ref. Data,* 11, Suppl. 1, 1982.
4. Younglove, B.A., and Ely, J.F., *Thermophysical Properties of Fluids. Part II, J. Phys. Chem. Ref. Data*, 16, 577, 1987.
5. Haar, L., Gallagher, J.S., and Kell, G.S., *NBS/NRC Steam Tables,* Hemisphere Publishing Corp., New York, 1984.
6. Mason, W.P., *Physical Acoustics and the Properties of Solids*, D. Van Nostrand Co., Princeton, N.J., 1958.
7. *Landolt-Börnstein, Numerical Data and Functional Relationships in Science and Technology, New Series, II/5, Molecular Acoustics,* Springer-Verlag, Heidelberg, 1967.

TABLE 1
Speed of Sound in Solids at Room Temperature

Name	v_1/m s^{-1}	v_s/m s^{-1}	v_{ext}/m s^{-1}
Metals			
Aluminum, rolled	6420	3040	5000
Berylium	12890	8880	12870
Brass (70 Cu, 30 Zn)	4700	2110	3480
Constantan	5177	2625	4270
Copper, annealed	4760	2325	3810
Copper, rolled	5010	2270	3750
Duralumin 17S	6320	3130	5150
Gold, hard-drawn	3240	1200	2030
Iron, cast	4994	2809	4480
Iron, electrolytic	5950	3240	5120
Iron, Armco	5960	3240	5200
Lead, annealed	2160	700	1190
Lead, rolled	1960	690	1210
Magnesium, annealed	5770	3050	4940
Molybdenum	6250	3350	5400
Monel metal	5350	2720	4400
Nickel	6040	3000	4900
Platinum	3260	1730	2800
Silver	3650	1610	2680
Steel (1% C)	5940	3220	5180
Steel, 347 Stainless	5790	3100	5000
Steel, K9	5940	3250	5250
Tin, rolled	3320	1670	2730
Titanium	6070	3125	5090
Tungsten, annealed	5220	2890	4620
Tungsten, drawn	5410	2640	4320
Zinc, rolled	4210	2440	3850
Other materials			
Fused silica	5968	3764	5760
Glass, heavy silicate flint	3980	2380	3720
Glass, light borate crown	5100	2840	4540
Glass, pyrex	5640	3280	5170
Lucite	2680	1100	1840
Nylon 6-6	2620	1070	1800
Polyethylene	1950	540	920
Polystyrene	2350	1120	1840
Rubber, butyl	1830		
Rubber, gum	1550		
Rubber, neoprene	1600		
Tungsten carbide	6655	3980	6220

TABLE 2
Speed of Sound in Liquids and Gases

Name	t/°C	v/m s^{-1}
Liquids		
Acetone	20	1203
Argon	-185.9	813
Benzene	25	1310
Bromobenzene	20	1169
Butane	-0.5	1034
1-Butanol	20	1258
Carbon disulphide	25	1140
Chlorobenzene	20	1311
Cyclohexane	19	1280
1-Decene	20	1250
Diethyl ether	25	976
Ethane	-88.6	1326
Ethanol	20	1162
Ethylene	-103.8	1309
Ethylene glycol	25	1658
Fluorobenzene	20	1183
Glycerol	25	1904
Helium	-268.9	180
Heptane	20	1162
1-Heptene	20	1128
Hexane	20	1083
Hydrogen	-252.9	1101
Iodobenzene	20	1114
Mercury	25	1450
Methane	-161.5	1337
Methanol	20	1121
Nitrobenzene	25	1463
Nitrogen	-195.8	939
1-Nonene	20	1218
Octane	20	1197
1-Octene	20	1184
Oxygen	-183.0	906
1-Pentadecene	20	1351
Pentane	20	1008
Propane	-42.1	1158
1-Propanol	20	1223
Tetrachloromethane	25	930
Trichloromethane	25	987
1-Undecene	20	1275
Water	25	1497
Water (sea, *S* = 3.5%)	25	1535
Gases at 1 atm		
Air, dry	25	346
Ammonia	0	415
Argon	27	323
Carbon monoxide	0	338
Carbon dioxide	0	259
Chlorine	0	206
Deuterium	0	890
Ethane	27	312
Ethylene	27	331
Helium	0	965
Hydrogen	27	1310
Hydrogen bromide	0	200
Hydrogen chloride	0	296
Hydrogen iodide	0	157
Hydrogen sulfide	0	289
Methane	27	450
Neon	0	435
Nitric oxide	10	325
Nitrogen	27	353
Nitrous oxide	0	263
Oxygen	27	330
Sulfur dioxide	0	213
Water (steam)	100	473

TABLE 3
Speed of Sound in Water and Seawater (S = 3.5%) at Different Temperatures

	v/m s^{-1}	
t/°C	Water	Seawater
0	1401.0	1449.4
10	1447.8	1490.4
20	1483.2	1522.2
25	1497.4	1535.1
30	1509.5	1546.2
40	1528.4	
50	1541.4	
60	1549.5	
70	1553.2	
80	1552.8	

ATTENUATION AND SPEED OF SOUND IN AIR AS A FUNCTION OF HUMIDITY AND FREQUENCY

This table gives the attenuation and speed of sound as a function of frequency at various values of relative humidity. All values refer to still air at 20°C.

REFERENCES

1. Tables of Absorption and Velocity of Sound in Still Air at 68°F (20°C), AD-738576, National Technical Information Service, Springfield, VA.
2. Evans, L. B., Bass, H. E., and Sutherland, L. C., *J. Acoust. Soc. Am.*, 51, 1565, 1972.

Frequency (Hz)	Attenuation (dB/km)	Speed (m/s)
Relative humidity 0%		
20	0.51	343.477
40	1.07	343.514
50	1.26	343.525
63	1.43	343.536
100	1.67	343.550
200	1.84	343.559
400	1.96	343.561
630	2.11	343.562
800	2.27	343.562
1250	2.82	343.562
2000	4.14	343.562
4000	8.84	343.564
6300	14.89	343.565
10000	26.28	343.566
12500	35.81	343.566
16000	52.15	343.567
20000	75.37	343.567
40000	267.01	343.567
63000	644.66	343.567
80000	1032.14	343.567
Relative humidity 30%		
20	0.03	343.807
40	0.11	343.808
50	0.17	343.810
63	0.25	343.810
100	0.50	343.814
200	1.01	343.821
400	1.59	343.826
630	2.24	343.827
800	2.85	343.828
1250	5.09	343.828
2000	10.93	343.829
4000	38.89	343.831
6300	90.61	343.836
10000	204.98	343.846
12500	294.08	343.854
16000	422.51	343.865
20000	563.66	343.877
40000	1110.97	343.911
63000	1639.47	343.924
80000	2083.08	343.929

Frequency (Hz)	Attenuation (dB/km)	Speed (m/s)
Relative humidity 60%		
20	0.02	344.182
40	0.06	344.183
50	0.09	344.183
63	0.15	344.184
100	0.34	344.185
200	0.99	344.190
400	1.94	344.197
630	2.57	344.200
800	2.94	344.201
1250	4.01	344.202
2000	6.55	344.203
4000	18.73	344.204
6300	42.51	344.204
10000	101.84	344.206
12500	155.67	344.208
16000	247.78	344.211
20000	373.78	344.215
40000	1195.37	344.238
63000	2220.64	344.262
80000	2951.71	344.274
Relative humidity 100%		
20	0.01	344.685
40	0.04	344.685
50	0.06	344.685
63	0.09	344.685
100	0.22	344.686
200	0.77	344.689
400	2.02	344.695
630	3.05	344.699
800	3.57	344.701
1250	4.59	344.704
2000	6.29	344.705
4000	13.58	344.706
6300	27.72	344.706
10000	63.49	344.706
12500	96.63	344.707
16000	154.90	344.708
20000	237.93	344.709
40000	884.28	344.718
63000	1973.62	344.731
80000	2913.01	344.742

SPEED OF SOUND IN DRY AIR

The values in this table were calculated from the equation of state for dry air (average molecular weight 28.96) treated as a real gas. Values refer to standard atmospheric pressure. The speed of sound varies only slightly with pressure; at two atmospheres and -100°C the value decreases by 0.13%, while at two atmospheres and 80°C the speed increases by 0.04%.

REFERENCE

Sytchev, V.V., Vasserman, A.A., Kozlov, A.D., Spiridonov, G.A., and Tsymarny, V.A., *Thermodynamic Properties of Air*, Hemisphere Publishing Corp., New York, 1987.

t/°C	v_s/m s^{-1}	t/°C	v_s/m s^{-1}	t/°C	v_s/m s^{-1}
-100	263.5	-35	309.5	30	349.1
-95	267.3	-30	312.7	35	352.0
-90	271.1	-25	315.9	40	354.8
-85	274.8	-20	319.1	45	357.6
-80	278.5	-15	322.3	50	360.4
-75	282.1	-10	325.4	55	363.2
-70	285.7	-5	328.4	60	365.9
-65	289.2	0	331.5	65	368.6
-60	292.7	5	334.5	70	371.3
-55	296.1	10	337.5	75	374.0
-50	299.5	15	340.4	80	376.7
-45	302.9	20	343.4		
-40	306.2	25	346.3		

MUSICAL SCALES

EQUAL TEMPERED CHROMATIC SCALE
A_4 = 440 Hz

American Standard pitch. Adopted by the American Standards Association in 1936

Note	Frequency	Note	Frequency	Note	Frequency	Note	Frequency
C_0	16.35	C_2	65.41	C_4	261.63	C_6	1046.50
$C\#_0$	17.32	$C\#_2$	69.30	$C\#_4$	277.18	$C\#_6$	1108.73
D_0	18.35	D_2	73.42	D_4	293.66	D_6	1174.66
$D\#_0$	19.45	$D\#_2$	77.78	$D\#_4$	311.13	$D\#_6$	1244.51
E_0	20.60	E_2	82.41	E_4	329.63	E_6	1318.51
F_0	21.83	F_2	87.31	F_4	349.23	F_6	1396.91
$F\#_0$	23.12	$F\#_2$	92.50	$F\#_4$	369.99	$F\#_6$	1479.98
G_0	24.50	G_2	98.00	G_4	392.00	G_6	1567.98
$G\#_0$	25.96	$G\#_2$	103.83	$G\#_4$	415.30	$G\#_6$	1661.22
A_0	27.50	A_2	110.00	A_4	440.00	A_6	1760.00
$A\#_0$	29.14	$A\#_2$	116.54	$A\#_4$	466.16	$A\#_6$	1864.66
B_0	30.87	B_2	123.47	B_4	493.88	B_6	1975.53
C_1	32.70	C_3	130.81	C_5	523.25	C_7	2093.00
$C\#_1$	34.65	$C\#_3$	138.59	$C\#_5$	554.37	$C\#_7$	2217.46
D_1	36.71	D_3	146.83	D_5	587.33	D_7	2349.32
$D\#_1$	38.89	$D\#_3$	155.56	$D\#_5$	622.25	$D\#_7$	2489.02
E_1	41.20	E_3	164.81	E_5	659.26	E_7	2637.02
F_1	43.65	F_3	174.61	F_5	698.46	F_7	2793.83
$F\#_1$	46.25	$F\#_3$	185.00	$F\#_5$	739.99	$F\#_7$	2959.96
G_1	49.00	G_3	196.00	G_5	783.99	G_7	3135.96
$G\#_1$	51.91	$G\#_3$	207.65	$G\#_5$	830.61	$G\#_7$	3322.44
A_1	55.00	A_3	220.00	A_5	880.00	A_7	3520.00
$A\#_1$	58.27	$A\#_3$	233.08	$A\#_5$	932.33	$A\#_7$	3729.31
B_1	61.74	B_3	246.94	B_5	987.77	B_7	3951.07
						C_8	4186.01

EQUAL TEMPERED CHROMATIC SCALE
A_4 = 435 Hz

International Pitch, adopted 1891

Note	Frequency	Note	Frequency	Note	Frequency	Note	Frequency
C_0	16.17	C_2	64.66	C_4	258.65	C_6	1034.61
$C\#_0$	17.13	$C\#_2$	68.51	$C\#_4$	274.03	$C\#_6$	1096.13
D_0	18.15	D_2	72.58	D_4	290.33	D_6	1161.31

$D\#_0$	19.22	$D\#_2$	76.90	$D\#_4$	307.59	$D\#_6$	1230.37
E_0	20.37	E_2	81.47	E_4	325.88	E_6	1303.53
F_0	21.58	F_2	86.31	F_4	345.26	F_6	1381.04
$F\#_0$	22.86	$F\#_2$	91.45	$F\#_4$	365.79	$F\#_6$	1463.16
G_0	24.22	G_2	96.89	G_4	387.54	G_6	1550.16
$G\#_0$	25.66	$G\#_2$	102.65	$G\#_4$	410.59	$G\#_6$	1642.34
A_0	27.19	A_2	108.75	A_4	435.00	A_6	1740.00
$A\#_0$	28.80	$A\#_2$	115.22	$A\#_4$	460.87	$A\#_6$	1843.47
B_0	30.52	B_2	122.07	B_4	488.27	B_6	1953.08
C_1	32.33	C_3	129.33	C_5	517.31	C_7	2069.22
$C\#_1$	34.25	$C\#_3$	137.02	$C\#_5$	548.07	$C\#_7$	2192.26
D_1	36.29	D_3	145.16	D_5	580.66	D_7	2322.62
$D\#_1$	38.45	$D\#_3$	153.80	$D\#_5$	615.18	$D\#_7$	2460.73
E_1	40.74	E_3	162.94	E_5	651.76	E_7	2607.05
F_1	43.16	F_3	172.63	F_5	690.52	F_7	2762.08
$F\#_1$	45.72	$F\#_3$	182.89	$F\#_5$	731.58	$F\#_7$	2926.32
G_1	48.44	G_3	193.77	G_5	775.08	G_7	3100.33
$G\#_1$	51.32	$G\#_3$	205.29	$G\#_5$	821.17	$G\#_7$	3284.68
A_1	54.38	A_3	217.50	A_5	870.00	A_7	3480.00
$A\#_1$	57.61	$A\#_3$	230.43	$A\#_5$	921.73	$A\#_7$	3686.93
B_1	61.03	B_3	244.14	B_5	976.54	B_7	3906.17
						C_8	4138.44

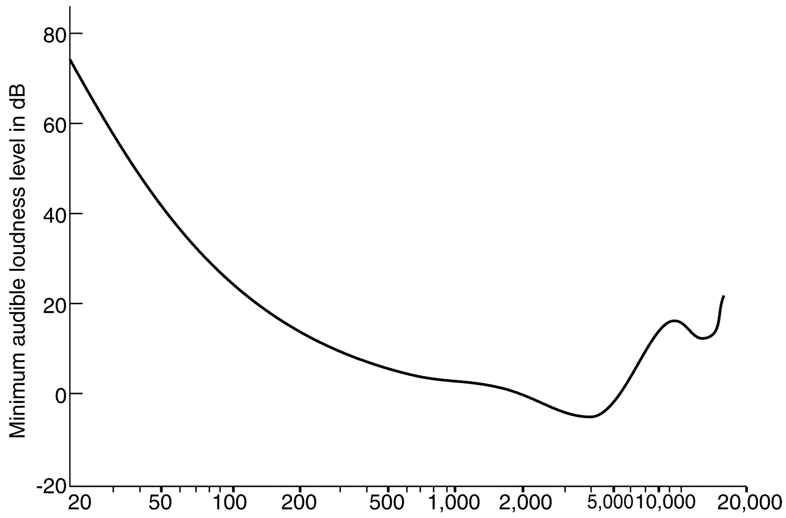
SCIENTIFIC OR JUST SCALE
C_4 = 256 Hz

Note	Frequency	Note	Frequency	Note	Frequency	Note	Frequency
C_0	16	C_2	64	C_4	256	C_6	1024
D_0	18	D_2	72	D_4	288	D_6	1152
E_0	20	E_2	80	E_4	320	E_6	1280
F_0	21.33	F_2	85.33	F_4	341.33	F_6	1365.33
G_0	24	G_2	96	G_4	384	G_6	1536
A_0	26.67	A_2	106.67	A_4	426.67	A_6	1706.67
B_0	30	B_2	120	B_4	480	B_6	1920
C_1	32	C_3	128	C_5	512	C_7	2048
D_1	36	D_3	144	D_5	576	D_7	2304
E_1	40	E_3	160	E_5	640	E_7	2560
F_1	42.67	F_3	170.67	F_5	682.67	F_7	2730.67
G_1	48	G_3	192	G_5	768	G_7	3072
A_1	53.33	A_3	213.33	A_5	853.33	A_7	3413.33
B_1	60	B_3	240	B_5	960	B_7	3840
						C_8	4096

CHARACTERISTICS OF HUMAN HEARING

The human ear is sensitive to sound waves with frequencies in the range from a few hertz to almost 20 kHz. Auditory response is usually expressed in terms of the *loudness level* of a sound, which is a measure of the sound pressure. The reference level, which is given in the unit *phon,* is a pure tone of frequency 1000 Hz with sound pressure of 20 mPa (in cgs units, $2 \cdot 10^{-4}$ dyn/cm^2); loudness level is usually expressed in decibels (dB) relative to this reference level. If a normal observer perceives an arbitrary sound to be equally loud as this reference sound, the sound is said to have the loudness level of the reference. The sensitivity of the typical human ear ranges from about 0 dB, the threshold loudness level, to about 140 dB, the level at which pain sets in. The minimum detectable level thus represents a sound wave of pressure 20 mPa and intensity (power density) 10^{-16} W/cm^2.

The following figure illustrates the frequency dependence of the threshold for an average young adult.



The relation between loudness level and frequency for a typical person is expressed by the following table:

Sound pressure level in dB relative to 20 mPa	Frequency in Hz					
	125	500	1000	4000	8000	10000
10			10	18		
20		16	20	28	11	
30	4	27	30	37	21	17
40	17	39	40	45	30	26
50	34	52	50	54	38	35
60	52	65	60	64	47	44
70	70	76	70	73	56	54
80	86	86	80	83	66	64
90	98	96	90	94	77	74
100	108	105	100	106	88	86

Thus, a 10,000 Hz tone at a pressure level of 50 dB seems equally loud as a 1000 Hz tone at a pressure of 35 dB.

The term *noise* refers to any unwanted sound, either a pure tone or a mixture of frequencies. Since the sensitivity of the ear is frequency dependent, as illustrated by the above table, noise level is expressed in a frequency-weighted scale, known as A-weighting. Decibel readings on this scale are designated as dBa. Typical noise levels from various sources are illustrated in this table:

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Source	Noise level in dBa
Rocket engine	200
Jet aircraft engine	160
Light aircraft, cruising	140
Tractor, 150 hp	115
Electric motor, 100 hp at 2600 rpm	105
Pneumatic drill	100
Subway train	90
Vacuum cleaner	85
Heavy automobile traffic	75
Conversational speech	65
Whispered speech	40
Background noise, recording studio	25-30

Recommended noise thresholds in the workplace have been established by the American Conference of Government Industrial Hygenists. Some examples of the maximum safe levels for different daily exposure times are given below.

Duration of exposure	Max. level in dBa
24 h	80
8 h	85
4 h	88
1 h	94
30 min	97
15 min	100
2 min	109
28 s	115
0.11 s	139

No exposure greater than 140 dBa is permitted. Further details may be found in Reference 3.

REFERENCES

1. Anderson, H. L., Editor, *A Physicist's Desk Reference*, American Institute of Physics, New York, 1989, chap. 2.
2. Gray, D. E., Ed., *American Institute of Physics Handbook, Third Edition*, McGraw Hill, New York, 1972, chap. 3.
3. *Threshold Limit Values for Chemical Substances and Physical Agents; Biological Exposure Indices*, 1999 Edition, American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634.

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INTERSTELLAR MOLECULES

Frank J. Lovas and Lewis E. Snyder

A number of molecules have been detected in the interstellar medium, in circumstellar envelopes around evolved stars, and comae and tails of comets through observation of their microwave, infrared, or optical spectra. The following list gives the molecules and the particular isotopic species that have been reported so far. Molecules are listed by molecular formula in the Hill order.

REFERENCES

1. Lovas, F. J., "Recommended Rest Frequencies for Observed Interstellar Molecule Microwave Transitions - 1991 Revision", *J. Phys. Chem. Ref. Data* 21, 181-272, 1992.

2. Snyder, L. E., "Cometary Molecules", Internat. Astron. Union Symposium No. 150, *Astrochemistry of Cosmic Phenomena*, ed. P.D. Singh, Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 427-434 (1992).

Molecular formula	Name	Isotopic species
AlCl	Aluminum monochloride	AlCl[a]
		$Al^{37}Cl$[a]
AlF	Aluminum monofluoride	AlF[a]
CH	Methylidyne	CH
CH^+	Methyliumylidene	CH^+
CHN	Hydrogen cyanide	HCN
		$H^{13}CN$
		$HC^{15}N$
		DCN
CHN	Hydrogen isocyanide	HNC
		$H^{15}NC$
		$HN^{13}C$
		DNC
		$D^{15}NC$
CHNO	Isocyanic acid	HNCO
		DNCO
CHNS	Isothiocyanic acid	HNCS
CHO	Oxomethyl	HCO
CHO^+	Oxomethylium	HCO^+
		$H^{13}CO^+$
		$HC^{17}O^+$
		$HC^{18}O^+$
		DCO^+
		$D^{13}CO^+$
CHO^+	Hydroxymethylidyne	HOC^+
$CHOS^+$	Protonated carbonyl sulfide	$HOCS^+$
CHO_2^+	Protonated carbon dioxide	$HOCO^+$
CHS^+	Thiooxomethylium	HCS^+
CH_2	Methylene	CH_2
CH_2N^+	Iminomethylium	$HCNH^+$
CH_2N	Methylene amidogen	CH_2N
CH_2N_2	Cyanamide	NH_2CN
CH_2O	Formaldehyde	H_2CO
		$H_2{}^{13}CO$
		$H_2C^{18}O$
		HDCO
		D_2CO
CH_2O_2	Formic acid	HCOOH
		$H^{13}COOH$
		HCOOD
		DCOOH
CH_2S	Thioformaldehyde	H_2CS
		$H_2{}^{13}CS$
		$H_2C^{34}S$
		HDCS
CH_3	Methyl	CH_3[a]
CH_3N	Methanimine	CH_2NH
		$^{13}CH_2NH$
CH_3NO	Formamide	NH_2CHO
		$NH_2{}^{13}CHO$
CH_3O^+	Hydroxy methylium ion	H_2COH^+
CH_4	Methane	CH_4
CH_4O	Methanol	CH_3OH
		$^{13}CH_3OH$
		$CH_3{}^{18}OH$
		CH_2DOH
		CH_3OD
CH_4S	Methanethiol	CH_3SH
CH_5N	Methylamine	CH_3NH_2
CMgN	Magnesium cyanide	MgCN[a]
CMgN	Magnesium isocyanide	MgNC[a]
CN	Cyanide radical	CN
		^{13}CN
		$C^{15}N$
CN^+	Cyanide radical ion	CN^+[b]
CNNa	Sodium cyanide	NaCN[a]
CO	Carbon monoxide	CO
		^{13}CO
		$C^{17}O$
		$C^{18}O$
		$^{13}C^{18}O$
CO^+	Carbon monoxide ion	CO^+
COS	Carbon oxysulfide	OCS
		$OC^{34}S$
		$O^{13}CS$
		^{18}OCS
CO_2	Carbon dioxide	CO_2
CO_2^+	Carbon dioxide ion	CO_2^+[b]
CP	Carbon phosphide	CP[a]
CS	Carbon monosulfide	CS
		$C^{33}S$
		$C^{34}S$
		$C^{36}S$
		^{13}CS
		$^{13}C^{34}S$
CSi	Silicon carbide	SiC[a]

INTERSTELLAR MOLECULES (continued)

Molecular formula	Name	Isotopic species
C_2	Dicarbon	C_2
C_2H	Ethynyl	C_2H
		^{13}CCH
		$C^{13}CH$
		C_2D
C_2HN	Cyanomethylene	HCCN
C_2H_2	Acetylene	HCCH
C_2H_2N	Cyanomethyl	CH_2CN
C_2H_2O	Ketene	H_2CCO
C_2H_3N	Acetonitrile	CH_3CN
		$^{13}CH_3CN$
		$CH_3{}^{13}CN$
		$CH_3C^{15}N$
		CH_2DCN
C_2H_3N	Isocyanomethane	CH_3NC
C_2H_4O	Acetaldehyde	CH_3CHO
C_2H_4O	Ethylene oxide	*c*-C_2H_4O [c]
$C_2H_4O_2$	Methyl formate	CH_3OCHO
$C_2H_4O_2$	Acetic acid	CH_3COOH
$C_2H_4O_2$	Glycolaldehyde	CH_2OHCHO
C_2H_6	Ethane	CH_3CH_3
C_2H_6O	*trans*-Ethanol	*t*-CH_3CH_2OH
C_2H_6O	*gauche*-Ethanol	*g*-CH_3CH_2OH
C_2H_6O	Dimethyl ether	CH_3OCH_3
C_2O	Oxoethenylidene	CCO
C_2S	Thioxoethenylidene	CCS
		$CC^{34}S$
C_2Si	Silicon dicarbide	SiC_2
		$^{29}SiC_2$
		$^{30}SiC_2$
		$Si^{13}CC$
C_3	Tricarbon	C_3
C_3H	Cyclopropenylidyne	*c*-C_3H [c]
C_3H	Propenylidyne	*l*-C_3H [d]
C_3HN	Cyanoacetylene	HCCCN
		$H^{13}CCCN$
		$HC^{13}CCN$
		$HCC^{13}CN$
		$HCCC^{15}N$
		DCCCN
C_3HN	Isocyanoacetylene	HCCNC
C_3HN	1,2-Propadienylidene, 3-imino	HNCCC
C_3H_2	Cyclopropenylidene	*c*-C_3H_2 [c]
		$H^{13}CCCH$
		$HC^{13}CCH$
		C_3HD
C_3H_2	Propadienylidene	H_2CCC
$C_3H_2N^+$	Protonated cyanoacetylene	$HCCCNH^+$
C_3H_2O	2-Propynal	HCCCHO
C_3H_3N	Acrylonitrile	CH_2CHCN
C_3H_4	Propyne	CH_3CCH
		$CH_3C^{13}CH$
		$^{13}CH_3CCH$
		CH_2DCCH
C_3H_5N	Propanenitrile	CH_3CH_2CN
C_3H_6O	Acetone	$(CH_3)_2CO$
C_3N	Cyanoethynyl	CCCN
C_3O	1,2-Propadienylidene, 3-oxo	CCCO

Molecular formula	Name	Isotopic species
C_3S	1,2-Propadienylidene, 3-thioxo	CCCS
C_3Si	Silicon tricarbon	SiC_3
C_4H	1,3-Butadiynyl radical	HCCCC
C_4H_2	Butatrienylidene	H_2CCCC
C_4H_2	1,3-Butadiyne	HCCCCH [a]
C_4H_3N	2-Butynenitrile	CH_3CCCN
C_4Si	Silicon tetracarbide	SiC_4[a]
C_5	Pentacarbon	C_5[a]
C_5H	2,4-Pentadiynylidyne	HCCCCC
C_5HN	2,4-Pentadiynenitrile	HCCCCCN
		$H^{13}CCCCCN$
		$HC^{13}CCCCN$
		$HCC^{13}CCCN$
		$HCCC^{13}CCN$
		$HCCCC^{13}CN$
		DCCCCCN
C_5H_4	1,3-Pentadiyne	CH_3C_4H
C_5N	1,3-Butadiynylium, 4-cyano	C_5N
C_6H	1,3,5-Hexatriynyl	HCCCCCC
C_6H_2	1,3,5-Hexatriyne	HCCCCCCH
C_6H_2	Hexatrienyl	$H_2CCCCCC$
C_7H	2,4,6-Heptatriynylidyne	HCCCCCCC
C_7HN	2,4,6-Heptatriynenitrile	HC_7N
C_8H	1,3,5,7-Octatetraynyl	HC_8
C_9HN	2,4,6,8-Nonatetraynenitrile	HC_9N
$C_{11}HN$	Cyanodecapentyne	$HC_{11}N$
ClH	Hydrogen chloride	$H^{35}Cl$
		$H^{37}Cl$
ClK	Potassium chloride	$K^{35}Cl$[a]
		$K^{37}Cl$
ClNa	Sodium chloride	$Na^{35}Cl$[a]
		$Na^{37}Cl$[a]
FH	Hydrogen fluoride	HF
HLi	Lithium Hydride	^7LiH
HN	Imidogen	HN
HNO	Nitrosyl hydride	HNO
HN_2^+	Hydrodinotrogen(1+)	N_2H^+
		$^{15}NNH^+$
		$N^{15}NH^+$
		N_2D^+
HO	Hydroxyl	OH
		^{17}OH
		^{18}OH
HO^+	Hydroxyl ion	HO^+ [b]
HS	Mercapto	SH
H_2	Hydrogen	H_2
H_2N	Amidogen	NH_2
H_2O	Water	H_2O
		$H_2{}^{18}O$
		HDO
H_2O^+	Oxoniumyl	H_2O^+
H_2S	Hydrogen sulfide	H_2S
		$H_2{}^{34}S$
		HDS
H_3^+	Trihydrogen ion	H_3^+
		H_2D^+
H_3N	Ammonia	NH_3
		$^{15}NH_3$

INTERSTELLAR MOLECULES (continued)

Molecular formula	Name	Isotopic species
		NH_2D
		NHD_2
H_3O^+	Oxonium hydride	H_3O^+
H_4Si	Silane	SiH_4 [a]
NO	Nitric oxide	NO
NP	Phosphorous nitride	NP
NS	Nitrogen sulfide	NS
		$N^{34}S$
NSi	Silicon nitride	SiN [a]
N_2^+	Nitrogen ion	N_2^+ [b]
N_2O	Nitrous oxide	N_2O
OS	Sulfur monoxide	SO
		^{34}SO
		^{33}SO
		$S^{18}O$
OS^+	Sulfur monoxide ion	SO^+
OSi	Silicon monoxide	SiO
		^{29}SiO
		^{30}SIO
O_2S	Sulfur dioxide	SO_2
		$^{33}SO_2$
		$^{34}SO_2$
		$OS^{18}O$
SSi	Silicon monosulfide	SiS
		$Si^{33}S$
		$Si^{34}S$
		^{29}SiS
		^{30}SiS
S_2	Disulfur	S_2 [b]

l- before the isotopic species indicates a linear configuration, while *c*- indicates a cyclic molecule.
[a] Reported only in circumstellar clouds.
[b] Reported only in comets.

STANDARD ITS-90 THERMOCOUPLE TABLES

The Instrument Society of America (ISA) has assigned standard letter designations to a number of thermocouple types having specified emf-temperature relations. These designations and the approximate metal compositions which meet the required relations, as well as the useful temperature ranges, are given below:

Type B	(Pt + 30% Rh) vs. (Pt + 6% Rh)	0 to 1820°C
Type E	(Ni + 10% Cr) vs. (Cu + 43% Ni)	-270 to 1000°C
Type J	Fe vs. (Cu + 43% Ni)	-210 to 1200°C
Type K	(Ni + 10% Cr) vs. (Ni + 2% Al + 2% Mn + 1% Si)	-270 to 1372°C
Type N	(Ni + 14% Cr + 1.5% Si) vs. (Ni + 4.5% Si + 0. 1% Mg)	-270 to 1300°C
Type R	(Pt + 13% Rh) vs. Pt	-50 to 1768°C
Type S	(Pt + 10% Rh) vs. Pt	-50 to 1768°C
Type T	Cu vs. (Cu + 43% Ni)	-270 to 400°C

The compositions are given in weight percent, and the positive leg is listed first. It should be emphasized that the standard letter designations do not imply a precise composition but rather that the specified emf-temperature relation is satisfied.

The first set of tables below lists, for each thermocouple type, the emf as a function of temperature on the International Temperature Scale of 1990 (ITS-90). The coefficients in the equation used to generate the table are also given. The second set of tables gives the inverse relationships, i.e., the coefficients in the polynomial equation which expresses the temperature as a function of thermocouple emf. The accuracy of these equations is also stated.

Further details and tables at closer intervals may be found in Reference 1.

REFERENCES

1. Burns, G. W., Seroger, M. G., Strouse, G. F., Croarkin, M. C., and Guthrie, W.F., *Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90*, Nat. Inst. Stand. Tech. (U.S.) Monogr. 175, 1993.
2. Schooley, J. F., *Thermometry*, CRC Press, Boca Raton, FL, 1986.

Type B thermocouples: emf-temperature (°C) reference table and equations

Thermocouple emf in Millivolts as a Function of Temperature in Degrees Celsius (ITS-90)

Reference Junctions at 0°C

t/°C	0	10	20	30	40	50	60	70	80	90	100
0	0.000	-0.002	-0.003	-0.002	-0.000	0.002	0.006	0.011	0.017	0.025	0.033
100	0.033	0.043	0.053	0.065	0.078	0.092	0.107	0.123	0.141	0.159	0.178
200	0.178	0.199	0.220	0.243	0.267	0.291	0.317	0.344	0.372	0.401	0.431
300	0.431	0.462	0.494	0.527	0.561	0.596	0.632	0.669	0.707	0.746	0.787
400	0.787	0.828	0.870	0.913	0.957	1.002	1.048	1.095	1.143	1.192	1.242
500	1.242	1.293	1.344	1.397	1.451	1.505	1.561	1.617	1.675	1.733	1.792
600	1.792	1.852	1.913	1.975	2.037	2.101	2.165	2.230	2.296	2.363	2.431
700	2.431	2.499	2.569	2.639	2.710	2.782	2.854	2.928	3.002	3.078	3.154
800	3.154	3.230	3.308	3.386	3.466	3.546	3.626	3.708	3.790	3.873	3.957
900	3.957	4.041	4.127	4.213	4.299	4.387	4.475	4.564	4.653	4.743	4.834
1000	4.834	4.926	5.018	5.111	5.205	5.299	5.394	5.489	5.585	5.682	5.780
1100	5.780	5.878	5.976	6.075	6.175	6.276	6.377	6.478	6.580	6.683	6.786
1200	6.786	6.890	6.995	7.100	7.205	7.311	7.417	7.524	7.632	7.740	7.848
1300	7.848	7.957	8.066	8.176	8.286	8.397	8.508	8.620	8.731	8.844	8.956
1400	8.956	9.069	9.182	9.296	9.410	9.524	9.639	9.753	9.868	9.984	10.099
1500	10.099	10.215	10.331	10.447	10.563	10.679	10.796	10.913	11.029	11.146	11.263
1600	11.263	11.380	11.497	11.614	11.731	11.848	11.965	12.082	12.199	12.316	12.433
1700	12.433	12.549	12.666	12.782	12.898	13.014	13.130	13.246	13.361	13.476	13.591
1800	13.591	13.706	13.820								

Temperature Ranges and Coefficients of Equations Used to Compute the Above Table

The equations are of the form: $E = c_0 + c_1t + c_2t^2 + c_3t^3 + ... c_nt^n$, where E is the emf in millivolts, t is the temperature in degrees Celsius (ITS-90), and c_0, c_1, c_2, c_3, etc. are the coefficients. These coefficients are extracted from NIST Monograph 175.

		0°C to 630.615°C	630.615°C to 1820°C
c_0	=	0.000 000 000 0	-3.893 816 862 1
c_1	=	$-2.465\ 081\ 834\ 6 \times 10^{-4}$	$2.857\ 174\ 747\ 0 \times 10^{-2}$
c_2	=	$5.904\ 042\ 117\ 1 \times 10^{-6}$	$-8.488\ 510\ 478\ 5 \times 10^{-5}$
c_3	=	$-1.325\ 793\ 163\ 6 \times 10^{-9}$	$1.578\ 528\ 016\ 4 \times 10^{-7}$
c_4	=	$1.566\ 829\ 190\ 1 \times 10^{-12}$	$-1.683\ 534\ 486\ 4 \times 10^{-10}$
c_5	=	$-1.694\ 452\ 924\ 0 \times 10^{-15}$	$1.110\ 979\ 401\ 3 \times 10^{-13}$
c_6	=	$6.299\ 034\ 709\ 4 \times 10^{-19}$	$-4.451\ 543\ 103\ 3 \times 10^{-17}$
c_7	=	. . . .	$9.897\ 564\ 082\ 1 \times 10^{-21}$
c_8	=	. . . .	$-9.379\ 133\ 028\ 9 \times 10^{-25}$

Type E thermocouples: emf-temperature (°C) reference table and equations

Thermocouple emf in Millivolts as a Function of Temperature in Degrees Celsius (ITS-90)

Reference Junctions at 0°C

t/°C	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100
-200	-8.825	-9.063	-9.274	-9.455	-9.604	-9.718	-9.797	-9.835			
-100	-5.237	-5.681	-6.107	-6.516	-6.907	-7.279	-7.632	-7.963	-8.273	-8.561	-8.825
0	0.000	-0.582	-1.152	-1.709	-2.255	-2.787	-3.306	-3.811	-4.302	-4.777	-5.237

t/°C	0	10	20	30	40	50	60	70	80	90	100
0	0.000	0.591	1.192	1.801	2.420	3.048	3.685	4.330	4.985	5.648	6.319
100	6.319	6.998	7.685	8.379	9.081	9.789	10.503	11.224	11.951	12.684	13.421
200	13.421	14.164	14.912	15.664	16.420	17.181	17.945	18.713	19.484	20.259	21.036
300	21.036	21.817	22.600	23.386	24.174	24.964	25.757	26.552	27.348	28.146	28.946
400	28.946	29.747	30.550	31.354	32.159	32.965	33.772	34.579	35.387	36.196	37.005
500	37.005	37.815	38.624	39.434	40.243	41.053	41.862	42.671	43.479	44.286	45.093
600	45.093	45.900	46.705	47.509	48.313	49.116	49.917	50.718	51.517	52.315	53.112
700	53.112	53.908	54.703	55.497	56.289	57.080	57.870	58.659	59.446	60.232	61.017
800	61.017	61.801	62.583	63.364	64.144	64.922	65.698	66.473	67.246	68.017	68.787
900	68.787	69.554	70.319	71.082	71.844	72.603	73.360	74.115	74.869	75.621	76.373
1000	76.373										

Temperature Ranges and Coefficients of Equations Used to Compute the Above Table

The equations are of the form: $E = c_0 + c_1t + c_2t^2 + c_3t^3 + \ldots c_nt^n$, where E is the emf in millivolts, t is the temperature in degrees Celsius (ITS-90), and c_0, c_1, c_2, c_3, etc. are the coefficients. These coefficients are extracted from NIST Monograph 175.

		-270°C to 0°C	0°C to 1000°C
c_0	=	0.000 000 000 0	0.000 000 000 0
c_1	=	$5.866\,550\,870\,8 \times 10^{-2}$	$5.866\,550\,871\,0 \times 10^{-2}$
c_2	=	$4.541\,097\,712\,4 \times 10^{-5}$	$4.503\,227\,558\,2 \times 10^{-5}$
c_3	=	$-7.799\,804\,868\,6 \times 10^{-7}$	$2.890\,840\,721\,2 \times 10^{-8}$
c_4	=	$-2.580\,016\,084\,3 \times 10^{-8}$	$-3.305\,689\,665\,2 \times 10^{-10}$
c_5	=	$-5.945\,258\,305\,7 \times 10^{-10}$	$6.502\,440\,327\,0 \times 10^{-13}$
c_6	=	$-9.321\,405\,866\,7 \times 10^{-12}$	$-1.919\,749\,550\,4 \times 10^{-16}$
c_7	=	$-1.028\,760\,553\,4 \times 10^{-13}$	$-1.253\,660\,049\,7 \times 10^{-18}$
c_8	=	$-8.037\,012\,362\,1 \times 10^{-16}$	$2.148\,921\,756\,9 \times 10^{-21}$
c_9	=	$-4.397\,949\,739\,1 \times 10^{-18}$	$-1.438\,804\,178\,2 \times 10^{-24}$
c_{10}	=	$-1.641\,477\,635\,5 \times 10^{-20}$	$3.596\,089\,948\,1 \times 10^{-28}$
c_{11}	=	$-3.967\,361\,951\,6 \times 10^{-23}$	. . . .
c_{12}	=	$-5.582\,732\,872\,1 \times 10^{-26}$	. . . .
c_{13}	=	$-3.465\,784\,201\,3 \times 10^{-29}$	. . . .

Type J thermocouples: emf-temperature (°C) reference table and equations

Thermocouple emf in Millivolts as a Function of Temperature in Degrees Celsius (ITS-90)

Reference Junctions at 0°C

t/°C	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100
-200	-7.890	-8.095									
-100	-4.633	-5.037	-5.426	-5.801	-6.159	-6.500	-6.821	-7.123	-7.403	-7.659	-7.890
0	0.000	-0.501	-0.995	-1.482	-1.961	-2.431	-2.893	-3.344	-3.786	-4.215	-4.633

t/°C	0	10	20	30	40	50	60	70	80	90	100
0	0.000	0.507	1.019	1.537	2.059	2.585	3.116	3.650	4.187	4.726	5.269
100	5.269	5.814	6.360	6.909	7.459	8.010	8.562	9.115	9.669	10.224	10.779
200	10.779	11.334	11.889	12.445	13.000	13.555	14.110	14.665	15.219	15.773	16.327
300	16.327	16.881	17.434	17.986	18.538	19.090	19.642	20.194	20.745	21.297	21.848
400	21.848	22.400	22.952	23.504	24.057	24.610	25.164	25.720	26.276	26.834	27.393
500	27.393	27.953	28.516	29.080	29.647	30.216	30.788	31.362	31.939	32.519	33.102
600	33.102	33.689	34.279	34.873	35.470	36.071	36.675	37.284	37.896	38.512	39.132
700	39.132	39.755	40.382	41.012	41.645	42.281	42.919	43.559	44.203	44.848	45.494
800	45.494	46.141	46.786	47.431	48.074	48.715	49.353	49.989	50.622	51.251	51.877
900	51.877	52.500	53.119	53.735	54.347	54.956	55.561	56.164	56.763	57.360	57.953
1000	57.953	58.545	59.134	59.721	60.307	60.890	61.473	62.054	62.634	63.214	63.792
1100	63.792	64.370	64.948	65.525	66.102	66.679	67.255	67.831	68.406	68.980	69.553
1200	69.553										

Temperature Ranges and Coefficients of Equations Used to Compute the Above Table

The equations are of the form: $E = c_0 + c_1t + c_2t^2 + c_3t^3 + ... c_nt^n$, where E is the emf in millivolts, t is the temperature in degrees Celsius (ITS-90), and c_0, c_1, c_2, c_3, etc. are the coefficients. These coefficients are extracted from NIST Monograph 175.

		-210°C to 760°C	760°C to 1200°C
c_0	=	0.000 000 000 0	$2.964\,562\,568\,1 \times 10^{2}$
c_1	=	$5.038\,118\,781\,5 \times 10^{-2}$	-1.497 612 778 6
c_2	=	$3.047\,583\,693\,0 \times 10^{-5}$	$3.178\,710\,392\,4 \times 10^{-3}$
c_3	=	$-8.568\,106\,572\,0 \times 10^{-8}$	$-3.184\,768\,670\,1 \times 10^{-6}$
c_4	=	$1.322\,819\,529\,5 \times 10^{-10}$	$1.572\,081\,900\,4 \times 10^{-9}$
c_5	=	$-1.705\,295\,833\,7 \times 10^{-13}$	$-3.069\,136\,905\,6 \times 10^{-13}$
c_6	=	$2.094\,809\,069\,7 \times 10^{-16}$	. . . .
c_7	=	$-1.253\,839\,533\,6 \times 10^{-19}$	. . . .
c_8	=	$1.563\,172\,569\,7 \times 10^{-23}$	. . . .

Type K thermocouples: emf-temperature (°C) reference table and equations

Thermocouple emf in Millivolts as a Function of Temperature in Degrees Celsius (ITS-90)

Reference Junctions at 0°C

t/°C	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100
-200	-5.891	-6.035	-6.158	-6.262	-6.344	-6.404	-6.441	-6.458			
-100	-3.554	-3.852	-4.138	-4.411	-4.669	-4.913	-5.141	-5.354	-5.550	-5.730	-5.891
0	0.000	-0.392	-0.778	-1.156	-1.527	-1.889	-2.243	-2.587	-2.920	-3.243	-3.554

t/°C	0	10	20	30	40	50	60	70	80	90	100
0	0.000	0.397	0.798	1.203	1.612	2.023	2.436	2.851	3.267	3.682	4.096
100	4.096	4.509	4.920	5.328	5.735	6.138	6.540	6.941	7.340	7.739	8.138
200	8.138	8.539	8.940	9.343	9.747	10.153	10.561	10.971	11.382	11.795	12.209
300	12.209	12.624	13.040	13.457	13.874	14.293	14.713	15.133	15.554	15.975	16.397
400	16.397	16.820	17.243	17.667	18.091	18.516	18.941	19.366	19.792	20.218	20.644
500	20.644	21.071	21.497	21.924	22.350	22.776	23.203	23.629	24.055	24.480	24.905
600	24.905	25.330	25.755	26.179	26.602	27.025	27.447	27.869	28.289	28.710	29.129
700	29.129	29.548	29.965	30.382	30.798	31.213	31.628	32.041	32.453	32.865	33.275
800	33.275	33.685	34.093	34.501	34.908	35.313	35.718	36.121	36.524	36.925	37.326
900	37.326	37.725	38.124	38.522	38.918	39.314	39.708	40.101	40.494	40.885	41.276
1000	41.276	41.665	42.053	42.440	42.826	43.211	43.595	43.978	44.359	44.740	45.119
1100	45.119	45.497	45.873	46.249	46.623	46.995	47.367	47.737	48.105	48.473	48.838
1200	48.838	49.202	49.565	49.926	50.286	50.644	51.000	51.355	51.708	52.060	52.410
1300	52.410	52.759	53.106	53.451	53.795	54.138	54.479	54.819			

Temperature Ranges and Coefficients of Equations Used to Compute the Above Table

The equations are of the form: $E = c_0 + c_1 t + c_2 t^2 + c_3 t^3 + \ldots c_n t^n$, where E is the emf in millivolts, t is the temperature in degrees Celsius (ITS-90), and c_0, c_1, c_2, c_3, etc. are the coefficients. In the 0°C to 1372°C range there is also an exponential term that must be evaluated and added to the equation. The exponential term is of the form: $c_0 \exp[c_1(t\text{-}126.9686)^2]$, where t is the temperature in °C and c_0 and c_1 are the coefficients. These coefficients are extracted from NIST Monograph 175.

		-270°C to 0°C	0°C to 1372°C	0°C to 1372°C (exponential term)
c_0	=	0.000 000 000 0	$-1.760\,041\,368\,6 \times 10^{-2}$	$1.185\,976 \times 10^{-1}$
c_1	=	$3.945\,012\,802\,5 \times 10^{-2}$	$3.892\,120\,497\,5 \times 10^{-2}$	$-1.183\,432 \times 10^{-4}$
c_2	=	$2.362\,237\,359\,8 \times 10^{-5}$	$1.855\,877\,003\,2 \times 10^{-5}$	. . . .
c_3	=	$-3.285\,890\,678\,4 \times 10^{-7}$	$-9.945\,759\,287\,4 \times 10^{-8}$	. . . .
c_4	=	$-4.990\,482\,877\,7 \times 10^{-9}$	$3.184\,094\,571\,9 \times 10^{-10}$	. . . .
c_5	=	$-6.750\,905\,917\,3 \times 10^{-11}$	$-5.607\,284\,488\,9 \times 10^{-13}$	. . . .
c_6	=	$-5.741\,032\,742\,8 \times 10^{-13}$	$5.607\,505\,905\,9 \times 10^{-16}$	. . . .
c_7	=	$-3.108\,887\,289\,4 \times 10^{-15}$	$-3.202\,072\,000\,3 \times 10^{-19}$	. . . .
c_8	=	$-1.045\,160\,936\,5 \times 10^{-17}$	$9.715\,114\,715\,2 \times 10^{-23}$	. . . .
c_9	=	$-1.988\,926\,687\,8 \times 10^{-20}$	$-1.210\,472\,127\,5 \times 10^{-26}$	. . . .
c_{10}	=	$-1.632\,269\,748\,6 \times 10^{-23}$	. . . .	. . . .

Type N thermocouples: emf-temperature (°C) reference table and equations

Thermocouple emf in Millivolts as a Function of Temperature in Degrees Celsius (ITS-90)

Reference Junctions at 0°C

t/°C	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100
-200	-3.990	-4.083	-4.162	-4.226	-4.277	-4.313	-4.336	-4.345			
-100	-2.407	-2.612	-2.808	-2.994	-3.171	-3.336	-3.491	-3.634	-3.766	-3.884	-3.990
0	0.000	-0.260	-0.518	-0.772	-1.023	-1.269	-1.509	-1.744	-1.972	-2.193	-2.407

t/°C	0	10	20	30	40	50	60	70	80	90	100
0	0.000	0.261	0.525	0.793	1.065	1.340	1.619	1.902	2.189	2.480	2.774
100	2.774	3.072	3.374	3.680	3.989	4.302	4.618	4.937	5.259	5.585	5.913
200	5.913	6.245	6.579	6.916	7.255	7.597	7.941	8.288	8.637	8.988	9.341
300	9.341	9.696	10.054	10.413	10.774	11.136	11.501	11.867	12.234	12.603	12.974
400	12.974	13.346	13.719	14.094	14.469	14.846	15.225	15.604	15.984	16.366	16.748
500	16.748	17.131	17.515	17.900	18.286	18.672	19.059	19.447	19.835	20.224	20.613
600	20.613	21.003	21.393	21.784	22.175	22.566	22.958	23.350	23.742	24.134	24.527
700	24.527	24.919	25.312	25.705	26.098	26.491	26.883	27.276	27.669	28.062	28.455
800	28.455	28.847	29.239	29.632	30.024	30.416	30.807	31.199	31.590	31.981	32.371
900	32.371	32.761	33.151	33.541	33.930	34.319	34.707	35.095	35.482	35.869	36.256
1000	36.256	36.641	37.027	37.411	37.795	38.179	38.562	38.944	39.326	39.706	40.087
1100	40.087	40.466	40.845	41.223	41.600	41.976	42.352	42.727	43.101	43.474	43.846
1200	43.846	44.218	44.588	44.958	45.326	45.694	46.060	46.425	46.789	47.152	47.513
1300	47.513										

Temperature Ranges and Coefficients of Equations Used to Compute the Above Table

The equations are of the form: $E = c_0 + c_1t + c_2t^2 + c_3t^3 + \ldots c_nt^n$, where E is the emf in millivolts, t is the temperature in degrees Celsius (ITS-90), and c_0, c_1, c_2, c_3, etc. are the coefficients. These coefficients are extracted from NIST Monograph 175.

		-270°C to 0°C	0°C to 1300°C
c_0	=	0.000 000 000 0	0.000 000 000 0
c_1	=	$2.615\ 910\ 596\ 2 \times 10^{-2}$	$2.592\ 939\ 460\ 1 \times 10^{-2}$
c_2	=	$1.095\ 748\ 422\ 8 \times 10^{-5}$	$1.571\ 014\ 188\ 0 \times 10^{-5}$
c_3	=	$-9.384\ 111\ 155\ 4 \times 10^{-8}$	$4.382\ 562\ 723\ 7 \times 10^{-8}$
c_4	=	$-4.641\ 203\ 975\ 9 \times 10^{-11}$	$-2.526\ 116\ 979\ 4 \times 10^{-10}$
c_5	=	$-2.630\ 335\ 771\ 6 \times 10^{-12}$	$6.431\ 181\ 933\ 9 \times 10^{-13}$
c_6	=	$-2.265\ 343\ 800\ 3 \times 10^{-14}$	$-1.006\ 347\ 151\ 9 \times 10^{-15}$
c_7	=	$-7.608\ 930\ 079\ 1 \times 10^{-17}$	$9.974\ 533\ 899\ 2 \times 10^{-19}$
c_8	=	$-9.341\ 966\ 783\ 5 \times 10^{-20}$	$-6.086\ 324\ 560\ 7 \times 10^{-22}$
c_9	=	. . . .	$2.084\ 922\ 933\ 9 \times 10^{-25}$
c_{10}	=	. . . .	$-3.068\ 219\ 615\ 1 \times 10^{-29}$

Type R thermocouples: emf-temperature (°C) reference table and equations

Thermocouple emf in Millivolts as a Function of Temperature in Degrees Celsius (ITS-90)

Reference Junctions at 0°C

t/°C	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100
0	0.000	-0.051	-0.100	-0.145	-0.188	-0.226					

t/°C	0	10	20	30	40	50	60	70	80	90	100
0	0.000	0.054	0.111	0.171	0.232	0.296	0.363	0.431	0.501	0.573	0.647
100	0.647	0.723	0.800	0.879	0.959	1.041	1.124	1.208	1.294	1.381	1.469
200	1.469	1.558	1.648	1.739	1.831	1.923	2.017	2.112	2.207	2.304	2.401
300	2.401	2.498	2.597	2.696	2.796	2.896	2.997	3.099	3.201	3.304	3.408
400	3.408	3.512	3.616	3.721	3.827	3.933	4.040	4.147	4.255	4.363	4.471
500	4.471	4.580	4.690	4.800	4.910	5.021	5.133	5.245	5.357	5.470	5.583
600	5.583	5.697	5.812	5.926	6.041	6.157	6.273	6.390	6.507	6.625	6.743
700	6.743	6.861	6.980	7.100	7.220	7.340	7.461	7.583	7.705	7.827	7.950
800	7.950	8.073	8.197	8.321	8.446	8.571	8.697	8.823	8.950	9.077	9.205
900	9.205	9.333	9.461	9.590	9.720	9.850	9.980	10.111	10.242	10.374	10.506
1000	10.506	10.638	10.771	10.905	11.039	11.173	11.307	11.442	11.578	11.714	11.850
1100	11.850	11.986	12.123	12.260	12.397	12.535	12.673	12.812	12.950	13.089	13.228
1200	13.228	13.367	13.507	13.646	13.786	13.926	14.066	14.207	14.347	14.488	14.629
1300	14.629	14.770	14.911	15.052	15.193	15.334	15.475	15.616	15.758	15.899	16.040
1400	16.040	16.181	16.323	16.464	16.605	16.746	16.887	17.028	17.169	17.310	17.451
1500	17.451	17.591	17.732	17.872	18.012	18.152	18.292	18.431	18.571	18.710	18.849
1600	18.849	18.988	19.126	19.264	19.402	19.540	19.677	19.814	19.951	20.087	20.222
1700	20.222	20.356	20.488	20.620	20.749	20.877	21.003				

Temperature Ranges and Coefficients of Equations Used to Compute the Above Table

The equations are of the form: $E = c_0 + c_1t + c_2t^2 + c_3t^3 + ... c_nt^n$, where E is the emf in millivolts, t is the temperature in degrees Celsius (ITS-90), and c_0, c_1, c_2, c_3, etc. are the coefficients. These coefficients are extracted from NIST Monograph 175.

		-50°C to 1064.18°C	1064.18°C to 1664.5°C	1664.5°C to 1768.1°C
c_0	=	0.000 000 000 00.	2.951 579 253 16	$1.522\,321\,182\,09 \times 10^{2}$
c_1	=	$5.289\,617\,297\,65 \times 10^{-3}$	$-2.520\,612\,513\,32 \times 10^{-3}$	$-2.688\,198\,885\,45 \times 10^{-1}$
c_2	=	$1.391\,665\,897\,82 \times 10^{-5}$	$1.595\,645\,018\,65 \times 10^{-5}$	$1.712\,802\,804\,71 \times 10^{-4}$
c_3	=	$-2.388\,556\,930\,17 \times 10^{-8}$	$-7.640\,859\,475\,76 \times 10^{-9}$	$-3.458\,957\,064\,53 \times 10^{-8}$
c_4	=	$3.569\,160\,010\,63 \times 10^{-11}$	$2.053\,052\,910\,24 \times 10^{-12}$	$-9.346\,339\,710\,46 \times 10^{-15}$
c_5	=	$-4.623\,476\,662\,98 \times 10^{-14}$	$-2.933\,596\,681\,73 \times 10^{-16}$	. . . .
c_6	=	$5.007\,774\,410\,34 \times 10^{-17}$	. . . .	. . . .
c_7	=	$-3.731\,058\,861\,91 \times 10^{-20}$	. . . .	. . . .
c_8	=	$1.577\,164\,823\,67 \times 10^{-23}$	. . . .	. . . .
c_9	=	$-2.810\,386\,252\,51 \times 10^{-27}$	. . . .	. . . .

Type S thermocouples: emf-temperature (°C) reference table and equations

Thermocouple emf in Millivolts as a Function of Temperature in Degrees Celsius (ITS-90)

Reference Junctions at 0°C

t/°C	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100
0	0.000	-0.053	-0.103	-0.150	-0.194	-0.236					

t/°C	0	10	20	30	40	50	60	70	80	90	100
0	0.000	0.055	0.113	0.173	0.235	0.299	0.365	0.433	0.502	0.573	0.646
100	0.646	0.720	0.795	0.872	0.950	1.029	1.110	1.191	1.273	1.357	1.441
200	1.441	1.526	1.612	1.698	1.786	1.874	1.962	2.052	2.141	2.232	2.323
300	2.323	2.415	2.507	2.599	2.692	2.786	2.880	2.974	3.069	3.164	3.259
400	3.259	3.355	3.451	3.548	3.645	3.742	3.840	3.938	4.036	4.134	4.233
500	4.233	4.332	4.432	4.532	4.632	4.732	4.833	4.934	5.035	5.137	5.239
600	5.239	5.341	5.443	5.546	5.649	5.753	5.857	5.961	6.065	6.170	6.275
700	6.275	6.381	6.486	6.593	6.699	6.806	6.913	7.020	7.128	7.236	7.345
800	7.345	7.454	7.563	7.673	7.783	7.893	8.003	8.114	8.226	8.337	8.449
900	8.449	8.562	8.674	8.787	8.900	9.014	9.128	9.242	9.357	9.472	9.587
1000	9.587	9.703	9.819	9.935	10.051	10.168	10.285	10.403	10.520	10.638	10.757
1100	10.757	10.875	10.994	11.113	11.232	11.351	11.471	11.590	11.710	11.830	11.951
1200	11.951	12.071	12.191	12.312	12.433	12.554	12.675	12.796	12.917	13.038	13.159
1300	13.159	13.280	13.402	13.523	13.644	13.766	13.887	14.009	14.130	14.251	14.373
1400	14.373	14.494	14.615	14.736	14.857	14.978	15.099	15.220	15.341	15.461	15.582
1500	15.582	15.702	15.822	15.942	16.062	16.182	16.301	16.420	16.539	16.658	16.777
1600	16.777	16.895	17.013	17.131	17.249	17.366	17.483	17.600	17.717	17.832	17.947
1700	17.947	18.061	18.174	18.285	18.395	18.503	18.609				

Temperature Ranges and Coefficients of Equations Used to Compute the Above Table

The equations are of the form: $E = c_0 + c_1t + c_2t^2 + c_3t^3 + \ldots c_nt^n$, where E is the emf in millivolts, t is the temperature in degrees Celsius (ITS-90), and c_0, c_1, c_2, c_3, etc. are the coefficients. These coefficients are extracted from NIST Monograph 175.

		-50°C to 1064.18°C	1064.18°C to 1664.5°C	1664.5°C to 1768.1°C
c_0	=	0.000 000 000 00	1.329 004 440 85	$1.466\ 282\ 326\ 36 \times 10^{2}$
c_1	=	$5.403\ 133\ 086\ 31 \times 10^{-3}$	$3.345\ 093\ 113\ 44 \times 10^{-3}$	$-2.584\ 305\ 167\ 52 \times 10^{-1}$
c_2	=	$1.259\ 342\ 897\ 40 \times 10^{-5}$	$6.548\ 051\ 928\ 18 \times 10^{-6}$	$1.636\ 935\ 746\ 41 \times 10^{-4}$
c_3	=	$-2.324\ 779\ 686\ 89 \times 10^{-8}$	$-1.648\ 562\ 592\ 09 \times 10^{-9}$	$-3.304\ 390\ 469\ 87 \times 10^{-8}$
c_4	=	$3.220\ 288\ 230\ 36 \times 10^{-11}$	$1.299\ 896\ 051\ 74 \times 10^{-14}$	$-9.432\ 236\ 906\ 12 \times 10^{-15}$
c_5	=	$-3.314\ 651\ 963\ 89 \times 10^{-14}$	. . . .	. . . .
c_6	=	$2.557\ 442\ 517\ 86 \times 10^{-17}$	. . . .	. . . .
c_7	=	$-1.250\ 688\ 713\ 93 \times 10^{-20}$	. . . .	. . . .
c_8	=	$2.714\ 431\ 761\ 45 \times 10^{-24}$	. . . .	. . . .

Type T thermocouples: emf-temperature (°C) reference table and equations

Thermocouple emf in Millivolts as a Function of Temperature in Degrees Celsius (ITS-90)

Reference Junctions at 0°C

t/°C	0	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100
-200	-5.603	-5.753	-5.888	-6.007	-6.105	-6.180	-6.232	-6.258			
-100	-3.379	-3.657	-3.923	-4.177	-4.419	-4.648	-4.865	-5.070	-5.261	-5.439	-5.603
0	0.000	-0.383	-0.757	-1.121	-1.475	-1.819	-2.153	-2.476	-2.788	-3.089	-3.379

t/°C	0	10	20	30	40	50	60	70	80	90	100
0	0.000	0.391	0.790	1.196	1.612	2.036	2.468	2.909	3.358	3.814	4.279
100	4.279	4.750	5.228	5.714	6.206	6.704	7.209	7.720	8.237	8.759	9.288
200	9.288	9.822	10.362	10.907	11.458	12.013	12.574	13.139	13.709	14.283	14.862
300	14.862	15.445	16.032	16.624	17.219	17.819	18.422	19.030	19.641	20.255	20.872
400	20.872										

Temperature Ranges and Coefficients of Equations Used to Compute the Above Table

The equations are of the form: $E = c_0 + c_1t + c_2t^2 + c_3t^3 + \ldots c_nt^n$, where E is the emf in millivolts, t is the temperature in degrees Celsius (ITS-90), and c_0, c_1, c_2, c_3, etc. are the coefficients. These coefficients are extracted from NIST Monograph 175.

		-270°C to 0°C	0°C to 400°C
c_0	=	0.000 000 000 0	0.000 000 000 0
c_1	=	$3.874\,810\,636\,4 \times 10^{-2}$	$3.874\,810\,636\,4 \times 10^{-2}$
c_2	=	$4.419\,443\,434\,7 \times 10^{-5}$	$3.329\,222\,788\,0 \times 10^{-5}$
c_3	=	$1.184\,432\,310\,5 \times 10^{-7}$	$2.061\,824\,340\,4 \times 10^{-7}$
c_4	=	$2.003\,297\,355\,4 \times 10^{-8}$	$-2.188\,225\,684\,6 \times 10^{-9}$
c_5	=	$9.013\,801\,955\,9 \times 10^{-10}$	$1.099\,688\,092\,8 \times 10^{-11}$
c_6	=	$2.265\,115\,659\,3 \times 10^{-11}$	$-3.081\,575\,877\,2 \times 10^{-14}$
c_7	=	$3.607\,115\,420\,5 \times 10^{-13}$	$4.547\,913\,529\,0 \times 10^{-17}$
c_8	=	$3.849\,393\,988\,3 \times 10^{-15}$	$-2.751\,290\,167\,3 \times 10^{-20}$
c_9	=	$2.821\,352\,192\,5 \times 10^{-17}$	. . . .
c_{10}	=	$1.425\,159\,477\,9 \times 10^{-19}$	. . . .
c_{11}	=	$4.876\,866\,228\,6 \times 10^{-22}$	. . . .
c_{12}	=	$1.079\,553\,927\,0 \times 10^{-24}$	. . . .
c_{13}	=	$1.394\,502\,706\,2 \times 10^{-27}$	. . . .
c_{14}	=	$7.979\,515\,392\,7 \times 10^{-31}$	. . . .

Type B thermocouples: coefficients (c_i) of polynomials for the computation of temperatures in °C as a function of the thermocouple emf in various temperature and emf ranges

Temperature Range:	250°C to 700°C	700°C to 1820°C
emf Range:	0.291 mV to 2.431 mV	2.431 mV to 13.820 mV
c_0 =	$9.842\,332\,1 \times 10^{1}$	$2.131\,507\,1 \times 10^{2}$
c_1 =	$6.997\,150\,0 \times 10^{2}$	$2.851\,050\,4 \times 10^{2}$
c_2 =	$-8.476\,530\,4 \times 10^{2}$	$-5.274\,288\,7 \times 10^{1}$
c_3 =	$1.005\,264\,4 \times 10^{3}$	$9.916\,080\,4$
c_4 =	$-8.334\,595\,2 \times 10^{2}$	$-1.296\,530\,3$
c_5 =	$4.550\,854\,2 \times 10^{2}$	$1.119\,587\,0 \times 10^{-1}$
c_6 =	$-1.552\,303\,7 \times 10^{2}$	$-6.062\,519\,9 \times 10^{-3}$
c_7 =	$2.988\,675\,0 \times 10^{1}$	$1.866\,169\,6 \times 10^{-4}$
c_8 =	$-2.474\,286\,0$	$-2.487\,858\,5 \times 10^{-6}$

Type E thermocouples: coefficients (c_i) of polynomials for the computation of temperatures in °C as a function of the thermocouple emf in various temperature and emf ranges

Temperature Range:	-200°C to 0°C	0°C to 1000°C
emf Range:	-8.825 mV to 0.0 mV	0.0 mV to 76.373 mV
c_0 =	$0.000\,000\,0$	$0.000\,000\,0$
c_1 =	$1.697\,728\,8 \times 10^{1}$	$1.705\,703\,5 \times 10^{1}$
c_2 =	$-4.351\,497\,0 \times 10^{-1}$	$-2.330\,175\,9 \times 10^{-1}$
c_3 =	$-1.585\,969\,7 \times 10^{-1}$	$6.543\,558\,5 \times 10^{-3}$
c_4 =	$-9.250\,287\,1 \times 10^{-2}$	$-7.356\,274\,9 \times 10^{-5}$
c_5 =	$-2.608\,431\,4 \times 10^{-2}$	$-1.789\,600\,1 \times 10^{-6}$
c_6 =	$-4.136\,019\,9 \times 10^{-3}$	$8.403\,616\,5 \times 10^{-8}$
c_7 =	$-3.403\,403\,0 \times 10^{-4}$	$-1.373\,587\,9 \times 10^{-9}$
c_8 =	$-1.156\,489\,0 \times 10^{-5}$	$1.062\,982\,3 \times 10^{-11}$
c_9 =	. . . .	$-3.244\,708\,7 \times 10^{-14}$

Type J thermocouples: coefficients (c_i) of polynomials for the computation of temperatures in °C as a function of the thermocouple emf in various temperature and emf ranges

Temperature Range:	-210°C to 0°C	0°C to 760°C	760°C to 1200°C
emf Range:	-8.095 mV to 0.0 mV	0.0 mV to 42.919 mV	42.919 mV to 69.553 mV
c_0 =	0.000 000 0	0.000 000	$-3.113\ 581\ 87 \times 10^{3}$
c_1 =	$1.952\ 826\ 8 \times 10^{1}$	$1.978\ 425 \times 10^{1}$	$3.005\ 436\ 84 \times 10^{2}$
c_2 =	-1.228 618 5	$-2.001\ 204 \times 10^{-1}$	-9.947 732 30
c_3 =	-1.075 217 8	$1.036\ 969 \times 10^{-2}$	$1.702\ 766\ 30 \times 10^{-1}$
c_4 =	$-5.908\ 693\ 3 \times 10^{-1}$	$-2.549\ 687 \times 10^{-4}$	$-1.430\ 334\ 68 \times 10^{-3}$
c_5 =	$-1.725\ 671\ 3 \times 10^{-1}$	$3.585\ 153 \times 10^{-6}$	$4.738\ 860\ 84 \times 10^{-6}$
c_6 =	$-2.813\ 151\ 3 \times 10^{-2}$	$-5.344\ 285 \times 10^{-8}$	. . . .
c_7 =	$-2.396\ 337\ 0 \times 10^{-3}$	$5.099\ 890 \times 10^{-10}$	. . . .
c_8 =	$-8.382\ 332\ 1 \times 10^{-5}$	. . . .	. . . .

Type K thermocouples: coefficients (c_i) of polynomials for the computation of temperatures in °C as a function of the thermocouple emf in various temperature and emf ranges

Temperature Range:	-200°C to 0°C	0°C to 500°C	500°C to 1372°C
emf Range:	-5.891 mV to 0.0 mV	0.0 mV to 20.644 mV	20.644 mV to 54.886 mV
c_0 =	0.000 000 0	0.000 000 0	$-1.318\ 058 \times 10^{2}$
c_1 =	$2.517\ 346\ 2 \times 10^{1}$	$2.508\ 355 \times 10^{1}$	$4.830\ 222 \times 10^{1}$
c_2 =	-1.166 287 8	$7.860\ 106 \times 10^{-2}$	-1.646 031
c_3 =	-1.083 363 8	$-2.503\ 131 \times 10^{-1}$	$5.464\ 731 \times 10^{-2}$
c_4 =	$-8.977\ 354\ 0 \times 10^{-1}$	$8.315\ 270 \times 10^{-2}$	$-9.650\ 715 \times 10^{-4}$
c_5 =	$-3.734\ 237\ 7 \times 10^{-1}$	$-1.228\ 034 \times 10^{-2}$	$8.802\ 193 \times 10^{-6}$
c_6 =	$-8.663\ 264\ 3 \times 10^{-2}$	$9.804\ 036 \times 10^{-4}$	$-3.110\ 810 \times 10^{-8}$
c_7 =	$-1.045\ 059\ 8 \times 10^{-2}$	$-4.413\ 030 \times 10^{-5}$	. . . .
c_8 =	$-5.192\ 057\ 7 \times 10^{-4}$	$1.057\ 734 \times 10^{-6}$	. . . .
c_9 =	. . . .	$-1.052\ 755 \times 10^{-8}$	. . . .

Type N thermocouples: coefficients (c_i) of polynomials for the computation of temperatures in °C as a function of the thermocouple emf in various temperature and emf ranges

Temperature Range:	-200°C to 0°C	0°C to 600°C	600°C to 1300°C
emf Range:	-3.990 mV to 0.0 mV	0.0 mV to 20.613 mV	20.613 mV to 47.513 mV
c_0 =	0.000 000 0	0.000 00	$1.972\ 485 \times 10^{1}$
c_1 =	$3.843\ 684\ 7 \times 10^{1}$	$3.868\ 96 \times 10^{1}$	$3.300\ 943 \times 10^{1}$
c_2 =	1.101 048 5	-1.082 67	$-3.915\ 159 \times 10^{-1}$
c_3 =	5.222 931 2	$4.702\ 05 \times 10^{-2}$	$9.855\ 391 \times 10^{-3}$
c_4 =	7.206 052 5	$-2.121\ 69 \times 10^{-6}$	$-1.274\ 371 \times 10^{-4}$
c_5 =	5.848 858 6	$-1.172\ 72 \times 10^{-4}$	$7.767\ 022 \times 10^{-7}$
c_6 =	2.775 491 6	$5.392\ 80 \times 10^{-6}$	. . . .
c_7 =	$7.707\ 516\ 6 \times 10^{-1}$	$-7.981\ 56 \times 10^{-8}$	. . . .
c_8 =	$1.158\ 266\ 5 \times 10^{-1}$	. . . .	. . . .
c_9 =	$7.313\ 886\ 8 \times 10^{-3}$	. . . .	. . . .

Type R thermocouples: coefficients (c_i) of polynomials for the computation of temperatures in °C as a function of the thermocouple emf in various temperature and emf ranges

Temperature Range:	-50°C to 250°C	250°C to 1200°C	1064°C to 1664.5°C	1664.5°C to 1768.1°C
emf Range:	-0.226 mV to 1.923 mV	1.923 mV to 13.228 mV	11.361 mV to 19.739 mV	19.739 mV to 21.103 mV
c_0 =	0.000 000 0	$1.334\ 584\ 505 \times 10^{1}$	$-8.199\ 599\ 416 \times 10^{1}$	$3.406\ 177\ 836 \times 10^{4}$
c_1 =	$1.889\ 138\ 0 \times 10^{2}$	$1.472\ 644\ 573 \times 10^{2}$	$1.553\ 962\ 042 \times 10^{2}$	$-7.023\ 729\ 171 \times 10^{3}$
c_2 =	$-9.383\ 529\ 0 \times 10^{1}$	$-1.844\ 024\ 844 \times 10^{1}$	-8.342 197 663	$5.582\ 903\ 813 \times 10^{2}$
c_3 =	$1.306\ 861\ 9 \times 10^{2}$	4.031 129 726	$4.279\ 433\ 549 \times 10^{-1}$	$-1.952\ 394\ 635 \times 10^{1}$
c_4 =	$-2.270\ 358\ 0 \times 10^{2}$	$-6.249\ 428\ 360 \times 10^{-1}$	$-1.191\ 577\ 910 \times 10^{-2}$	$2.560\ 740\ 231 \times 10^{-1}$
c_5 =	$3.514\ 565\ 9 \times 10^{2}$	$6.468\ 412\ 046 \times 10^{-2}$	$1.492\ 290\ 091 \times 10^{-4}$	. . . .
c_6 =	$-3.895\ 390\ 0 \times 10^{2}$	$-4.458\ 750\ 426 \times 10^{-3}$	. . . .	. . . .
c_7 =	$2.823\ 947\ 1 \times 10^{2}$	$1.994\ 710\ 149 \times 10^{-4}$	. . . .	. . . .
c_8 =	$-1.260\ 728\ 1 \times 10^{2}$	$-5.313\ 401\ 790 \times 10^{-6}$	. . . .	. . . .
c_9 =	$3.135\ 361\ 1 \times 10^{1}$	$6.481\ 976\ 217 \times 10^{-8}$	. . . .	. . . .
c_{10} =	-3.318 776 9	. . . .	. . . .	. . . .

Type S thermocouples: coefficients (c_i) of polynomials for the computation of temperatures in °C as a function of the thermocouple emf in various temperature and emf ranges

Temperature Range:	-50°C to 250°C	250°C to 1200°C	1064°C to 1664.5°C	1664.5°C to 1768.1°C
emf Range:	-0.235 mV to 1.874 mV	1.874 mV to 11.950 mV	10.332 mV to 17.536 mV	17.536 mV to 18.693 mV
c_0 =	0.000 000 00	$1.291\ 507\ 177 \times 10^{1}$	$-8.087\ 801\ 117 \times 10^{1}$	$5.333\ 875\ 126 \times 10^{4}$
c_1 =	$1.849\ 494\ 60 \times 10^{2}$	$1.466\ 298\ 863 \times 10^{2}$	$1.621\ 573\ 104 \times 10^{2}$	$-1.235\ 892\ 298 \times 10^{4}$
c_2 =	$-8.005\ 040\ 62 \times 10^{1}$	$-1.534\ 713\ 402 \times 10^{1}$	-8.536 869 453	$1.092\ 657\ 613 \times 10^{3}$
c_3 =	$1.022\ 374\ 30 \times 10^{2}$	3.145 945 973	$4.719\ 686\ 976 \times 10^{-1}$	$-4.265\ 693\ 686 \times 10^{1}$
c_4 =	$-1.522\ 485\ 92 \times 10^{2}$	$-4.163\ 257\ 839 \times 10^{-1}$	$-1.441\ 693\ 666 \times 10^{-2}$	$6.247\ 205\ 420 \times 10^{-1}$
c_5 =	$1.888\ 213\ 43 \times 10^{2}$	$3.187\ 963\ 771 \times 10^{-2}$	$2.081\ 618\ 890 \times 10^{-4}$	. . . .
c_6 =	$-1.590\ 859\ 41 \times 10^{2}$	$-1.291\ 637\ 500 \times 10^{-3}$	. . . .	. . . .
c_7 =	$8.230\ 278\ 80 \times 10^{1}$	$2.183\ 475\ 087 \times 10^{-5}$	. . . .	. . . .
c_8 =	$-2.341\ 819\ 44 \times 10^{1}$	$-1.447\ 379\ 511 \times 10^{-7}$	. . . .	. . . .
c_9 =	2.797 862 60	$8.211\ 272\ 125 \times 10^{-9}$	. . . .	. . . .

Type T thermocouples: coefficients (c_i) of polynomials for the computation of temperatures in °C as a function of the thermocouple emf in various temperature and emf ranges

Temperature Range:	-200°C to 0°C	0°C to 400°C
emf Range:	-5.603 mV to 0.0 mV	0.0 mV to 20.872 mV
c_0 =	0.000 000 0	0.000 000
c_1 =	$2.594\ 919\ 2 \times 10^{1}$	$2.592\ 800 \times 10^{1}$
c_2 =	$-2.131\ 696\ 7 \times 10^{-1}$	$-7.602\ 961 \times 10^{-1}$
c_3 =	$7.901\ 869\ 2 \times 10^{-1}$	$4.637\ 791 \times 10^{-2}$
c_4 =	$4.252\ 777\ 7 \times 10^{-1}$	$-2.165\ 394 \times 10^{-3}$
c_5 =	$1.330\ 447\ 3 \times 10^{-1}$	$6.048\ 144 \times 10^{-5}$
c_6 =	$2.024\ 144\ 6 \times 10^{-2}$	$-7.293\ 422 \times 10^{-7}$
c_7 =	$1.266\ 817\ 1 \times 10^{-3}$	. . . .

PROPERTIES OF COMMON LABORATORY SOLVENTS

This table give properties of 200 organic solvents which are frequently used in laboratory and industrial applications. Compounds are listed in alphabetical order by the most common name; synonyms are given in some cases. The properties tabulated are:

MF: Molecular formula
CAS RN: Chemical Abstracts Service Registry Number
M_r: Molecular weight
t_m: Melting point in °C
t_b: Normal boiling point in °C
ρ: Density in g/cm³ at the temperature in °C indicated by the superscript
c_p: Specific heat capacity of the liquid at constant pressure at 25°C in J/g K
vp: Vapor pressure at 25°C in kPa (1 kPa = 7.50 mmHg)
μ: Electric dipole moment in debye units. Values in parentheses are measurements on the pure liquid or in solution; these are less reliable than the other values, which were obtained in the gas phase.
FP: Flash point temperature in °C. The fact that no flash point is listed does not necessarily mean that the substance is nonflammable, because some liquids will burn if the quantity is large or impurities are present.
Fl. Lim.: Flammable (explosive) range in air in percent by volume
Ign. Temp.: Autoignition temperature in °C
TLV: Threshold limit for allowable airborne concentration, given in parts per million by volume at 25°C and atmospheric pressure (see table "Threshold Limit Values for Airborne Contaminants" in Section 16)

REFERENCES

1. Lide, D.R., *Handbook of Organic Solvents*, CRC Press, Boca Raton, FL, 1994.
2. Lide, D.R., and Kehiaian, H.V., *CRC Handbook of Thermophysical and Thermochemical Data*, CRC Press, Boca Raton, FL, 1994.
3. Riddick, J.A., Bunger, W.B., and Sakano, T.K., *Organic Solvents, Fourth Edition*, John Wiley & Sons, New York, 1986.
4. *Fire Protection Guide to Hazardous Materials*, 10th Edition , National Fire Protection Association, Quincy, MA, 1991.
5. Urben, P.G., Ed., *Bretherick's Handbook of Reactive Chemical Hazards, 5th Edition,* Butterworth-Heinemann, Oxford, 1995.

Name	MF	CAS RN	M_r	t_m/°C	t_b/°C	ρ/g cm^{-3}	c_p/J g^{-1}K^{-1}	vp/kPa	μ/D	FP/°C	Fl. Lim.	Ign. Temp./°C	TLV
Acetal (1,1-Diethoxyethane)	$C_6H_{14}O_2$	105-57-7	118.18	-100	102.2	0.8254^{20}	2.01	3.68	(1.4)	-21	2-10%	230	
Acetic acid	$C_2H_4O_2$	64-19-7	60.05	17	118	1.0492^{20}	2.06	2.07	1.70	39	4-20%	463	10
Acetone	C_3H_6O	67-64-1	58.08	-95	56	0.7899^{20}	2.18	30.8	2.88	-20	3-13%	465	750
Acetonitrile	C_2H_3N	75-05-8	41.05	-44	82	0.7857^{20}	2.23	11.8	3.92	6	3-16%	524	40
Acetylacetone	$C_5H_8O_2$	123-54-6	100.12	-23	138	0.9721^{25}	2.08	1.02	(2.8)	34		340	
Acrylonitrile	C_3H_3N	107-13-1	53.06	-83.5	77.3	0.8060^{20}	2.05	14.1	3.87	0	3-17%	481	2
Adiponitrile	$C_6H_8N_2$	111-69-3	108.14	1	295	0.9676^{20}	1.19	<0.01		93	2-5%	550	2
Allyl alcohol	C_3H_6O	107-18-6	58.08	-129	97.0	0.8540^{20}	2.39	3.14	1.60	21	3-18%	378	2
Allylamine	C_3H_7N	107-11-9	57.10	-88.2	53.3	0.758^{20}		33.1	1.2	-29	2-22%	374	
2-Aminoisobutanol	$C_4H_{11}NO$	124-68-5	89.14	25.5	165.5	0.934^{20}				67			
Benzal chloride	$C_7H_6Cl_2$	98-87-3	161.03	-17	205	1.26^{25}		0.06	(2.1)				
Benzaldehyde	C_7H_6O	100-52-7	106.12	-26	179.0	1.0415^{10}	1.62	0.17	(3.0)	63		192	
Benzene	C_6H_6	71-43-2	78.11	6	80	0.8765^{20}	1.74	12.7	0	-11	1-8%	498	10
Benzonitrile	C_7H_5N	100-47-0	103.12	-12.7	191.1	1.0093^{15}	1.60	0.11	4.18				
Benzyl chloride	C_7H_7Cl	100-44-7	126.59	-45	179	1.1004^{20}	1.44	0.16	(1.8)	67	1%-	585	1
Bromochloromethane	CH_2BrCl	74-97-5	129.38	-87.9	68.0	1.9344^{20}	0.41	19.5	(1.7)				200
Bromoform (Tribromomethane)	$CHBr_3$	75-25-2	252.73	8.0	149	2.899^{15}	0.52	0.73	0.99	83			0.5

PROPERTIES OF COMMON LABORATORY SOLVENTS (continued)

Name	MF	CAS RN	M_r	t_m/°C	t_b/°C	ρ/g cm^{-3}	c_p/J g^{-1}K^{-1}	vp/kPa	μ/D	FP/°C	Fl. Lim.	Ign. Temp./°C	TLV
Butyl acetate	$C_6H_{12}O_2$	123-86-4	116.16	-78	126	0.8825^{20}	1.96	1.66	(1.9)	22	2-8%	425	150
Butyl alcohol	$C_4H_{10}O$	71-36-3	74.12	-90	118	0.8098^{20}	2.39	0.86	1.66	37	1-11%	343	50
sec-Butyl alcohol	$C_4H_{10}O$	78-92-2	74.12	-114.7	99.5	0.8063^{20}	2.66	2.32	(1.8)	24	2-10%	405	100
tert-Butyl alcohol	$C_4H_{10}O$	75-65-0	74.12	26	82	0.7887^{20}	2.97	5.52	(1.7)	11	2-8%	478	100
Butylamine	$C_4H_{11}N$	109-73-9	73.14	-49	77	0.7414^{20}	2.45	12.2	1.0	-12	2-10%	312	5
tert-Butylamine	$C_4H_{11}N$	75-64-9	73.14	-67	44	0.6958^{20}	2.63	48.4	(1.3)	-9	2-9%	380	
Butyl methyl ketone	$C_6H_{12}O$	591-78-6	100.16	-56	128	0.8113^{20}	2.13	1.54	(2.7)	25	1-8%	423	5
p-*tert*-Butyltoluene	$C_{11}H_{16}$	98-51-1	148.25	-52	190	0.8612^{20}		0.09	≈0	68			10
γ-Butyrolactone	$C_4H_6O_2$	96-48-0	86.09	-43.3	204	1.1284^{16}	1.64	0.43	4.27	98			
Caprolactam	$C_6H_{11}NO$	105-60-2	113.16	69	270		1.38	<0.01	(3.9)	125			5
Carbon disulfide	CS_2	75-15-0	76.14	-112	46	1.2632^{20}	1.00	48.2	0	-30	1-50%	90	10
Carbon tetrachloride	CCl_4	56-23-5	153.82	-23	77	1.5940^{20}	0.85	15.2	0				5
1-Chloro-1,1-difluoroethane	$C_2H_3ClF_2$	75-68-3	100.50	-131	-10	1.107^{25}	1.30	351	2.14				
Chlorobenzene	C_6H_5Cl	108-90-7	112.56	-45	132	1.1058^{20}	1.33	1.6	1.69	28	1-10%	593	10
Chloroform	$CHCl_3$	67-66-3	119.38	-64	61	1.4832^{20}	0.96	26.2	1.04				10
Chloropentafluoroethane	C_2ClF_5	76-15-3	154.47	-99	-38	1.5678^{-42}	1.19	912	0.52				1000
Cumene (Isopropylbenzene)	C_9H_{12}	98-82-8	120.19	-96.0	152	0.8618^{20}	1.75	0.61	0.79	36	1-7%	424	50
Cyclohexane	C_6H_{12}	110-82-7	84.16	7	81	0.7785^{20}	1.84	13.0	≈0	-20	1-8%	245	300
Cyclohexanol	$C_6H_{12}O$	108-93-0	100.16	25	161	0.9624^{20}	2.08	0.10		68	1-9%	300	50
Cyclohexanone	$C_6H_{10}O$	108-94-1	98.14	-31	155	0.9478^{20}	1.86	0.53	2.87	44	1-9%	420	25
Cyclohexylamine	$C_6H_{13}N$	108-91-8	99.18	-18	134	0.8191^{20}		1.20	(1.3)	31	1-9%	293	10
Cyclopentane	C_5H_{10}	287-92-3	70.13	-93.8	49.3	0.7457^{20}	1.84	42.3	≈0	<-7	2%-	361	600
Cyclopentanone	C_5H_8O	120-92-3	84.12	-51.3	130.5	0.9487^{20}	1.84	1.55	3.3	26			
p-Cymene	$C_{10}H_{14}$	99-87-6	134.22	-69	177	0.8573^{20}	1.76	0.19	≈0	47	1-6%	436	
cis-Decalin	$C_{10}H_{18}$	493-01-6	138.25	-42.9	195.8	0.8965^{20}	1.68	0.10	≈0				
trans-Decalin	$C_{10}H_{18}$	493-02-7	138.25	-30.3	187.3	0.8699^{20}	1.65	0.16	≈0	54	1-5%	255	
Diacetone alcohol	$C_6H_{12}O_2$	123-42-2	116.16	-44	168	0.9387^{20}	1.91	0.22	(3.2)	58	2-7%	643	50
1,2-Dibromoethane	$C_2H_4Br_2$	106-93-4	187.86	9.9	131.6	2.1791^{20}	0.72	1.55	(1.2)				
Dibromofluoromethane	$CHBr_2F$	1868-53-7	191.83	-78	64.9	2.421^{20}							
Dibromomethane	CH_2Br_2	74-95-3	173.83	-52.5	97	2.4969^{20}	0.61	6.12	1.43				
1,2-Dibromotetrafluoroethane	$C_2Br_2F_4$	124-73-2	259.82	-110.4	47.3	2.149^{25}	0.69	43.4					
Dibutylamine	$C_8H_{19}N$	111-92-2	129.25	-62	160	0.7670^{20}	2.27	0.34	(1.0)	47	1-6%		
o-Dichlorobenzene	$C_6H_4Cl_2$	95-50-1	147.00	-17	180	1.3059^{20}	1.10	0.18	2.50	66	2-9%	648	25
1,1-Dichloroethane	$C_2H_4Cl_2$	75-34-3	98.96	-97	57	1.1757^{20}	1.28	30.5	2.06	-17	5-11%	458	100
1,2-Dichloroethane	$C_2H_4Cl_2$	107-06-2	98.96	-36	84	1.2351^{20}	1.30	10.6	(1.8)	13	6-16%	413	10
1,1-Dichloroethylene	$C_2H_2Cl_2$	75-35-4	96.94	-122.5	31.6	1.213^{20}	1.15	80.0	1.34	-15	7-16%	570	5
cis-1,2-Dichloroethylene	$C_2H_2Cl_2$	156-59-2	96.94	-80	60	1.2837^{20}	1.20	26.8	1.90	6	3-15%	460	200
trans-1,2-Dichloroethylene	$C_2H_2Cl_2$	156-60-5	96.94	-50	49	1.2565^{20}	1.20	44.2	0	2	6-13%	460	200
Dichloroethyl ether	$C_4H_8Cl_2O$	111-44-4	143.01	-52	179	1.22^{20}	1.54	0.14	(2.6)	55	3%-	369	5
Dichloromethane	CH_2Cl_2	75-09-2	84.93	-95	40	1.3266^{20}	1.19	58.2	1.60		13-23%	556	50
1,2-Dichloropropane	$C_3H_6Cl_2$	78-87-5	112.99	-100	96	1.1560^{20}	1.32	6.62	(1.8)	16	3-15%	557	75
1,2-Dichlorotetrafluoroethane	$C_2Cl_2F_4$	76-14-2	170.92	-94	4	1.518^{4}	0.96	215	0.5				1000
Diethanolamine	$C_4H_{11}NO_2$	111-42-2	105.14	28	269	1.0966^{20}	2.22	<0.01	(2.8)	172	2-13%	662	0.46
Diethylamine	$C_4H_{11}N$	109-89-7	73.14	-50	55	0.7056^{20}	2.31	30.1	0.92	-23	2-10%	312	5
Diethyl carbonate	$C_5H_{10}O_3$	105-58-8	118.13	-43	126	0.9752^{20}	1.80	1.63	1.10	25			
Diethylene glycol	$C_4H_{10}O_3$	111-46-6	106.12	-10	246	1.1197^{15}	2.31	<0.01	(2.3)	124	2-17%	224	
Diethylene glycol dimethyl ether	$C_6H_{14}O_3$	111-96-6	134.18	-68	162	0.9434^{20}	2.04	0.31	(2.0)	67			
Diethylene glycol monoethyl ether	$C_6H_{14}O_3$	111-90-0	134.18		196	0.9885^{20}	2.24	0.02	(1.6)	96			

PROPERTIES OF COMMON LABORATORY SOLVENTS (continued)

Name	MF	CAS RN	M_r	t_m/°C	t_b/°C	ρ/g cm^{-3}	c_p/J g^{-1}K^{-1}	vp/kPa	μ/D	FP/°C	Fl. Lim.	Ign. Temp./°C	TLV
Diethylene glycol monoethyl ether acetate	$C_8H_{16}O_4$	112-15-2	176.21	-25	218.5	1.0096^{20}		0.03	(1.8)	110		425	
Diethylene glycol monomethyl ether	$C_5H_{12}O_3$	111-77-3	120.15		193	1.035^{20}	2.26	0.02	(1.6)	96	1-23%	240	
Diethylenetriamine	$C_4H_{13}N_3$	111-40-0	103.17	-39	207	0.9569^{20}	2.46	0.03	(1.9)	98	2-7%	358	1
Diethyl ether	$C_4H_{10}O$	60-29-7	74.12	-116	34	0.7138^{20}	2.33	71.7	1.15	-45	2-36%	180	400
Diisobutyl ketone	$C_9H_{18}O$	108-83-8	142.24	-42	169	0.8062^{20}	2.09	0.23	(2.7)	49	1-7%	396	25
Diisopropyl ether	$C_6H_{14}O$	108-20-3	102.18	-87	69	0.7241^{20}	2.12	19.9	1.13	-28	1-8%	443	250
N,*N*-Dimethylacetamide	C_4H_9NO	127-19-5	87.12	-20	165	0.9366^{25}	2.02	0.07	(3.7)	70	2-12%	490	10
Dimethylamine	C_2H_7N	124-40-3	45.08	-92	7	0.6804^{0}	3.05	203	1.01	20	3-14%	400	5
Dimethyl disulfide	$C_2H_6S_2$	624-92-0	94.20	-85	109.8	1.0625^{20}	1.55	3.82	(1.8)	24			
N,*N*-Dimethylformamide	C_3H_7NO	68-12-2	73.09	-60	153	0.944^{25}	2.06	0.44	3.82	58	2-15%	445	10
Dimethyl sulfoxide	C_2H_6OS	67-68-5	78.14	19	189	1.1014^{20}	1.96	0.08	3.96	95	3-42%	215	
1,4-Dioxane	$C_4H_8O_2$	123-91-1	88.11	12	101	1.0337^{20}	1.74	4.95	0	12	2-22%	180	25
1,3-Dioxolane	$C_3H_6O_2$	646-06-0	74.08	-95	78	1.060^{20}	1.59	14.6	1.19	2			
Dipentene	$C_{10}H_{16}$	7705-14-8	136.24	-95.5	178	0.8402^{21}	1.83	0.26		45		237	
Epichlorohydrin	C_3H_5ClO	106-89-8	92.52	-26	116	1.1812^{20}	1.42	2.2	(1.8)	31	4-21%	411	2
Ethanolamine (Glycinol)	C_2H_7NO	141-43-5	61.08	11	171	1.0180^{20}	3.20	0.05	(2.3)	86	3-24%	410	3
Ethyl acetate	$C_4H_8O_2$	141-78-6	88.11	-84	77	0.9003^{20}	1.94	12.6	1.78	-4	2-12%	426	400
Ethyl acetoacetate	$C_6H_{10}O_3$	141-97-9	130.14	-45	180.8	1.0368^{10}	1.91	0.09		57	1-10%	295	
Ethyl alcohol	C_2H_6O	64-17-5	46.07	-114	78	0.7893^{20}	2.44	7.87	1.69	13	3-19%	363	1000
Ethylamine	C_2H_7N	75-04-7	45.08	-81	17	0.686^{17}	2.88	142	1.22	<-18	4-14%	385	5
Ethylbenzene	C_8H_{10}	100-41-4	106.17	-95	136	0.8670^{20}	1.73	1.28	0.59	21	1-7%	432	100
Ethyl bromide	C_2H_5Br	74-96-4	108.97	-118.6	38.5	1.4604^{20}	0.93	62.5	2.03		7-8%	511	5
Ethyl chloride	C_2H_5Cl	75-00-3	64.51	-139	12	0.909^{12}	1.62	160	2.05	-50	4-15%	519	1000
Ethylene carbonate	$C_3H_4O_3$	96-49-1	88.06	36.4	248	1.3214^{39}	1.52	<0.01	(4.9)	143			
Ethylenediamine	$C_2H_8N_2$	107-15-3	60.10	11	117	0.8979^{20}	2.87	1.62	1.99	40	3-12%	385	10
Ethylene glycol	$C_2H_6O_2$	107-21-1	62.07	-13	197	1.1088^{20}	2.41	0.01	2.28	111	3-22%	398	50
Ethylene glycol diethyl ether	$C_6H_{14}O_2$	629-14-1	118.18	-74	119.4	0.8484^{20}	2.19	4.33		35			
Ethylene glycol dimethyl ether	$C_4H_{10}O_2$	110-71-4	90.12	-58	85	0.8691^{20}	2.14	9.93		-2		202	
Ethylene glycol monobutyl ether	$C_6H_{14}O_2$	111-76-2	118.18	-75	168	0.9015^{20}	2.38	0.15	(2.1)	69	4-13%	238	25
Ethylene glycol monoethyl ether	$C_4H_{10}O_2$	110-80-5	90.12	-70	135	0.9297^{20}	2.34	0.71	(2.1)	43	3-18%	235	5
Ethylene glycol ethyl ether acetate	$C_6H_{12}O_3$	111-15-9	132.16	-62	156	0.9740^{20}	2.85	0.24	(2.2)	56	2-8%	379	5
Ethylene glycol monomethyl ether	$C_3H_8O_2$	109-86-4	76.10	-85	124	0.9647^{20}	2.25	1.31	2.36	39	2-14%	285	5
Ethylene glycol momomethyl ether acetate	$C_5H_{10}O_3$	110-49-6	118.13	-70	143	1.0074^{19}	2.62	0.67	(2.1)	49	2-12%	392	5
Ethyl formate	$C_3H_6O_2$	109-94-4	74.08	-80	54	0.9168^{20}	2.02	32.3	1.9	-20	3-16%	455	100
Furan	C_4H_4O	110-00-9	68.08	-86	31	0.9514^{20}	1.69	80.0	0.66	<0	2-14%		
Furfural	$C_5H_4O_2$	98-01-1	96.09	-37	162	1.1594^{20}	1.70	0.29	(3.5)	60	2-19%	316	2
Furfuryl alcohol	$C_5H_6O_2$	98-00-0	98.10	-31	171	1.1296^{20}	2.08	0.10	(1.9)	75	2-16%	491	10
Glycerol	$C_3H_8O_3$	56-81-5	92.09	18	290	1.2613^{20}	2.38	<0.01	(2.6)	199	3-19%	370	
Heptane	C_7H_{16}	142-82-5	100.20	-91	98	0.6837^{20}	2.24	6.09	≈0	-4	1-7%	204	400
1-Heptanol	$C_7H_{16}O$	111-70-6	116.20	-34	176.4	0.8219^{20}	2.34						
Hexane	C_6H_{14}	110-54-3	86.18	-95	69	0.6548^{25}	2.27	20.2	≈0	-22	1-8%	225	50
1-Hexanol (Caproyl alcohol)	$C_6H_{14}O$	111-27-3	102.18	-44.6	157.6	0.8136^{20}	2.35	0.11		63			
Hexylene glycol	$C_6H_{14}O_2$	107-41-5	118.18	-50	197	0.923^{15}	2.84	<0.01	(2.9)	102	1-9%	306	25
Hexyl methyl ketone	$C_8H_{16}O$	111-13-7	128.21	-16	172.5	0.820^{20}	2.13		(2.7)	52			
Isobutyl acetate	$C_6H_{12}O_2$	110-19-0	116.16	-99	117	0.8712^{20}	2.01	2.39	(1.9)	18	1-11%	421	150
Isobutyl alcohol	$C_4H_{10}O$	78-83-1	74.12	-108	108	0.8018^{20}	2.44	1.39	1.64	28	2-11%	415	50

PROPERTIES OF COMMON LABORATORY SOLVENTS (continued)

Name	MF	CAS RN	M_r	t_m/°C	t_b/°C	ρ/g cm^{-3}	c_p/J g^{-1}K^{-1}	vp/kPa	μ/D	FP/°C	Fl. Lim.	Ign. Temp./°C	TLV
Isobutylamine	$C_4H_{11}N$	78-81-9	73.14	-87	68	0.724^{25}	2.50	19.0	(1.3)	-9	2-12%	378	
Isopentyl acetate	$C_7H_{14}O_2$	123-92-2	130.19	-79	143	0.876^{15}	1.91	0.73	(1.9)	25	1-8%	360	100
Isophorone	$C_9H_{14}O$	78-59-1	138.21	-8	215	0.9255^{20}	1.83	0.06		84	1-4%	460	5
Isopropyl acetate	$C_5H_{10}O_2$	108-21-4	102.13	-73	89	0.8718^{20}	1.95	8.1		2	2-8%	460	250
Isopropyl alcohol	C_3H_8O	67-63-0	60.10	-90	82	0.7855^{20}	2.58	6.02	1.56	12	2-13%	399	400
Isoquinoline	C_9H_7N	119-65-3	129.16	26.47	243.2	1.0910^{30}	1.52		2.73				
d-Limonene (Citrene)	$C_{10}H_{16}$	5989-27-5	136.24	-97	178	0.8411^{20}	1.83	0.28		49			
2,6-Lutidine	C_7H_9N	108-48-5	107.16	-6.1	144.1	0.9226^{20}	1.73	0.75	(1.7)				
Mesitylene	C_9H_{12}	108-67-8	120.19	-45	165	0.8652^{20}	1.74	0.33	0	50	1-5%	559	25
Mesityl oxide	$C_6H_{10}O$	141-79-7	98.14	-59	130	0.8653^{20}	2.17	1.47	(2.8)	31	1-7%	344	15
Methyl acetate	$C_3H_6O_2$	79-20-9	74.08	-98	57	0.9342^{20}	1.92	28.8	1.72	-10	3-16%	454	200
Methylal	$C_3H_8O_2$	109-87-5	76.10	-105	42	0.8593^{20}	2.12	53.1	(0.7)	-32	2-14%	237	1000
Methyl alcohol	CH_4O	67-56-1	32.04	-98	65	0.7914^{20}	2.53	16.9	1.70	11	6-36%	464	200
Methylamine	CH_5N	74-89-5	31.06	-93	-6	0.656^{25}	3.29	353	1.31	0	5-21%	430	5
Methyl benzoate	$C_8H_8O_2$	93-58-3	136.15	-15	199	1.0933^{15}	1.63	0.05	(1.9)	83			
Methylcyclohexane	C_7H_{14}	108-87-2	98.19	-127	101	0.7694^{20}	1.88	6.18	≈0	-4	1-7%	250	400
Methyl ethyl ketone	C_4H_8O	78-93-3	72.11	-87	80	0.8054^{20}	2.20	12.6	2.78	-9	1-11%	404	200
N-Methylformamide	C_2H_5NO	123-39-7	59.07	-3.8	199.5	1.011^{19}	2.10		3.83				
Methyl formate	$C_2H_4O_2$	107-31-3	60.05	-99	32	0.9742^{20}	1.98	78.1	1.77	-19	5-23%	449	100
Methyl iodide	CH_3I	74-88-4	141.94	-66.4	42.5	2.279^{20}	0.89	53.9	1.62				2
Methyl isobutyl ketone	$C_6H_{12}O$	108-10-1	100.16	-84	116	0.7978^{20}	2.13	2.64		18	1-8%	448	50
Methyl isopentyl ketone	$C_7H_{14}O$	110-12-3	114.19		144	0.888^{20}		0.69		36	1-8%	191	50
2-Methylpentane	C_6H_{14}	107-83-5	86.18	-153.7	60.2	0.650^{25}	2.25	28.2	≈0	<-29	1-7%	264	
4-Methyl-2-pentanol	$C_6H_{14}O$	108-11-2	102.18	-90	132	0.8075^{20}	2.67	0.70		41	1-6%		25
Methyl pentyl ketone	$C_7H_{14}O$	110-43-0	114.19	-35	151	0.8111^{20}	2.04	0.49	(2.6)	39	1-8%	393	50
Methyl propyl ketone	$C_5H_{10}O$	107-87-9	86.13	-77	102	0.809^{20}	2.14	4.97	(2.7)	7	2-8%	452	200
N-Methyl-2-pyrrolidone	C_5H_9NO	872-50-4	99.13	-24	202	1.0230^{25}	3.11	0.04	(4.1)	96	1-10%	346	
Morpholine	C_4H_9NO	110-91-8	87.12	-5	128	1.0005^{20}	1.89	1.34	1.55	37	1-11%	290	20
Nitrobenzene	$C_6H_5NO_2$	98-95-3	123.11	6	211	1.2037^{20}	1.51	0.03	4.22	88	2-9%	482	1
Nitroethane	$C_2H_5NO_2$	79-24-3	75.07	-90	114	1.0448^{25}	1.79	2.79	3.23	28	3-17%	414	100
Nitromethane	CH_3NO_2	75-52-5	61.04	-29	101	1.1371^{20}	1.75	4.79	3.46	35	7-22%	418	20
1-Nitropropane	$C_3H_7NO_2$	108-03-2	89.09	-108	131.1	0.9961^{25}	1.97	1.36	3.66	36	2%-	421	25
2-Nitropropane	$C_3H_7NO_2$	79-46-9	89.09	-91	120	0.9821^{25}	1.91	2.3	3.73	24	3-11%	428	10
Octane	C_8H_{18}	111-65-9	114.23	-57	126	0.6986^{25}	2.23	1.86	≈0	13	1-7%	206	300
1-Octanol	$C_8H_{18}O$	111-87-5	130.23	-15.5	195.1	0.8262^{25}	2.34	0.01	(1.8)	81			
Pentachloroethane	C_2HCl_5	76-01-7	202.29	-29	160	1.6796^{20}	0.86	0.48	0.92				
Pentamethylene glycol	$C_5H_{12}O_2$	111-29-5	104.15	-18	239	0.9914^{20}	3.08		(2.5)	129		335	
Pentane	C_5H_{12}	109-66-0	72.15	-130	36	0.6262^{20}	2.32	68.3	≈0	<-40	2-8%	260	600
1-Pentanol	$C_5H_{12}O$	71-41-0	88.15	-79	138	0.8144^{20}	2.36	0.26	(1.7)	33	1-10%	300	
Pentyl acetate	$C_7H_{14}O_2$	628-63-7	130.19	-71	149	0.8756^{20}	2.00	0.60	1.75	16	1-8%	360	100
2-Picoline	C_6H_7N	109-06-8	93.13	-67	129	0.9443^{20}	1.70	1.5	1.85	39		538	
α-Pinene	$C_{10}H_{16}$	80-56-8	136.24	-64	156	0.8539^{25}		0.64		35		275	
β-Pinene	$C_{10}H_{16}$	127-91-3	136.24	-61.5	166	0.860^{25}		0.61		38		275	
Piperidine	$C_5H_{11}N$	110-89-4	85.15	-11	106	0.8606^{20}	2.11	4.28	(1.2)	16	1-10%		
Propanenitrile	C_3H_5N	107-12-0	55.08	-93	97	0.7818^{20}	2.17	6.14	4.05	2	3-14%	512	
Propyl acetate	$C_5H_{10}O_2$	109-60-4	102.13	-93	102	0.8878^{20}	1.92	4.49	(1.8)	13	2-8%	450	200
Propyl alcohol	C_3H_8O	71-23-8	60.10	-126	97	0.8035^{20}	2.39	2.76	1.55	23	2-14%	412	200
Propylamine	C_3H_9N	107-10-8	59.11	-83	47	0.7173^{20}	2.75	42.1	1.17	-37	2-10%	318	
Propylbenzene	C_9H_{12}	103-65-1	120.19	-99.5	159.2	0.8620^{20}	1.79		≈0	30	1-6%	450	

PROPERTIES OF COMMON LABORATORY SOLVENTS (continued)

Name	MF	CAS RN	M_r	t_m/°C	t_b/°C	ρ/g cm^{-3}	c_p/J g^{-1}K^{-1}	vp/kPa	μ/D	FP/°C	Fl. Lim.	Ign. Temp./°C	TLV
Propylene glycol	$C_3H_8O_2$	57-55-6	76.10	-60	188	1.0361^{20}	2.51	0.02	(2.2)	99	3-13%	371	
Pseudocumene	C_9H_{12}	95-63-6	120.19	-44	169	0.8758^{20}	1.79	0.30	≈0	44	1-6%	500	25
Pyridine	C_5H_5N	110-86-1	79.10	-42	115	0.9819^{20}	1.68	2.76	2.21	20	2-12%	482	5
Pyrrole	C_4H_5N	109-97-7	67.09	-23.4	129.7	0.9698^{20}	1.90	1.10	1.74	39			
Pyrrolidine	C_4H_9N	123-75-1	71.12	-57.8	86.5	0.8586^{20}	2.20	8.40	(1.6)	3			
2-Pyrrolidone	C_4H_7NO	616-45-5	85.11	25	251	1.120^{20}	1.99		(3.5)	129			
Quinoline	C_9H_7N	91-22-5	129.16	-14.78	237.1	1.0977^{15}	1.51		2.29			480	
Styrene	C_8H_8	100-42-5	104.15	-31	145	0.9060^{20}	1.75	0.81		31	1-7%	490	50
Sulfolane	$C_4H_8O_2S$	126-33-0	120.17	28	287	1.2723^{18}	1.50	<0.01	(4.8)	177			
α-Terpinene	$C_{10}H_{16}$	99-86-5	136.24		174	0.8375^{19}							
1,1,1,2-Tetrachloro-2,2-difluoroethane	$C_2Cl_4F_2$	76-11-9	203.83	40.6	91.5	1.649^{25}		7.36					500
1,1,2,2-Tetrachloro-1,2-difluoroethane	$C_2Cl_4F_2$	76-12-0	203.83	26	93	1.6447^{25}	0.85	7.51					500
1,1,1,2-Tetrachloroethane	$C_2H_2Cl_4$	630-20-6	167.85	-70	131	1.5406^{20}	0.92	1.6			5-12%		
1,1,2,2-Tetrachloroethane	$C_2H_2Cl_4$	79-34-5	167.85	-44	146	1.5953^{20}	0.97	0.62	1.32		20-54%		1
Tetrachloroethylene	C_2Cl_4	127-18-4	165.83	-22	121	1.6227^{20}	0.86	2.42	0				50
Tetraethylene glycol	$C_8H_{18}O_5$	112-60-7	194.23	-6.2	328	1.1285^{15}	2.21			182			
Tetrahydrofuran	C_4H_8O	109-99-9	72.11	-108	65	0.8892^{20}	1.72	21.6	1.75	-14	2-12%	321	200
1,2,3,4-Tetrahydronaphthalene	$C_{10}H_{12}$	119-64-2	132.21	-36	208	0.9660^{25}	1.65	0.05	≈0	71	1-5%	385	
Tetrahydropyran	$C_5H_{10}O$	142-68-7	86.13	-45	88	0.8814^{20}	1.82	9.54	1.74	-20			
Tetramethylsilane	$C_4H_{12}Si$	75-76-3	88.22	-99.0	26.6	0.648^{19}	2.31	94.2	0				
Toluene	C_7H_8	108-88-3	92.14	-95	111	0.8669^{20}	1.70	3.79	0.37	4	1-7%	480	50
o-Toluidine	C_7H_9N	95-53-4	107.16	-16.3	200.3	0.9984^{20}	1.96	0.04	(1.6)	85		482	2
Triacetin	$C_9H_{14}O_6$	102-76-1	218.21	-78	259	1.1583^{20}	1.76	<0.01		138	1%-	433	
Tributylamine	$C_{12}H_{27}N$	102-82-9	185.35	-70	217	0.7770^{20}		0.01	(0.8)	86	1-5%		
1,1,1-Trichloroethane	$C_2H_3Cl_3$	71-55-6	133.40	-30	74	1.3390^{20}	1.08	16.5	1.76		8-13%	537	350
1,1,2-Trichloroethane	$C_2H_3Cl_3$	79-00-5	133.40	-37	114	1.4397^{20}	1.13	3.1	(1.4)	32	6-28%	460	10
Trichloroethylene	C_2HCl_3	79-01-6	131.39	-85	87	1.4642^{20}	0.95	9.91	(0.8)	32	8-11%	420	50
Trichlorofluoromethane	CCl_3F	75-69-4	137.37	-111	24	1.478^{24}	0.89	106	0.46				1000
1,1,2-Trichlorotrifluoroethane	$C_2Cl_3F_3$	76-13-1	187.38	-35	48	1.5635^{25}	0.91	44.8					1000
Triethanolamine	$C_6H_{15}NO_3$	102-71-6	149.19	21	335	1.1242^{20}	2.61	<0.01	(3.6)	179	1-10%		0.5
Triethylamine	$C_{10}H_{22}O_2$	121-44-8	101.19	-115	89	0.7275^{20}	2.17	7.70	0.66	-7	1-8%	249	1
Triethylene glycol	$C_6H_{14}O_4$	112-27-6	150.17	-7	285	1.1274^{15}	2.18			177	1-9%	371	
Triethyl phosphate	$C_6H_{15}O_4P$	78-40-0	182.16	-56.4	215.5	1.0695^{20}			(3.1)	115		454	
Trimethylamine	C_3H_9N	75-50-3	59.11	-117	3	0.627^{25}	2.33	215	0.61	-7	2-12%	190	5
Trimethylene glycol	$C_3H_8O_2$	504-63-2	76.10	-26.7	214.4	1.0538^{20}			(2.5)			400	
Trimethyl phosphate	$C_3H_9O_4P$	512-56-1	140.08	-46	197.2	1.2144^{20}		0.11	(3.2)	107			
Veratrole	$C_8H_{10}O_2$	91-16-7	138.17	22.5	206	1.0810^{25}			(1.3)				
o-Xylene	C_8H_{10}	95-47-6	106.17	-25	144	0.8802^{10}	1.75	0.88	0.64	32	1-7%	463	100
m-Xylene	C_8H_{10}	108-38-3	106.17	-48	139	0.8642^{20}	1.72	1.13	≈0	27	1-7%	527	100
p-Xylene	C_8H_{10}	106-42-3	106.17	13	138	0.8611^{20}	1.71	1.19	0	27	1-7%	528	100

DEPENDENCE OF BOILING POINT ON PRESSURE

The normal boiling point of a liquid is defined as the temperature at which the vapor pressure reaches standard atmospheric pressure, 101.325 kPa. The change in boiling point with pressure may be calculated from the representation of the vapor pressure by the Antoine Equation,

$$\ln p = A_1 - A_2/(T + A_3)$$

where p is the vapor pressure, T the absolute temperature, and A_1, A_2, and A_3 are constants. This table, which has been calculated using the Antoine constants in Reference 1, gives values of $\Delta t/\Delta p$ for a number of liquids, in units of both °C/kPa and °C/mmHg. The correction to the boiling point is generally accurate to 0.1 to 0.2 °C as long as the pressure is within 10% of standard atmospheric pressure.

A slightly less accurate estimate of $\Delta t/\Delta p$ may be obtained from the Claussius-Clapeyron equation, with the assumption that the change in volume upon vaporization equals the ideal-gas volume of the vapor. This leads to the equation

$$\Delta t/\Delta p = RT_b^2/p_0\,\Delta_{vap}H(T_b)$$

where R is the molar gas constant, p_0 is 101.325 kPa, T_b is the normal boiling point temperature (absolute), and $\Delta_{vap}H(T_b)$ is the molar enthalpy of vaporization at the normal boiling point. Values of the last quantity may be obtained from the table "Enthalpy of Vaporization" in Section 6.

REFERENCE

1. Lide, D.R., and Kehiaian, H.V., *CRC Handbook of Thermophysical and Thermochemical Data*, CRC Press, Boca Raton, FL, 1994, pp. 49-59.

Compound	t_b °C	$\Delta t/\Delta p$ °C/kPa	$\Delta t/\Delta p$ °C/mmHg
Acetaldehyde	20.1	0.261	0.0348
Acetic acid	117.9	0.324	0.0432
Acetone	56.0	0.289	0.0385
Acetonitrile	81.6	0.316	0.0421
Ammonia	-33.33	0.198	0.0264
Aniline	184.1	0.378	0.0504
Anisole	153.7	0.367	0.0489
Benzaldehyde	179.0	0.392	0.0523
Benzene	80.0	0.321	0.0428
Bromine	58.8	0.300	0.0400
Butane	-0.5	0.267	0.0356
1-Butanol	117.7	0.278	0.0371
Carbon disulfide	46.2	0.304	0.0405
Chlorine	-34.04	0.224	0.0299
Chlorobenzene	131.7	0.365	0.0487
1-Chlorobutane	78.6	0.321	0.0428
Chloroethane	12.3	0.262	0.0349
Chloroethylene	-13.3	0.241	0.0321
Cyclohexane	80.7	0.328	0.0437
Cyclohexanol	160.8	0.344	0.0459
Cyclohexanone	155.4	0.382	0.0509
Decane	174.1	0.388	0.0517
Dibutyl ether	140.2	0.363	0.0484
Dichloromethane	39.6	0.276	0.0368
Diethyl ether	34.5	0.278	0.0371
Dimethyl sulfoxide	189.0	0.379	0.0505
1,4-Dioxane	101.5	0.321	0.0428
Dipropyl ether	90.0	0.326	0.0435
Ethanol	78.2	0.249	0.0332
Ethyl acetate	77.1	0.300	0.0400
Ethylene glycol	197.3	0.331	0.0441
Heptane	98.5	0.336	0.0448
Hexafluorobenzene	80.2	0.305	0.0407
Hexane	68.7	0.314	0.0419
1-Hexanol	157.6	0.318	0.0424
Hydrogen fluoride	20.1	0.276	0.0368
Iodomethane	42.5	0.291	0.0388
Isobutane	-11.7	0.254	0.0339
Methanol	64.6	0.251	0.0335
Methyl acetate	56.8	0.282	0.0376
Methyl formate	31.7	0.582	0.0776
N-Methylaniline	196.2	0.396	0.0528
N-Methylformamide	199.5	0.371	0.0495
Nitrobenzene	210.8	0.418	0.0557
Nitromethane	101.1	0.320	0.0427
1-Octanol	195.1	0.360	0.0480
Pentane	36.0	0.289	0.0385
1-Pentanol	137.9	0.296	0.0395
Phenol	181.8	0.349	0.0465
Propane	-42.1	0.224	0.0299
1-Propanol	97.2	0.261	0.0348
2-Propanol	82.3	0.247	0.0329
Pyridine	115.2	0.340	0.0453
Pyrrole	129.7	0.330	0.0440
Pyrrolidine	86.5	0.309	0.0412
Styrene	145.1	0.369	0.0492
Sulfur dioxide	-10.05	0.221	0.0295
Tetrachloroethylene	121.3	0.354	0.0472
Tetrachloromethane	76.8	0.325	0.0433
Toluene	110.6	0.353	0.0471
Trichloroethylene	87.2	0.330	0.0440
Trichloromethane	61.1	0.302	0.0403
Trimethylamine	2.8	0.248	0.0331
Water	100.0	0.276	0.0368
o-Xylene	144.5	0.373	0.0497
m-Xylene	139.1	0.368	0.0491
p-Xylene	138.3	0.369	0.0492

EBULLIOSCOPIC CONSTANTS FOR CALCULATION OF BOILING POINT ELEVATION

The boiling point T_b of a dilute solution of a non-volatile, non-dissociating solute is elevated relative to that of the pure solvent. If the solution is ideal (i.e., follows Raoult's Law), the amount of elevation depends only on the number of particles of solute present. Hence the change in boiling point ΔT_b can be expressed as

$$\Delta T_b = E_b\, m_2$$

where m_2 is the molality (moles of solute per kilogram of solvent) and E_b is the Ebullioscopic Constant, a characteristic property of the solvent. The Ebullioscopic Constant may be calculated from the relation

$$E_b = R\, T_b^2\, M/\Delta_{vap}H$$

where R is the molar gas constant, T_b is the normal boiling point temperature (absolute) of the solvent, M the molar mass of the solvent, and $\Delta_{vap}H$ the molar enthalpy (heat) of vaporization of the solvent at its normal boiling point.

This table lists E_b values for some common solvents, as calculated from data in the table "Enthalpy of Vaporization" in Section 6.

Compound	E_b/K kg mol^{-1}
Acetic acid	3.22
Acetone	1.80
Acetonitrile	1.44
Aniline	3.82
Anisole	4.20
Benzaldehyde	4.24
Benzene	2.64
1-Butanol	2.17
Carbon disulfide	2.42
Chlorobenzene	4.36
1-Chlorobutane	3.13
Cyclohexane	2.92
Cyclohexanol	3.5
Decane	6.10
Dichloromethane	2.42
Diethyl ether	2.20
Dimethyl sulfoxide	3.22
1,4-Dioxane	3.01
Ethanol	1.23
Ethyl acetate	2.82
Ethylene glycol	2.26
Heptane	3.62
Hexane	2.90
Iodomethane	4.31
Methanol	0.86
Methyl acetate	2.21
N-Methylaniline	4.3
N-Methylformamide	2.2
Nitrobenzene	5.2
Nitromethane	2.09
1-Octanol	5.06
Phenol	3.54
1-Propanol	1.66
2-Propanol	1.58
Pyridine	2.83
Pyrrole	2.33
Pyrrolidine	2.32
Tetrachloroethylene	6.18
Tetrachloromethane	5.26
Toluene	3.40
Trichloroethylene	4.52
Trichloromethane	3.80
Water	0.513
o-Xylene	4.25

CRYOSCOPIC CONSTANTS FOR CALCULATION OF FREEZING POINT DEPRESSION

The freezing point T_f of a dilute solution of a non-volatile, non-dissociating solute is depressed relative to that of the pure solvent. If the solution is ideal (i.e., follows Raoult's Law), this lowering is a function only of the number of particles of solute present. Thus the absolute value of the lowering of freezing point ΔT_f can be expressed as

$$\Delta T_f = E_f \, m_2$$

where m_2 is the molality (moles of solute per kilogram of solvent) and E_f is the Cryoscopic Constant, a characteristic property of the solvent. The Cryoscopic Constant may be calculated from the relation

$$E_f = R \, T_f^2 \, M/\Delta_{fus}H$$

where R is the molar gas constant, T_b is the freezing point temperature (absolute) of the solvent, M the molar mass of the solvent, and $\Delta_{fus}H$ the molar enthalpy (heat) of fusion of the solvent.

This table lists cryscopic constants for selected substances, as calculated from data in the table "Enthalpy of Fusion" in Section 6.

Compound	E_f/K kg mol^{-1}
Acetamide	3.92
Acetic acid	3.63
Acetophenone	5.16
Aniline	5.23
Benzene	5.07
Benzonitrile	5.35
Benzophenone	8.58
(+)-Camphor	37.8
1-Chloronaphthalene	7.68
o-Cresol	5.92
m-Cresol	7.76
p-Cresol	7.20
Cyclohexane	20.8
Cyclohexanol	42.2
cis-Decahydronaphthalene	6.42
trans-Decahydronaphthalene	4.70
Dibenzyl ether	6.17
p-Dichlorobenzene	7.57
Diethanolamine	3.16
Dimethyl sulfoxide	3.85
1,4-Dioxane	4.63
Diphenylamine	8.38
Ethylene glycol	3.11
Formamide	4.25
Formic acid	2.38
Glycerol	3.56
Methylcyclohexane	2.60
Naphthalene	7.45
Nitrobenzene	6.87
Phenol	6.84
Pyridine	4.26
Quinoline	6.73
Succinonitrile	19.3
1,1,2,2-Tetrabromoethane	21.4
1,1,2,2-Tetrachloro-1,2-difluoroethane	41.0
Toluene	3.55
p-Toluidine	4.91
Tribromomethane	15.0
Water	1.86
p-Xylene	4.31

FREEZING POINT LOWERING BY ELECTROLYTES IN AQUEOUS SOLUTION

REFERENCE

Forsythe, W. E., *Smithsonian Physical Tables, Ninth Edition*, Smithsonian Institution, Washington, 1956.

	Lowering of freezing point of water (in °C) as function of molality (mol/kg)									
Compound	**0.05**	**0.10**	**0.25**	**0.50**	**0.75**	**1.00**	**1.50**	**2.00**	**2.50**	**3.00**
$CaCl_2$	0.25	0.49	1.27	2.66	4.28	6.35	10.78	15.27	20.42	28.08
$CuSO_4$	0.13	0.23	0.47	0.96						
HCl	0.18	0.36	0.90	1.86	2.90	4.02	6.63	9.94		
HNO_3	0.18	0.35	0.88	1.80	2.78	3.80	5.98	8.34	10.95	13.92
H_2SO_4	0.20	0.39	0.96	1.95	3.04	4.28	7.35	11.35	16.32	
KBr	0.18	0.36	0.92	1.78						
KCl	0.17	0.35	0.86	1.68	2.49	3.29	4.88	6.50	8.14	9.77
KNO_3	0.17	0.33	0.78	1.47	2.11	2.66				
K_2SO_4	0.23	0.43	1.01	1.87						
LiCl	0.18	0.35	0.88	1.80	2.78					
$MgSO_4$	0.13	0.24	0.55	1.01	1.50	2.08	3.41			
NH_4Cl	0.17	0.34	0.85	1.70	2.55					
NaCl	0.18	0.35	0.85	1.68	2.60					
$NaNO_3$	0.18	0.36	0.80	1.62	2.63	3.10				

DETERMINATION OF RELATIVE HUMIDITY FROM DEW POINT

The relative humidity of a water vapor-air mixture is defined as 100 times the partial pressure of water divided by the saturation vapor pressure of water at the same temperature. The relative humidity may be determined from the dew point t_{dew}, which is the temperature at which liquid water first condenses when the mixture is cooled from an initial temperature *t*. This table gives relative humidity as a function of the dew point depression $t - t_{dew}$ for several values of the dew point. Values are calculated from the vapor pressure table in Section 6.

	t_{dew}/°C				
$t - t_{dew}$	-10	0	10	20	30
0.0	100	100	100	100	100
0.2	99	99	99	99	99
0.4	97	97	97	98	98
0.6	95	96	96	96	97
0.9	94	94	95	95	96
1.0	92	93	94	94	94
1.2	91	92	92	93	93
1.4	90	90	91	92	92
1.6	88	89	90	91	91
1.8	87	88	89	90	90
2.0	86	87	88	88	89
2.2	84	85	86	87	89
2.4	83	84	85	86	87
2.6	82	83	84	85	86
2.8	80	82	83	84	85
3.0	79	81	82	83	84
3.2	78	80	81	82	83
3.4	77	79	80	81	82
3.6	76	77	79	80	82
3.8	75	76	78	79	81
4.0	73	75	77	78	80
4.2	72	74	76	77	79
4.4	71	73	75	77	78
4.6	70	72	74	76	77
4.8	69	71	73	75	76
5.0	69	70	72	74	75
5.2	67	69	71	73	75
5.4	66	68	70	72	74
5.6	65	67	69	71	73
5.9	64	66	69	70	72
6.0	63	66	68	70	71
6.2	62	65	67	69	71
6.4	61	64	66	68	70
6.6	60	63	65	67	69
6.8	60	62	64	66	68
7.0	59	61	63	66	68
7.2	58	60	63	65	67
7.4	57	60	62	64	66
7.6	56	59	61	63	65
7.8	55	58	60	63	65
8.0	54	57	60	62	64
8.2	54	56	59	61	63
8.4	53	56	58	60	63
8.6	52	55	57	60	62
8.8	51	54	57	59	61
9.0	51	53	56	58	61
9.2	50	53	55	58	60
9.4	49	52	55	57	59
9.6	48	51	54	56	59
9.8	48	51	53	56	58
10.0	47	50	53	55	57
10.5	45	48	51	54	56
11.0	44	47	49	52	55
11.5	42	45	48	51	53
12.0	41	44	47	49	52
12.5	39	42	45	48	50
13.0	38	41	44	46	49
13.5	37	40	43	45	48
14.0	35	38	41	44	47
14.5	34	37	40	43	45
15.0	33	36	39	42	44
15.5	32	35	38	40	
16.0	31	34	37	39	
16.5	30	33	36	38	
17.0	29	32	35	37	
17.5	28	31	34	36	
18.0	27	30	33	35	
18.5	26	29	32	34	
19.0	25	28	31	33	
19.5	24	27	30	33	
20.0	24	26	29	32	
21.0	22	25	27	30	
22.0	21	23	26	29	
23.0	19	22	24	27	
24.0	18	21	23	26	
25.0	17	19	22	24	
26.0	16	18	21	23	
27.0	15	17	20	22	
28.0	14	16	19	21	
29.0	13	15	18	20	
30.0	12	14	17	19	

DETERMINATION OF RELATIVE HUMIDITY FROM WET AND DRY BULB TEMPERATURES

Relative humidity may be determined by comparing temperature readings of wet and dry bulb thermometers. The following table, extracted from more extensive U.S. National Weather Service tables, gives the relative humidity as a function of air temperature t_d (dry bulb) and the difference t_d - t_w between dry and wet bulb temperatures. The data assume a pressure near normal atmospheric pressure and an instrumental configuration with forced ventilation.

	(t_d - t_w)/°C											
t_d/°C	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**
-10	83	67	51	35	19							
-8	86	71	57	43	29	15						
-6	88	74	61	49	37	25	8					
-4	89	77	66	55	44	33	23	12				
-2	90	79	69	60	50	40	31	22	12			
0	91	81	72	64	55	46	38	29	21	13	5	
2	91	84	76	68	60	52	44	37	29	22	14	7
4	92	85	78	71	63	57	49	43	36	29	22	16
6	93	86	79	73	66	60	54	48	41	35	29	24
8	93	87	81	75	69	63	57	51	46	40	35	29
10	94	88	82	77	71	66	60	55	50	44	39	34
12	94	89	83	78	73	68	63	58	53	48	43	39
14	95	90	85	79	75	70	65	60	56	51	47	42
16	95	90	85	81	76	71	67	63	58	54	50	46
18	95	91	86	82	77	73	69	65	61	57	53	49
20	96	91	87	83	78	74	70	66	63	59	55	51
22	96	92	87	83	80	76	72	68	64	61	57	54
24	96	92	88	84	80	77	73	69	66	62	59	56
26	96	92	88	85	81	78	74	71	67	64	61	58
28	96	93	89	85	82	78	75	72	69	65	62	59
30	96	93	89	86	83	79	76	73	70	67	64	61
35	97	94	90	87	84	81	78	75	72	69	67	64
40	97	94	91	88	85	82	80	77	74	72	69	67

	(t_d - t_w)/°C											
t_d/°C	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**	**10.0**	**11.0**	**12.0**	**13.0**	**14.0**	**15.0**
4	9											
6	17	11	5									
8	24	19	14	8								
10	29	24	20	15	10	6						
12	34	29	25	21	16	12	5					
14	38	34	30	26	22	18	10					
16	42	38	34	30	26	23	15	8				
18	45	41	38	34	30	27	20	14	7			
20	48	44	41	37	34	31	24	18	12	6		
22	50	47	44	40	37	34	28	22	17	11	6	
24	53	49	46	43	40	37	31	26	20	15	10	5
26	54	51	49	46	43	40	34	29	24	19	14	10
28	56	53	51	48	45	42	37	32	27	22	18	13
30	58	55	52	50	47	44	39	35	30	25	21	17
32	60	57	54	51	49	46	41	37	32	28	24	20
34	61	58	56	53	51	48	43	39	35	30	26	23
36	62	59	57	54	52	50	45	41	37	33	29	25
38	63	61	58	56	54	51	47	43	39	35	31	27
40	64	62	59	57	54	53	48	44	40	36	33	29

CONSTANT HUMIDITY SOLUTIONS

Anthony Wexler

An excess of a water soluble salt in contact with its saturated solution and contained within an enclosed space produces a constant relative humidity and water vapor pressure according to

$$RH = A \exp(B/T)$$

where *RH* is the percent relative humidity (generally accurate to ±2 %), *T* is the temperature in kelvin, and the constants *A* and *B* and the range of valid temperatures are given in the table below. The vapor pressure, *p*, can be calculated from

$$p = (RH/100) \times p_0$$

where p_0 is the vapor pressure of pure water at temperature *T* as given in the table in Section 6 titled "Vapor Pressure of Water from 0 to 370°C".

REFERENCES

1. Wexler, A. S. and Seinfeld, J. H., *Atmospheric Environment*, 25A, 2731, 1991.
2. Greenspan, L., *J. Res. National Bureau of Standards*, 81A, 89, 1977.
3. Broul, et al., *Solubility of Inorganic Two-Component Systems*, Elsevier, New York, 1981.
4. Wagman, D. D. et al., *J. Phys. Chem. Ref. Data*, Vol. 11, Suppl. 2, 1982.

Compound	Temperature range (°C)	*RH* 25°C	*A*	*B*
$NaOH \cdot H_2O$	15—60	6	5.48	27
$LiBr \cdot 2H_2O$	10—30	6	0.23	996
$ZnBr_2 \cdot 2H_2O$	5—30	8	1.69	455
$KOH \cdot 2H_2O$	5—30	9	0.014	1924
$LiCl \cdot H_2O$	20—65	11	14.53	–75
$CaBr_2 \cdot 6H_2O$	11—22	16	0.17	1360
$LiI \cdot 3H_2O$	15—65	18	0.15	1424
$CaCl_2 \cdot 6H_2O$	15—25	29	0.11	1653
$MgCl_2 \cdot 6H_2O$	5—45	33	29.26	34
$NaI \cdot 2H_2O$	5—45	38	3.62	702
$Ca(NO_3)_2 \cdot 4H_2O$	10—30	51	1.89	981
$Mg(NO_3)_2 \cdot 6H_2O$	5—35	53	25.28	220
$NaBr \cdot 2H_2O$	0—35	58	20.49	308
NH_4NO_3	10—40	62	3.54	853
KI	5—30	69	29.35	254
$SrCl_2 \cdot 6H_2O$	5—30	71	31.58	241
$NaNO_3$	10—40	74	26.94	302
NaCl	10—40	75	69.20	25
NH_4Cl	10—40	79	35.67	235
KBr	5—25	81	40.98	203
$(NH_4)_2SO_4$	10—40	81	62.06	79
KCl	5—25	84	49.38	159
$Sr(NO_3)_2 \cdot 4H_2O$	5—25	85	28.34	328
$BaCl_2 \cdot 2H_2O$	5—25	90	69.99	75
CsI	5—25	91	70.77	75
KNO_3	0—50	92	43.22	225
K_2SO_4	10—50	97	86.75	34

STANDARD SALT SOLUTIONS FOR HUMIDITY CALIBRATION

Saturated aqueous solutions of inorganic salts are convenient secondary standards for calibration of instruments for measurement of relative humidity. The International Union of Pure and Applied Chemistry has recommended salt solutions for calibrations in the range of 10% to 90% relative humidity, and the American Society for Testing and Materials has published similar standards. The data in this table are taken from the IUPAC recommendations, except for K_2CO_3 and K_2SO_4, which are ASTM recommendations.

Details on the preparation and use of these standards may be found in References 1 and 2. Data for other salts are given in Reference 3.

REFERENCES

1. Marsh, K. N., Editor, *Recommended Reference Materials for the Realization of Physicochemical Properties*, Blackwell Scientific Publications, Oxford, 1987, pp.157-162.
2. *Standard Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions*, ASTM Standard E 104-85, Reapproved 1991.
3. Greenspan, L., *J. Res. Nat. Bur. Stand.*, 81A, 89, 1977.

Relative Humidity in %

t/°C	LiCl	$MgCl_2$	K_2CO_3	$Mg(NO_3)_2$	NaCl	KCl	K_2SO_4
0		33.66±0.33	43.1±0.7	60.35±0.55	75.51±0.34	88.61±0.53	98.8±2.1
5		33.60±0.28	43.1±0.5	58.86±0.43	75.65±0.27	87.67±0.45	98.5±0.9
10		33.47±0.24	43.1±0.4	57.36±0.33	75.67±0.22	86.77±0.39	98.2±0.8
15		33.30±0.21	43.2±0.3	55.87±0.27	75.61±0.18	85.92±0.33	97.9±0.6
20	11.31±0.31	33.07±0.18	43.2±0.3	54.38±0.23	75.47±0.14	85.11±0.29	97.6±0.5
25	11.30±0.27	32.78±0.16	43.2±0.4	52.89±0.22	75.29±0.12	84.34±0.26	97.3±0.5
30	11.28±0.24	32.44±0.14	43.2±0.5	51.40±0.24	75.09±0.11	83.62±0.25	97.0±0.4
35	11.25±0.22	32.05±0.13		49.91±0.29	74.87±0.12	82.95±0.25	96.7±0.4
40	11.21±0.21	31.60±0.13		48.42±0.37		82.32±0.25	96.4±0.4
45	11.16±0.21	31.10±0.13		46.93±0.47		81.74±0.28	96.1±0.4
50	11.10±0.22	30.54±0.14		45.44±0.60		81.20±0.31	95.8±0.5
55	11.03±0.23	29.93±0.16				80.70±0.35	
60	10.95±0.26	29.26±0.18				80.25±0.41	
65	10.86±0.29	28.54±0.21				79.85±0.48	
70	10.75±0.33	27.77±0.25				79.49±0.57	
75	10.64±0.38	26.94±0.29				79.17±0.66	
80	10.51±0.44	26.05±0.34				78.90±0.77	

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LOW TEMPERATURE BATHS FOR MAINTAINING CONSTANT TEMPERATURE

A liquid-solid slurry is a convenient means of maintaining a constant temperature environment below room temperature. The following is a list of readily available organic liquids suitable for this purpose, arranged in order of their melting (freezing) points t_m. The normal boiling points t_b are also given.

Compound	t_m/°C	t_b/°C
Isopentane (2-Methylbutane)	-159.9	27.8
Methylcyclopentane	-142.5	71.8
3-Chloropropene (Allyl chloride)	-134.5	45.1
Pentane	-129.7	36.0
Allyl alcohol	-129	97.0
Ethanol	-114.1	78.2
Carbon disulfide	-111.5	46
Isobutyl alcohol	-108	107.8
Toluene	-94.9	110.6
Acetone	-94.8	56.0
Ethyl acetate	-83.6	77.1
Dry ice + acetone	-78	
p-Cymene	-68.9	177.1
Trichloromethane (Chloroform)	-63.6	61.1
N-Methylaniline	-57	196.2
Chlorobenzene	-45.2	131.7
Anisole	-37.5	153.7
Bromobenzene	-30.6	156.0
Tetrachloromethane (Carbon tetrachloride)	-23	76.8
Benzonitrile	-12.7	191.1

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WIRE TABLES

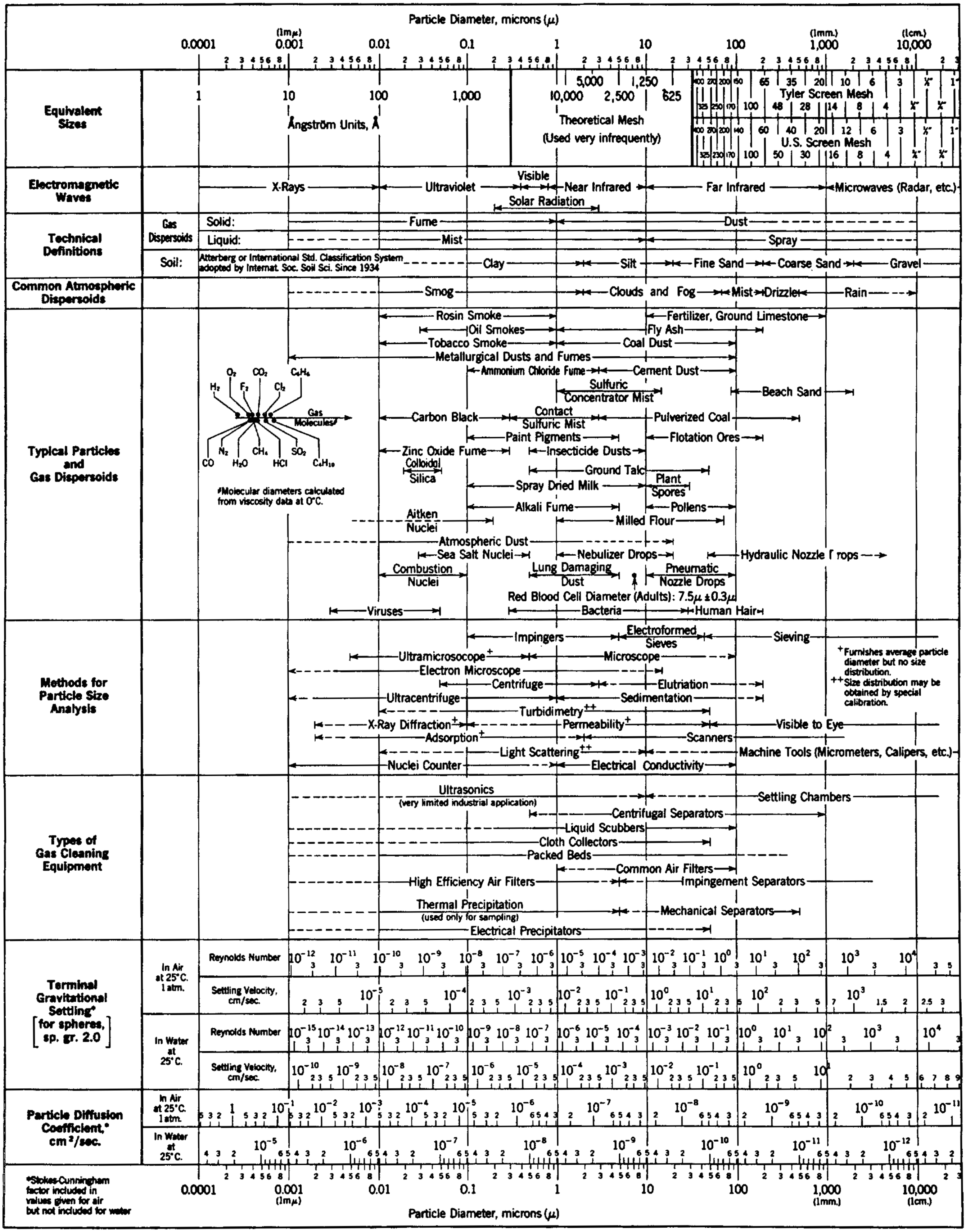
The resistance per unit length of wires of various metals is tabulated here. Values were calculated from resistivity values in the tables “Electrical Resistivity of Pure Metals” and “Electrical Resistivity of Selected Alloys”, which appear in Section 12. In practice, resistance may vary because of differing heat treatments and metal composition. The values in the table refer to 20°C, but values at other temperatures may be calculated from the following resistivity data:

Metal	Resistivity in 10^{-8} Ω m at temperature			
	0°C	**20°C**	**25°C**	**100°C**
Aluminum	2.417	2.650	2.709	3.56
Brass (70% Cu, 30% Zn)	5.87	6.08	6.13	6.91
Constantan (60% Cu, 40% Ni)	45.43	45.38	45.35	45.11
Copper	1.543	1.678	1.712	2.22
Nichrome (79% Ni, 21% Cr)	107.3	107.5	107.6	108.3
Platinum	9.6	10.5	10.7	13.6
Silver	1.467	1.587	1.617	2.07
Tungsten	4.82	5.28	5.39	7.18

Resistance per unit length at 20°C in Ω/m

B & S Gauge	Diameter (mm)	Aluminum	Brass	Constantan	Copper	Nichrome	Platinum	Silver	Tungsten
0	8.252	0.000495	0.00114	0.00848	0.000314	0.0201	0.00196	0.000297	0.00099
2	6.543	0.000788	0.00181	0.0135	0.000499	0.0320	0.00312	0.000472	0.00157
4	5.189	0.00125	0.00287	0.0214	0.000793	0.0508	0.00496	0.000750	0.00250
6	4.115	0.00199	0.00457	0.0341	0.00126	0.0808	0.00789	0.00119	0.00397
8	3.264	0.00317	0.00727	0.0542	0.00200	0.128	0.0125	0.00190	0.00631
10	2.588	0.00504	0.0115	0.0863	0.00319	0.204	0.0200	0.00302	0.0100
12	2.053	0.00800	0.0184	0.137	0.00507	0.325	0.0317	0.00479	0.0159
14	1.628	0.0127	0.0292	0.218	0.00806	0.516	0.0504	0.00762	0.0254
16	1.291	0.0202	0.0464	0.347	0.0128	0.821	0.0802	0.0121	0.0403
18	1.024	0.0322	0.0738	0.551	0.0204	1.30	0.127	0.0193	0.0641
20	0.8118	0.0512	0.117	0.877	0.0324	2.08	0.203	0.0307	0.102
22	0.6439	0.0814	0.187	1.39	0.0515	3.30	0.322	0.0487	0.162
24	0.5105	0.129	0.297	2.22	0.0820	5.25	0.513	0.0775	0.258
26	0.4049	0.206	0.472	3.52	0.130	8.35	0.815	0.123	0.410
28	0.3211	0.327	0.751	5.60	0.207	13.3	1.30	0.196	0.652
30	0.2548	0.520	1.19	8.90	0.329	21.1	2.06	0.311	1.03
32	0.2019	0.828	1.90	14.2	0.524	33.6	3.28	0.496	1.65
34	0.1601	1.32	3.02	22.5	0.833	53.4	5.22	0.788	2.62
36	0.1270	2.09	4.80	35.8	1.32	84.9	8.29	1.25	4.17
38	0.1007	3.33	7.63	57.0	2.11	135	13.2	1.99	6.63
40	0.07988	5.29	12.1	90.5	3.35	214	20.9	3.17	10.5

CHARACTERISTICS OF PARTICLES AND PARTICLE DISPERSOIDS



C. E. Lapple, Stanford Research Institute Journal, Vol. 5, p.95 (Third Quarter, 1961)

DENSITY OF VARIOUS SOLIDS

This table gives the range of density for miscellaneous solid materials whose characteristics depend on the source or method of preparation.

REFERENCES

1. Forsythe, W. E., *Smithsonian Physical Tables, Ninth Edition*, Smithsonian Institution, Washington, 1956.
2. Kaye, G. W. C., and Laby, T. H., *Tables of Physical and Chemical Constants, 16th Edition*, Longman, London, 1995.
3. Brandrup, J., and Immergut, E. H., *Polymer Handbook, Third Edition*, John Wiley & Sons, New York, 1989.

Material	ρ/ g cm^{-3}
Agate	2.5-2.7
Alabaster,	
carbonate	2.69-2.78
sulfate	2.26-2.32
Albite	2.62-2.65
Amber	1.06-1.11
Amphiboles	2.9-3.2
Anorthite	2.74-2.76
Asbestos	2.0-2.8
Asbestos slate	1.8
Asphalt	1.1-1.5
Basalt	2.4-3.1
Beeswax	0.96-0.97
Beryl	2.69-2.70
Biotite	2.7-3.1
Bone	1.7-2.0
Brasses	8.44-8.75
Brick	1.4-2.2
Bronzes	8.74-8.89
Butter	0.86-0.87
Calamine	4.1-4.5
Calcspar	2.6-2.8
Camphor	0.99
Cardboard	0.69
Celluloid	1.4
Cement, set	2.7-3.0
Chalk	1.9-2.8
Charcoal,	
oak	0.57
pine	0.28-0.44
Cinnabar	8.12
Clay	1.8-2.6
Coal,	
anthracite	1.4-1.8
bituminous	1.2-1.5
Coke	1.0-1.7
Copal	1.04-1.14
Cork	0.22-0.26
Corundum	3.9-4.0
Diamond	3.51
Dolomite	2.84
Ebonite	1.15
Emery	4.0
Epidote	3.25-3.50
Feldspar	2.55-2.75
Flint	2.63
Fluorite	3.18
Galena	7.3-7.6
Garnet	3.15-4.3
Gelatin	1.27
Glass,	
common	2.4-2.8
lead	3-4
Pyrex	2.23
Granite	2.64-2.76
Graphite	2.30-2.72
Gum arabic	1.3-1.4
Gypsum	2.31-2.33
Hematite	4.9-5.3
Hornblende	3.0
Ice	0.917
Iron, cast	7.0-7.4
Ivory	1.83-1.92
Kaolin	2.6
Leather, dry	0.86
Lime, slaked	1.3-1.4
Limestone	2.68-2.76
Linoleum	1.18
Magnetite	4.9-5.2
Malachite	3.7-4.1
Marble	2.6-2.84
Meerschaum	0.99-1.28
Mica	2.6-3.2
Muscovite	2.76-3.00
Ochre	3.5
Opal	2.2
Paper	0.7-1.15
Paraffin	0.87-0.91
Peat blocks	0.84
Pitch	1.07
Polyamides	1.15-1.25
Polyethylene	0.92-0.97
Poly(methyl methacrylate)	1.19
Polypropylene	0.91-0.94
Polystyrene	1.06-1.12
Polytetrafluoroethylene	2.28-2.30
Poly(vinyl acetate)	1.19
Poly(vinyl chloride)	1.39-1.42
Porcelain	2.3-2.5
Porphyry	2.6-2.9
Pyrite	4.95-5.10
Quartz	2.65
Resin	1.07
Rock salt	2.18
Rubber,	
hard	1.19
soft	1.1
pure gum	0.91-0.93
Neoprene	1.23-1.25
Sandstone	2.14-2.36
Serpentine	2.50-2.65
Silica, fused,	2.21
Silicon carbide	3.16
Slag	2.0-3.9
Slate	2.6-3.3
Soapstone	2.6-2.8
Solder	8.7-9.4
Starch	1.53
Steel, stainless	7.8
Sugar	1.59
Talc	2.7-2.8
Tallow, beef	0.94
Tar	1.02
Topaz	3.5-3.6
Tourmaline	3.0-3.2
Tungsten carbide	14.0-15.0
Wax, sealing	1.8
Wood (seasoned)	
alder	0.42-0.68
apple	0.66-0.84
ash	0.65-0.85
balsa	0.11-0.14
bamboo	0.31-0.40
basswood	0.32-0.59
beech	0.70-0.90
birch	0.51-0.77
blue gum	1.00
box	0.95-1.16
butternut	0.38
cedar	0.49-0.57
cherry	0.70-0.90
dogwood	0.76
ebony	1.11-1.33
elm	0.54-0.60
hickory	0.60-0.93
holly	0.76
juniper	0.56
larch	0.50-0.56
locust	0.67-0.71
logwood	0.91
mahogany	0.66-0.85
maple	0.62-0.75
oak	0.60-0.90
pear	0.61-0.73
pine, pitch	0.83-0.85
white	0.35-0.50
yellow	0.37-0.60
plum	0.66-0.78
poplar	0.35-0.50
satinwood	0.95
spruce	0.48-0.70
sycamore	0.40-0.60
teak, Indian	0.66-0.98
walnut	0.64-0.70
water gum	1.00
willow	0.40-0.60
Wood’s metal	9.70

DIELECTRIC STRENGTH OF INSULATING MATERIALS

L. I. Berger

The loss of the dielectric properties by a sample of a gaseous, liquid, or solid insulator as a result of application to the sample of an electric field* greater than a certain critical magnitude is called *dielectric breakdown.* The critical magnitude of electric field at which the breakdown of a material takes place is called the *dielectric strength* of the material (or *breakdown voltage*). The dielectric strength of a material depends on the specimen thickness (as a rule, thin films have greater dielectric strength than that of thicker samples of a material), the electrode shape**, the rate of the applied voltage increase, the shape of the voltage vs. time curve, and the medium surrounding the sample, e.g., air or other gas (or a liquid — for solid materials only).

Breakdown in Gases

The current carriers in gases are free electrons and ions generated by external radiation. The equilibrium concentration of these particles at normal pressure is about 10^3 cm^{-3}, and hence the electrical conductivity is very small, of the order of 10^{-16} - 10^{-15} S/cm. But in a strong electric field, these particles acquire kinetic energy along their free pass, large enough to ionize the gas molecules. The new charged particles ionize more molecules; this avalanche-like process leads to formation between the electrodes of channels of conducting plasma (streamers), and the electrical resistance of the space between the electrodes decreases virtually to zero.

Because the dielectric strength (breakdown voltage) of gases strongly depends on the electrode geometry and surface condition and the gas pressure, it is generally accepted to present the data for a particular gas as a fraction of the dielectric strength of either nitrogen or sulfur hexafluoride measured at the same conditions. In Table 1, the data are presented in comparison with the dielectric strength of nitrogen, which is considered equal to 1.00. For convenience to the reader, a few average magnitudes of the dielectric strength of some gases are expressed in kilovolts per millimeter. The data in the table relate to the standard conditions, unless indicated otherwise.

Breakdown in Liquids

If a liquid is pure, the breakdown mechanism in it is similar to that in gases. If a liquid contains liquid impurities in the form of small drops with greater dielectric constant than that of the main liquid, the breakdown is the result of formation of ellipsoids from these drops by the electric field. In a strong enough electric field, these ellipsoids merge and form a high-conductivity channel between the electrodes. The current increases the temperature in the channel, liquid boils, and the current along the steam canal leads to breakdown. Formation of a conductive channel (bridge) between the electrodes is observed also in liquids with solid impurities. If a liquid contains gas impurities in the form of small bubbles, breakdown is the result of heating of the liquid in strong electric fields. In the locations with the highest current density, the liquid boils, the size of the gas bubbles increases, they merge and form gaseous channels between the electrodes, and the breakdown medium is again the gas plasma.

Breakdown in Solids

It is known that the current in solid insulators does not obey Ohm's law in strong electric fields. The current density increases almost exponentially with the electric field, and at a certain field magnitude it jumps to very high magnitudes at which a specimen of a material is destroyed. The two known kinds of electric breakdown are thermal and electrical breakdowns. The former is the result of material heating by the electric current. Destruction of a sample of a material happens when, at a certain voltage, the amount of heat produced by the current exceeds the heat release through the sample surface; the breakdown voltage in this case is proportional to the square root of the ratio of the thermal conductivity and electrical conductivity of the material. The electrical breakdown results from the tunneling of the charge carriers from electrodes or from the valence band or from the impurity levels into the conduction band, or by the impact ionization. The tunnel effect breakdown happens mainly in thin layers, e.g., in thin p-n junctions. Otherwise, the impact ionization mechanism dominates. For this mechanism, the dielectric strength of an insulator can be estimated using Boltzmann's kinetic equation for electrons in a crystal.

In the following tables, the dielectric strength values are for room temperature and normal atmospheric pressure, unless indicated otherwise.

* The unit of electric field in the SI system is newton per coulomb or volt per meter.

** For example, the U.S. standard ASTM D149 is based on use of symmetrical electrodes, while per U.K. standard BS2918 one electrode is a plane and the other is a rod with the axis normal to the plane.

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Table 1
Dielectric Strength of Gases

Material	Dielectric* Strength	Ref.
Nitrogen, N_2	1.00	
Hydrogen, H_2	0.50	1,2
Helium, He	0.15	1
Oxygen, O_2	0.92	2
Air	0.97	6
Air (flat electrodes), kV/mm	3.0	3
Air, kV/mm	0.4-0.7	4
Air, kV/mm	1.40	5
Neon, Ne	0.25	1
	0.16	2
Argon, Ar	0.18	2
Chlorine, Cl_2	1.55	1
Carbon monoxide, CO	1.02	1
	1.05	2
Carbon dioxide, CO_2	0.88	1
	0.82	2
	0.84	6
Nitrous oxide, N_2O	1.24	2
Sulfur dioxide, SO_2	2.63	2
	2.68	6
Sulfur monochloride, S_2Cl_2 (at 12.5 Torr)	1.02	1
Thionyl fluoride, SOF_2	2.50	1
Sulfur hexafluoride, SF_6	2.50	1
	2.63	2
Sulfur hexafluoride, SF_6, kV/mm	8.50	7
	9.8	8
Perchloryl fluoride, ClO_3F	2.73	1
Tetrachloromethane, CCl_4	6.33	1
	6.21	2
Tetrafluoromethane, CF_4	1.01	1
Methane, CH_4	1.00	1
	1.13	2
Bromotrifluoromethane, CF_3Br	1.35	1
	1.97	2
Bromomethane, CH_3Br	0.71	2
Chloromethane, CH_3Cl	1.29	2
Iodomethane, CH_3I	3.02	2
Iodomethane, CH_3I, at 370 Torr	2.20	7
Dichloromethane, CH_2Cl_2	1.92	2
Dichlorodifluoromethane, CCl_2F_2	2.42	1
	2.63	2,6
Chlorotrifluoromethane, $CClF_3$	1.43	1
	1.53	2
Trichlorofluoromethane, CCl_3F	3.50	1
	4.53	2
Trichloromethane, $CHCl_3$	4.2	1
	4.39	2
Methylamine, CH_3NH_2	0.81	1
Difluoromethane, CH_2F_2	0.79	2
Trifluoromethane, CHF_3	0.71	2
Bromochlorodifluoromethane, CF_2ClBr	3.84	2
Chlorodifluoromethane, $CHClF_2$	1.40	1
	1.11	2
Dichlorofluoromethane, $CHCl_2F$	1.33	1
	2.61	2
Chlorofluoromethane, CH_2ClF	1.03	1
Hexafluoroethane, C_2F_6	1.82	1
	2.55	2
Ethyne (Acetylene), C_2H_2	1.10	1
	1.11	2
Chloropentafluoroethane, C_2ClF_5	2.3	1
	3.0	6
Dichlorotetrafluoroethane, $C_2Cl_2F_4$	2.52	1
Chlorotrifluoroethylene, C_2ClF_3	1.82	2
1,1,1-Trichloro-2,2,2-trifluoroethane	6.55	2
1,1,2-Trichloro-1,2,2-trifluoroethane	6.05	2
Chloroethane, C_2H_5Cl	1.00	1
1,1-Dichloroethane	2.66	2
Trifluoroacetonitrile, CF_3CN	3.5	1
Acetonitrile, CH_3CN	2.11	2
Dimethylamine, $(CH_3)_2NH$	1.04	1
Ethylamine, $C_2H_5NH_2$	1.01	1
Ethylene oxide (oxirane), CH_3CHO	1.01	1
Perfluoropropene, C_3F_6	2.55	2
Octafluoropropane, C_3F_8	2.19	1
	2.47	2
3,3,3-Trifluoro-1-propene, CH_2CHCF_3	2.11	2
Pentafluoroisocyanoethane, C_2F_5NC	4.5	1
1,1,1,4,4,4-Hexafluoro-2-butyne, CF_3CCCF_3	5.84	2
Octafluorocyclobutane, C_4F_8	3.34	2
1,1,1,2,3,4,4,4-Octafluoro-2-butene	2.8	1
Decafluorobutane, C_4F_{10}	3.08	1
Perfluorobutanenitrile, C_3F_7CN	5.5	1
Perfluoro-2-methyl-1,3-butadiene, C_5F_8	5.5	1
Hexafluorobenzene, C_6F_6	2.11	2
Perfluorocyclohexane, C_6F_{12}, (saturated vapor)	6.18	2

*Relative to nitrogen, unless units of kV/mm are indicated.

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Table 2
Dielectric Strength of Liquids

Material	Dielectric strength kV/mm	Ref.
Helium, He, liquid, 4.2 K	10	9
Static	10	11
Dynamic	5	11
	23	12
Nitrogen, N_2, liquid, 77K		
Coaxial cylinder electrodes	20	10
Sphere to plane electrodes	60	10
Water, H_2O, distilled	65-70	13
Carbon tetrachloride, CCl_4	5.5	14
	16.0	15
Hexane, C_6H_{14}	42.0	16
Two 2.54 cm diameter spherical electrodes, 50.8 μm space	156	17,18
Cyclohexane, C_6H_{12}	42-48	16
2-Methylpentane, C_6H_{14}	149	17,18
2,2-Dimethylbutane, C_6H_{14}	133	17,18
2,3-Dimethylbutane, C_6H_{14}	138	17,18
Benzene, C_6H_6	163	17,18
Chlorobenzene, C_6H_5Cl	7.1	14
	18.8	15
2,2,4-Trimethylpentane, C_8H_{18}	140	17,18
Phenylxylylethane	23.6	19
Heptane, C_7H_{16}	166	17,18
2,4-Dimethylpentane, C_7H_{16}	133	17,18
Toluene, $C_6H_5CH_3$	199	17,18
	46	16
	12.0	14
	20.4	15
Octane, C_8H_{18}	16.6	14
	20.4	15
	179	17,18
Ethylbenzene, C_8H_{10}	226	17,18
Propylbenzene, C_9H_{12}	250	17,18
Isopropylbenzene, C_9H_{12}	238	17,18
Decane, $C_{10}H_{22}$	192	17,18
Synthetic Paraffin Mixture		
Synfluid 2cSt PAO	29.5	37
Butylbenzene, $C_{10}H_{14}$	275	17,18
Isobutylbenzene, $C_{10}H_{14}$	222	17,18
Silicone oils—polydimethylsiloxanes, $(CH_3)_3Si\text{-}O\text{-}[Si(CH_3)_2]_x\text{-}O\text{-}Si(CH_3)_3$		
Polydimethylsiloxane silicone fluid	15.4	20
Dimethyl silicone	24.0	21,22
Phenylmethyl silicone	23.2	22
Silicone oil, Basilone M50	10-15	23
Mineral insulating oils	11.8	6
Polybutene oil for capacitors	13.8	6
Transformer dielectric liquid	28-30	6
Isopropylbiphenyl capacitor oil	23.6	6
Transformer oil	110.7	24
Transformer oil Agip ITE 360	9-12.6	23
Perfluorinated hydrocarbons		
Fluorinert FC 6001	8.0	23
Fluorinert FC 77	10.7	23
Perfluorinated polyethers		
Galden XAD (Mol. wt. 800)	10.5	23
Galden D40 (Mol. wt. 2000)	10.2	23
Castor oil	65	25

Table 3
Dielectric Strength of Solids

Material	Dielectric strength kV/mm	Ref
Sodium chloride, NaCl, crystalline	150	26
Potassium bromide, KBr, crystalline	80	26
Ceramics		
Alumina (99.9% Al_2O_3)	13.4	6,27a
Aluminum silicate, Al_2SiO_5	5.9	6
Berillia (99% BeO)	13.8	6,27b
Boron nitride, BN	37.4	6
Cordierite, $Mg_2Al_4Si_5O_{18}$	7.9	6,27c
Forsterite, Mg_2SiO_4	9.8	28
Porcelain	35-160	26
Steatite, $Mg_3Si_4O_{11}\cdot H_2O$	9.1-15.4	6
Titanates of Mg, Ca, Sr, Ba, and Pb	20-120	3
Barium titanate, glass bonded	>30	36
Zirconia, ZrO_2	11.4	29
Glasses		
Fused silica, SiO_2	470-670	26
Alkali-silicate glass	200	26
Standard window glass	9.8-13.8	28
Micas		
Muscovite, ruby, natural	118	6
Phlogopite, amber, natural	118	6
Fluorophlogopite, synthetic	118	6
Glass-bonded mica	14.0-15.7	6
Thermoplastic Polymers		
Polypropylene	23.6	6
Amide polymer nylon 6/6, dry	23.6	6
Polyamide-imide copolymer	22.8	6
Modified polyphenylene oxide	21.7	6
Polystyrene	19.7	6
Polymethyl methacrylate	19.7	6
Polyetherimide	18.9	6
Amide polymer nylon 11(dry)	16.7	6
Polysulfone	16.7	6
Styrene-acrylonitrile copolymer	16.7	6
Acrylonitrile-butadiene-styrene	16.7	6
Polyethersulfone	15.7	6
Polybutylene terephthalate	15.7	6
Polystyrene-butadiene copolymer	15.7	6
Acetal homopolymer	15.0	6
Acetal copolymer	15.0	6

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Table 3
Dielectric Strength of Solids (continued)

Material	Dielectric strength kV/mm	Ref.
Polyphenylene sulfide	15.0	6
Polycarbonate	15.0	6
Acetal homopolymer resin (molding resin)	15.0	6
Acetal copolymer resin	15.0	6
Thermosetting Molding Compounds		
Glass-filled allyl (Type GDI-30 per MIL-M-14G)	15.7	6
Glass-filled epoxy, electrical grade	15.4	6
Glass-filled phenolic (Type GPI-100 per MIL-M-14G)	15.0	6
Glass-filled alkyd/polyester (Type MAI-60 per MIL-M-14G)	14.8	6
Glass-filled melamine (Type MMI-30 per MIL-M-14G)	13.4	6
Extrusion Compounds for High-Temperature Insulation		
Polytetrafluoroethylene	19.7	6
Perfluoroalkoxy polymer	21.7	6
Fluorinated ethylene-propylene copolymer	19.7	6
Ethylene-tetrafluoroethylene copolymer	15.7	6
Polyvinylidene fluoride	10.2	6
Ethylene-chlorotrifluoroethylene copolymer	19.3	6
Polychlorotrifluoroethylene	19.7	6
Extrusion Compounds for Low-Temperature Insulation		
Polyvinyl chloride		
Flexible	11.8-15.7	30
Rigid	13.8-19.7	30
Polyethylene	18.9	28
Polyethylene, low-density	21.7	6
	300	31
Polyethylene, high-density	19.7	6
Polypropylene/polyethylene copolymer	23.6	6
Embedding Compounds		
Basic epoxy resin: bisphenol-A/epichlorohydrin polycondensate	19.7	6
Cycloaliphatic epoxy: alicyclic diepoxy carboxylate	19.7	6
Polyetherketone	18.9	30
Polyurethanes		
Two-component, polyol-cured	25.4	6
Two-part solventless, polybutylene-based	24.0	6
Silicones		
Clear two-part heat curing eletrical grade silicone embedding resin	21.7	6
Red insulating enamel (MIL-E-22118)		
Dry	47.2	6
Wet	11.8	6
Enamels		
Red enamel, fast cure		
Standard conditions	78.7	6
Immersion conditions	47.2	6
Black enamel		
Standard conditions	70.9	6
Immersion conditions	47.2	6
Varnishes		
Vacuum-pressure impregnated baking type solventless polyester varnish		
Rigid, two-part	70.9	6
Semiflexible high-bond thixotropic	78.7	6
Rigid high-bond high-flash freon-resistant	68.9	6
Baking type epoxy varnish		
Solventless, rigid, low viscosity, one-part	90.6	6
Solventless, semiflexible, one-part	82.7	6
Solventless, semirigid, chemical resistant, low dielectric constant	106.3	6
Solvable, for hermetic electric motors	181.1	6
Polyurethane coating		
Clear conformal, fast cure		
Standard conditions	78.7	6
Immersion conditions	47.2	6
Insulating Films and Tapes		
Low-density polyethylene film (40 μm thick)	300	31
Poly-*p*-xylylene film	410-590	32
Aromatic polymer films		
Kapton H (Du Pont)	389-430	33
Ultem (GE Plastic and Roem AG)	437-565	33
Hostaphan (Hoechst AG)	338-447	33
Amorphous Stabar K2000 (ICI film)	404-422	33
Stabar S100 (ICI film)	353-452	33
Polyetherimide film (26 μm)	486	34
Parylene N/D (poly-*p*-xylylene/poly-dichloro-*p*-xylylene) 25 μm film	275	6
Cellulose acetate film	157	6
Cellulose triacetate film	157	6
Polytetrafluoroethylene film	87-173	6
Perfluoroalkoxy film	157-197	6
Fluorinated ethylene-propylene copolymer film	197	6
Ethylene-tetrafluoroethylene film	197	6
Ethylene-chlorotrifluoroethylene copolymer film	197	6
Polychlorotrifluoroethylene film	118-153.5	6
High-voltage rubber insulating tape	28	6
Composites		
Isophthalic polyester (vinyl toluene monomer) filled with		
Calcium carbonate, $CaCO_3$	15.0	38
Gypsum, $CaSO_4$	14.4	38
Alumina trihydrate	15.4	38
Clay	14.4	38
BPA fumarate polyester (vinyl toluene monomer) filled with		
Calcium carbonate	6.1	38
Gypsum	5.9	38
Alumina trihydrate	11.8	38
Clay	12.6	38

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Table 3
Dielectric Strength of Solids (continued)

Material	Dielectric strength kV/mm	Ref.	Material	Dielectric strength kV/mm	Ref.
Polysulfone resin—30% glass fiber	16.5-18.7	38	Butyl rubber	23.6	6
Polyamid resin (Nylon 66)— 30% carbon fiber	13.0	38	Neoprene	15.7-27.6	6
Polyimide thermoset resin, glass reinforced	12.0	39	Silicone rubber	26-36	6
Polyester resin (thermoplastic)— 40% glass fiber	20.0	38	Room-temperature vulcanized silicone rubber	9.2-10.9	35
Epoxy resin (diglycidyl ether of bisphenol A), glass reinforced	16.0	40	Ureas (from carbamide to tetraphenylurea)	11.8-15.7	28
Various Insulators			Dielectric papers		
Rubber, natural	100-215	26	Aramid paper, calendered	28.7	6
			Aramid paper, uncalendered	12.2	6
			Aramid with Mica	39.4	6

REFERENCES

1. Vijh, A. K. *IEEE Trans.,* EI-12, 313, 1997.
2. Brand, K. P., *IEEE Trans.*, EI-17, 451, 1982.
3. *Encyclopedic Dictionary in Physics,* Vedensky, B. A. and Vul, B. M., Eds., Vol. 4, Soviet Encyclopedia Publishing House, Moscow, 1965.
4. Kubuki, M., Yoshimoto, R., Yoshizumi, K., Tsuru, S., and Hara, M., *IEEE Trans.,* DEI-4, 92, 1997.
5. Al-Arainy, A. A. Malik, N. H., and Cureshi, M. I., *IEEE Trans.,* DEI-1, 305, 1994.
6. Shugg, W. T., *Handbook of Electrical and Electronic Insulating Materials,* Van Nostrand Reinhold, New York, 1986.
7. Devins, J. C., *IEEE Trans.,* EI-15, 81, 1980.
8. Xu, X., Jayaram, S., and Boggs, S. A., *IEEE Trans.*, DEI-3, 836, 1996.
9. Okubo, H., Wakita, M., Chigusa, S., Nayakawa, N., and Hikita, M., *IEEE Trans.,* DEI-4, 120, 1997.
10. Hayakawa, H., Sakakibara, H., Goshima, H., Hikita, M., and Okubo, H., *IEEE Trans.*, DEI-4, 127, 1997.
11. Okubo, H., Wakita, M., Chigusa, S., Hayakawa, N., and Hikita, M., *IEEE Trans.,* DEI-4, 220, 1997.
12. Von Hippel, A. R., *Dielectric Materials and Applications,* MIT Press, Cambridge, MA, 1954.
13. Jones, H. M. and Kunhards, E. E., *IEEE Trans.,* DEI-1, 1016, 1994.
14. Nitta, Y. and Ayhara, Y., *IEEE Trans.*, EI-11, 91, 1976.
15. Gallagher, T. J., *IEEE Trans.*, EI-12, 249, 1977.
16. Wong, P. P. and Forster, E. O., in *Dielectric Materials. Measurements and Applications,* IEE Conf. Publ. 177, 1, 1979.
17. Kao, K. C. *IEEE Trans.*, EI-11, 121, 1976.
18. Sharbaugh, A. H., Crowe, R. W., and Cox, E. B., *J. Appl. Phys.,* 27, 806, 1956.
19. Miller, R. L., Mandelcorn, L., and Mercier, G. E., in *Proc. Intl. Conf. on Properties and Applications of Dielectric Materials,* Xian, China, June 24-28, 1985; cited in Ref. 6, p. 492.
20. Hakim, R. M., Oliver, R. G., and St-Onge, H., *IEEE Trans.,* EI-12, 360, 1977.
21. Hosticka, C., *IEEE Trans.*, 389, 1977.
22. Yasufuku, S., Umemura, T., and Ishioka, Y., *IEEE Trans.*, EI-12, 402, 1977.
23. Forster, E. O., Yamashita, H., Mazzetti, C., Pompini, M., Caroli, L., and Patrissi, S., *IEEE Trans.,* DEI-1, 440, 1994.
24. Bell, W. R., *IEEE Trans.*, 281, 1977.
25. Ramu, T. C. and Narayana Rao, Y., in *Dielectric Materials. Measurements and Applications,* IEE Conf. Publ. 177, 37.
26. Skanavi, G. I., *Fizika Dielektrikov; Oblast Silnykh Polei* (Physics of Dielectrics; Strong Fields). Gos. Izd. Fiz. Mat. Nauk (State Publ. House for Phys. and Math. Scis.), Moscow, 1958.
27. Kleiner, R. N., in *Practical Handbook of Materials Science,* Lynch, C. T., Ed., CRC Press, 1989; 27a: p. 304; 27b: p.300; 27c: p. 316.
28. *Materials Selector Guide. Materials and Methods,* Reinhold Publ., New York, 1973.
29. Flinn, R. A. and Trojan, P. K., *Engineering Materials and Their Applications,* 2nd ed., Houghton Mifflin, 1981, p. 614.
30. Lynch, C. T., Ed., *Practical Handbook of Materials Science,* CRC Press, Boca Raton, FL, 1989.
31. Suzuki, H., Mukai, S., Ohki, Y., Nakamichi, Y., and Ajiki, K., *IEEE Trans.,* DEI-4, 238, 1997.
32. Mori, T., Matsuoka, T., and Muzitani, T., *IEEE Trans.,* DEI-1, 71, 1994.
33. Bjellheim, P. and Helgee, B., *IEEE Trans.,* DEI-1, 89, 1994.
34. Zheng, J. P., Cygan, P. J., and Jow, T. R., *IEEE Trans.,* DEI-3, 144, 1996.
35. Danukas, M. G., *IEEE Trans.*, DEI-1, 1196, 1994.
36. Burn, I. and Smithe, D. H., *J. Mater. Sci.,* 7, 339, 1972.
37. Hope, K.D., Chevron Chemical, Private Communication.

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38. *Engineering Materials Handbook*, vol. 1, Composites, C.A. Dostal, Ed., ASM Intl., 1987.
39. 1985 Materials Selector, *Mater. Eng.*, (12) 1984.
40. *Modern Plastics Encyclopedia*, McGraw-Hill, v. 62 (No. 10A) 1985–1986.

Review Literature on the Subject

R1. Kuffel, E. and Zaengl, W. S., *HV Engineering Fundamentals*, Pergamon, 1989.
R2. Kok, J. A., *Electrical Breakdown of Insulating Liquids,* Phillips Tech. Library, Cleaver-Hum, Longon, 1961.
R3. Gallagher, T. J., *Simple Dielectric Liquids*, Clarendon, Oxford, 1975.
R4. Meek, J. M. and Craggs, J. D., Eds., *Electric Breakdown in Gases*, John Wiley & Sons, 1976.
R5. Von Hippel, A. R., *Dielectric Materials and Applications,* MIT Press, Cambridge, MA, 1954.

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ALLOCATION OF FREQUENCIES IN THE RADIO SPECTRUM

In the United States the National Telecommunications and Information Administration (NTIA) has responsibility for assigning each portion of the radio spectrum (9 kHz to 300 GHz) for different uses. These assignments must be compatible with the rules of the International Telecommunications Union (ITU), to which the United States is bound by treaty. The current assignments are given in a wall chart (Reference 1) and may also be found on the NTIA web site (Reference 2). The list below summarizes the broad features of the spectrum allocation, with particular attention to those sections of scientific interest. The references should be consulted for details of the allocations in the frequency bands listed here, which in some cases are quite complex.

REFERENCES

1. *United States Frequency Allocations*, 1996 Spectrum Wall Chart, Stock No. 003-000-00652-2, U. S. Government Printing Office, P. O. Box 371954, Pittsburgh, PA 15250-7954.
2. http://www.ntia.doc.gov/osmhome/allochrt.html

Frequency range	Allocation
9 - 19.95 kHz	Maritime communication, navigation
19.95 - 20.05 kHz	Standard frequency and time signal (also at 60 kHz and 2.5, 5, 10, 15, 20, 25 MHz)
20.05 - 535 kHz	Maritime and aeronautical communication, navigation
535 - 1605 kHz	AM radio broadcasting
1605 - 3500 kHz	Mobile communication and navigation, amateur radio (1800-1900 kHz)
3.5 - 4.0 MHz	Amateur radio
4.0 - 5.95 MHz	Mobile communication
5.95 - 13.36 MHz	Mobile communication, amateur, short-wave broadcasting
13.36 - 13.41 MHz	Radioastronomy
13.41 - 25.55 MHz	Mobile communication, amateur, short-wave broadcasting
25.55 - 25.67 MHz	Radioastronomy
25.67 - 37.5 MHz	Mobile communication, amateur, short-wave broadcasting
37.5 -38.25 MHz	Radioastronomy
38.25 - 50.0 MHz	Mobile communication
50.0 - 54.0 MHz	Amateur
54.0 - 72.0 MHz	TV channels 2-4
72.0 - 73.0 MHz	Mobile communication
73.0 - 74.6 MHz	Radioastronomy
74.6 - 76.0 MHz	Mobile communication
76.0 - 88.0 MHz	TV channels 5-6
88.0 - 108.0 MHz	FM radio broadcasting
108.0 - 118.0 MHz	Aeronautical navigation
118.0 - 174.0 MHz	Mobile communication, space research, meteorological satellites
174.0 - 216.0 MHz	TV channels 7-13
216.0 - 400.05 MHz	Mobile communication
400.05 - 400.15 MHz	Standard frequency and time satellite (also 20 and 25 GHz)
400.15 - 406.1 MHz	Meteorological aids (radiosonde)
406.1 - 410.0 MHz	Radioastronomy
410.0 - 470.0 MHz	Mobile communication, amateur
470.0 - 512.0 MHz	TV channels 14-20
512.0 - 608.0 MHz	TV channels 21-36
608.0 - 614.0 MHz	Radioastronomy
614.0 - 806.0 MHz	TV channels 38-69
806 -1400 MHz	Mobile communication, navigation
1400 - 1427 MHz	Radioastronomy, space research
1427 - 1660 MHz	Various navigation and satellite applications
1660 - 1710 MHz	Radioastronomy, space research, meteorology
1710 - 2655 MHz	Various navigation and satellite applications
2655 - 2700 MHz	Radioastronomy, space research
2.7 - 4.99 GHz	Various navigation and satellite applications
4.99 - 5.0 GHz	Radioastronomy, space research
5.0 - 10.6 GHz	Various navigation and satellite applications
10.6 - 10.7 GHz	Radioastronomy, space research
10.7 - 15.35 GHz	Various navigation and satellite applications
15.35 - 15.4 GHz	Radioastronomy, space research
15.4 - 22.21 GHz	Various navigation and satellite applications

ALLOCATION OF FREQUENCIES IN THE RADIO SPECTRUM (continued)

Frequency range	Allocation
22.21 - 22.5 GHz	Radioastronomy, space research
22.25 - 23.6 GHz	Various navigation and satellite applications
23.6 - 24.0 GHz	Radioastronomy, space research
24.0 - 31.3 GHz	Various navigation and satellite applications
31.3 - 31.8 GHz	Radioastronomy, space research
31.8 - 42.5 GHz	Various navigation and satellite applications
42.5 - 43.5 GHz	Radioastronomy
43.5 - 51.4 GHz	Various navigation and satellite applications
51.4 - 54.25 GHz	Radioastronomy, space research
54.25 - 58.2 GHz	Space research
58.2 - 59.0 GHz	Radioastronomy, space research
59.0 - 64.0 GHz	Satellite applications
64.0 - 65.0 GHz	Radioastronomy, space research
65.0 - 72.77 GHz	Various navigation and satellite applications
72.77 - 72.91 GHz	Radioastronomy, space research
72.91 - 86.0 GHz	Various navigation and satellite applications
86.0 - 92.0 GHz	Radioastronomy, space research
92.0 - 105.0 GHz	Various navigation and satellite applications
105.0 - 116.0 GHz	Radioastronomy, space research
116.0 - 164.0 GHz	Various navigation and satellite applications
164.0 - 168.0 GHz	Radioastronomy, space research
168.0 - 182.0 GHz	Various navigation and satellite applications
182.0 - 185.0 GHz	Radioastronomy, space research
185.0 - 217.0 GHz	Various navigation and satellite applications
217.0 - 231.0 GHz	Radioastronomy, space research
231.0 - 265.0 GHz	Various navigation and satellite applications
265.0 - 275.0 GHz	Radioastronomy
275.0 - 300.0 GHz	Mobile communications

HANDLING AND DISPOSAL OF CHEMICALS IN LABORATORIES

Robert Joyce and Blaine C. McKusick

The following material has been extracted from two books prepared under the auspices of the Committee on Hazardous Substances in the Laboratory of the National Academy of Sciences — National Research Council. Readers are referred to these books for full details:

Prudent Practices for Handling Hazardous Chemicals in Laboratories, National Academy Press, Washington, 1981.
Prudent Practices for Disposal of Chemicals from Laboratories, National Academy Press, Washington, 1983.

The permission of the National Academy Press to use these extracts is gratefully acknowledged.

INCOMPATIBLE CHEMICALS

The term "incompatible chemicals" refers to chemicals that can react with each other

- Violently
- With evolution of substantial heat
- To produce flammable products
- To produce toxic products

Good laboratory safety practice requires that incompatible chemicals be stored, transported, and disposed of in ways that will prevent their coming together in the event of an accident. Tables 1 and 2 give some basic guidelines for the safe handling of acids, bases, reactive metals, and other chemicals. Neither of these tables is exhaustive, and additional information on incompatible chemicals can be found in the following references.

1. L. Bretherick, *Handbook of Reactive Chemical Hazards*, 3rd ed., Butterworths, London–Boston, 1985.
2. L. Bretherick, Ed., *Hazards in the Chemical Laboratory*, 3rd ed., Royal Society of Chemistry, London, 1981.
3. *Manual of Hazardous Chemical Reactions, A Compilation of Chemical Reactions Reported to be Potentially Hazardous*, National Fire Protection Association, NFPA 491M, 1975, NFPA, 470 Atlantic Avenue, Boston, MA 02210.

TABLE 1
General Classes of Incompatible Chemicals

A	B
Acids	Bases, reactive metals
Oxidizing agents[a]	Reducing agents[a]
Chlorates	Ammonia, anhydrous and aqueous
Chromates	Carbon
Chromium trioxide	Metals
Dichromates	Metal hydrides
Halogens	Nitrites
Halogenating agents	Organic compounds
Hydrogen peroxide	Phosphorus
Nitric acid	Silicon
Nitrates	Sulfur
Perchlorates	
Peroxides	
Permanganates	
Persulfates	

[a] The examples of oxidizing and reducing agents are illustrative of common laboratory chemicals; they are not intended to be exhaustive.

TABLE 2
Examples of Incompatible Chemicals

Chemical	Is incompatible with
Acetic acid	Chromic acid, nitric acid, hydroxyl compounds, ethylene glycol, perchloric acid, peroxides, permanaganates
Acetylene	Chlorine, bromine, copper, fluorine, silver, mercury
Acetone	Concentrated nitric and sulfuric acid mixtures
Alkali and alkaline earth metals (such as powdered aluminum or magnesium, calcium, lithium, sodium, potassium)	Water, carbon tetrachloride or other chlorinated hydrocarbons, carbon dioxide, halogens
Ammonia (anhydrous)	Mercury (in manometers, for example), chlorine, calcium hypochlorite, iodine, bromine, hydrofluoric acid (anhydrous)
Ammonium nitrate	Acids, powdered metals, flammable liquids, chlorates, nitrites, sulfur, finely divided organic or combustible materials
Aniline	Nitric acid, hydrogen peroxide
Arsenical materials	Any reducing agent
Azides	Acids
Bromine	See Chlorine
Calcium oxide	Water
Carbon (activated)	Calcium hypochlorite, all oxidizing agents
Carbon tetrachloride	Sodium
Chlorates	Ammonium salts, acids, powdered metals, sulfur, finely divided organic or combustible materials
Chromic acid and chromium troixide	Acetic acid, naphthalene, camphor, glycerol, alcohol, flammable liquids in general
Chlorine	Ammonia, acetylene, butadiene, butane, methane, propane (or other petroleum gases), hydrogen, sodium carbide, benzene, finely divided metals, turpentine
Chlorine dioxide	Ammonia, methane, phosphine, hydrogen sulfide
Copper	Acetylene, hydrogen peroxide
Cumene hydroperoxide	Acids (organic or inorganic)
Cyanides	Acids
Flammable liquids	Ammonium nitrate, chromic acid, hydrogen peroxide, nitric acid, sodium peroxide, halogens
Fluorine	Everything
Hydrocarbons (such as butane, propane, benzene)	Fluorine, chlorine, bromine, chromic acid, sodium peroxide
Hydrocyanic acid	Nitric acid, alkali
Hydrofluoric acid (anhydrous)	Ammonia (aqueous or anhydrous)
Hydrogen peroxide	Copper, chromium, iron, most metals or their salts, alcohols, acetone, organic materials, aniline, nitromethane, combustible matierals
Hydrogen sulfide	Fuming nitric acid, oxidizing gases
Hypochlorites	Acids, activated carbon
Iodine	Acetylene, ammonia (aqueous or anhydrous), hydrogen
Mercury	Acetylene, fulminic acid, ammonia
Nitrates	Sulfuric acid
Nitric acid (concentrated)	Acetic acid, aniline, chromic acid, hydrocyanic acid, hydrogen sulfide, flammable liquids, flammable gases, copper, brass, any heavy metals
Nitrites	Acids
Nitroparaffins	Inorganic bases, amines
Oxalic acid	Silver, mercury

TABLE 2
Examples of Incompatible Chemicals (continued)

Chemical	Is incompatible with
Oxygen	Oils, grease, hydrogen, flammable liquids, solids, or gases
Perchloric acid	Acetic anhydride, bismuth and its alloys, alcohol, paper, wood, grease, oils
Peroxides, organic	Acids (organic or mineral), avoid friction, store cold
Phosphorus (white)	Air, oxygen, alkalis, reducing agents
Potassium	Carbon tetrachloride, carbon dioxide, water
Potassium chlorate	Sulfuric and other acids
Potassium perchlorate (see also chlorates)	Sulfuric and other acids
Potassium permanganate	Glycerol, ethylene glycol, benzaldehyde, surfuric acid
Selenides	Reducing agents
Silver	Acetylene, oxalic acid, tartartic acid, ammonium compounds, fulminic acid
Sodium	Carbon tetrachloride, carbon dioxide, water
Sodium nitrite	Ammonium nitrate and other ammonium salts
Sodium peroxide	Ethyl or methyl alcohol, glacial acetic acid, acetic anhydride, benzaldehyde, carbon disulfide, glycerin, ethylene glycol, ethyl acetate, methyl acetate, furfural
Sulfides	Acids
Sulfuric acid	Potassium chlorate, potassium perchlorate, potassium permanganate (similar compounds of light metals, such as sodium, lithium)
Tellurides	Reducing agents

EXPLOSION HAZARDS

Table 3 lists some common classes of laboratory chemicals that have potential for producing a violent explosion when subjected to shock or friction. These chemicals should never be disposed of as such, but should be handled by procedures given in *Prudent Practices for Disposal of Chemicals from Laboratories*, National Academy Press, 1983, chapters 6 and 7. Additional information on these, as well as on some less common classes of explosives, can be found in L. Bretherick, *Handbook of Reactive Chemical Hazards*, 3rd ed., Butterworths, London–Boston, 1985.

Table 4 lists some illustrative combinations of common laboratory reagents that can produce explosions when they are brought together or that form reaction products that can explode without any apparent external initiating action. This list is not exhaustive, and additional information on potentially explosive reagent combinations can be found in Manual of Hazardous Chemical Reactions, A Compilation of Chemical Reactions Reported to be Potentially Hazardous, National Fire Protection Association, NFPA 491M, 1975, NFPA, 470 Atlantic Avenue, Boston, MA 02210.

WATER-REACTIVE CHEMICALS

Table 5 lists some common laboratory chemicals that react violently with water and that should always be stored and handled so that they do not come into contact with liquid water or water vapor. Procedures for decomposing laboratory quantities are given in Prudent Practices for Disposal of Chemicals from Laboratories, chapter 6; the pertinent section of that chapter is given in parentheses.

PYROPHORIC CHEMICALS

Many members of the classes of readily oxidized, common laboratory chemicals listed in Table 6 ignite spontaneously in air. A more extensive list can be found in L. Bretherick, *Handbook of Reactive Chemical Hazards*, 3rd ed., Butterworths, London-Boston, 1985. Pyrophoric chemicals should be stored in tightly closed containers under an inert atmosphere (or, for some, an inert liquid), and all transfers and manipulations of them must be carried out under an inert atmosphere or liquid. Suggested procedures for decomposing them are given in Prudent Practices for Disposal of Chemicals from Laboratories, chapter 6; the pertinent section of that chapter is given in parentheses.

TABLE 3
Shock–Sensitive Compounds

Acetylenic compounds, especially polyacetylenes, haloacetylenes, and heavy metal salts of acetylenes (copper, silver, and mercury salts are particularly sensitive)
Acyl nitrates
Alkyl nitrates, particularly polyol nitrates such as nitrocellulose and nitroglycerine
Alkyl and acyl nitrites
Alkyl perchlorates
Amminemetal oxosalts: metal compounds with coordinated ammonia, hydrazine, or similar nitrogenous donors and ionic perchlorate, nitrate, permanganate, or other oxidizing group
Azides, including metal, nonmetal, and organic azides
Chlorite salts of metals, such as $AgClO_2$ and $Hg(ClO_2)_2$
Diazo compounds such as CH_2N_2
Diazonium slats, when dry
Fulminates (silver fulminate, AgCNO, can form in the reaction mixture from the Tollens' test for aldehydes if it is allowed to stand for some time; this can be prevented by adding dilute nitric acid to the test mixture as soon as the test has been completed)
Hydrogen peroxide becomes increasingly treacherous as the concentration rises above 30%, forming explosive mixtures with organic materials and decomposing violently in the presence of traces of transition metals
N–Halogen compounds such as difluoroamino compounds and halogen azides
N–Nitro compounds such as *N*–nitromethylamine, nitrourea, nitroguanidine, and nitric amide
Oxo salts of nitrogenous bases: perchlorates, dichromates, nitrates, iodates, chlorites, chlorates, and permanganates of ammonia, amines, hydroxylamine, guanidine, etc.
Perchlorate salts. Most metal, nonmetal, and amine perchlorates can be detonated and may undergo violent reaction in contact with combustible materials
Peroxides and hydroperoxides, organic (see Chapter 6, Section II.P)
Peroxides (solid) that crystallize from or are left from evaporation of peroxidizable solvents (see Chapter 6 and Appendix I)
Peroxides, transition–metal salts
Picrates, especially salts of transition and heavy metals, such as Ni, Pb, Hg, Cu, and Zn; picric acid is explosive but is less sensitive to shock or friction than its metal salts and is relatively safe as a water–wet paste (see Chapter 7)
Polynitroalkyl compounds such as tetranitromethane and dinitroacetonitrile
Polynitroaromatic compounds, especially polynitro hydrocarbons, phenols, and amines

TABLE 4
Potentially Explosive Combinations of Some Common Reagents

Acetone + chloroform in the presence of base
Acetylene + copper, silver, mercury, or their salts
Ammonia (including aqueous solutions) + Cl_2, Br_2, or I_2
Carbon disulfide + sodium azide
Chlorine + an alcohol
Chloroform or carbon tetrachloride + powdered Al or Mg
Decolorizing carbon + an oxidizing agent
Diethyl ether + chlorine (including a chlorine atmosphere)
Dimethyl sulfoxide + an acyl halide, $SOCl_2$ or $POCl_3$
Dimethyl sulfoxide + CrO_3
Ethanol + calcium hypochlorite
Ethanol + silver nitrate
Nitric acid + acetic anhydride or acetic acid
Picric acid + a heavy–metal salt, such as of Pb, Hg, or Ag
Silver oxide + ammonia + ethanol
Sodium + a cholrinated hydrocarbon
Sodium hypochlorite + an amine

TABLE 5
Water–Reactive Chemicals

Alkali metals (III.D)
Alkali metal hydrides (III.C.2)
Alkali metal amides (III.C.7)
Metal alkyls, such as lithium alkyls and aluminum alkyls (IV.A)
Grignard reagents (IV.A)
Halides of nonmetals, such as BCl_3, BF_3, PCl_3, PCl_5, $SiCl_4$, S_2Cl_2 (III.F)
Inorganic acid halides, such as $POCl_3$, $SOCl_2$, SO_2Cl_2 (III.F)
Anhydrous metal halides, such as $AlCl_3$, $TiCl_4$, $ZrCl_4$, $SnCl_4$ (III.E)
Phosphorus pentoxide (III.I)
Calcium carbide (IV.E)
Organic acid halides and anhydrides of low molecular weight (II.J)

TABLE 6
Classes of Pyrophoric Chemicals

Grignard reagents, RMgX (IV.A)
Metal alkyls and aryls, such as RLi, RNa, R_3Al, R_2Zn (IV.A)
Metal carbonyls, such as Ni $(CO)_4$, $Fe(CO)_5$, $Co_2(CO)_8$ (IV.B)
Alkali metals such as Na, K (III.D.1)
Metal powders, such as Al, Co, Fe, Mg, Mn, Pd, Pt, Ti, Sn, Zn, Zr (III.D.2)
Metal hydrides, such as NaH, $LiAlH_4$ (IV.C.2)
Nonmetal hydrides, such as B_2H_6 and other boranes, PH_3, AsH_3 (III.G)
Nonmetal alkyls, such as R_3B, R_3P, R_3As (IV.C)
Phosphorus (white) (III.H)

HAZARDS FROM PEROXIDE FORMATION

Many common laboratory chemicals can form peroxides when allowed access to air over a period of time. A single opening of a container to remove some of the contents can introduce enough air for peroxide formation to occur. Some types of compounds form peroxides that are treacherously and violently explosive in concentrated solution or as solids. Accordingly, peroxide–containing liquids should never be evaporated near to or to dryness. Peroxide formation can also occur in many polymerizable unsaturated compounds, and these peroxides can initiate a runaway, sometimes explosive, polymerization reaction. Procedures for testing for peroxides and for removing small amounts from laboratory chemicals are given in Prudent Practices for Disposal of Chemicals from Laboratories, chapter 6, Section II.P.

Table 7 provides a list of structural characteristics in organic compounds that can peroxidize. These structures are listed in approximate order of decreasing hazard. Reports of serious incidents involving the last five structural types are extremely rare, but these structures are listed because laboratory workers should be aware that they can form peroxides that can influence the course of experiments in which they are used.

Table 8 gives examples of common laboratory chemicals that are prone to form peroxides on exposure to air. The lists are not exhaustive, and analogous organic compounds that have any of the structural features given in Table 7 should be tested for peroxides before being used as solvents or reagents, or before being distilled. The recommended retention times begin with the date of synthesis or of opening the original container.

DISPOSAL OF TOXIC CHEMICALS

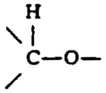
It is often desirable to precipitate toxic cations or hazardous anions from solution to facilitate recovery or disposal. Table 9 lists precipitants for many common cations, and Table 10 gives precipitants for some hazardous anions. Many cations can be precipitated as sulfides by adding sodium sulfide solution (preferable to the highly toxic hydrogen sulfide) to a neutral solution of the cation (Table 11). Control of pH is important because some sulfides will redissolve in excess sulfide ion. After precipitation, excess sulfide can be destroyed by addition of hypochlorite.

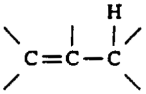
Most metal cations are precipitated as hydroxides or oxides at high pH. Since many of these precipitates will redissolve in excess base, it is often necessary to control pH. Table 12 shows the recommended pH range for precipitating many cations in their most common oxidation state. The notation "1 N" in the right–hand column indicates that the precipitate will not dissolve in 1 N sodium hydroxide (pH 14).

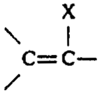
The distinctions between high and low toxicity or hazard are based on toxicological and other data, and are relative. There is no implication of a sharp distinction between high and low, or that any cations or anions are totally without hazard.

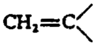
TABLE 7
Types of Chemicals That Are Prone to Form Peroxides

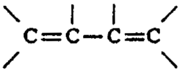
A. Organic structures (in approximate order of decreasing hazard)

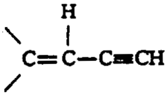
1.  Ethers and acetals with a hydrogen atoms

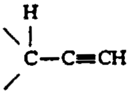
2.  Olefins with allylic hydrogen atoms

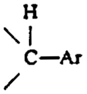
3.  Chloroolefins and fluoroolefins

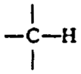
4.  Vinyl halides, esters, and ethers

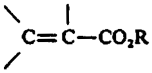
5.  Dienes

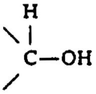
6.  Vinylacetylenes with α hydrogen atoms

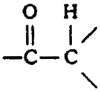
7.  Alkylacetylenes with α hydrogen atoms

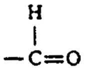
8.  Alkylarenes that contain tertiary hydrogen atoms

9.  Alkanes and cycloalkanes that contain tertiary hydrogen atoms

10.  Acrylates and methacrylates

11.  Secondary alcohols

12.  Ketones that contain a hydrogen atoms

13.  Aldehydes

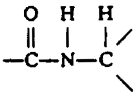
14.  Ureas, amides, and lactams that have a hydrogen atom on a carbon atom attached to nitrogen

TABLE 7
Types of Chemicals That Are Prone to Form Peroxides (continued)

B. Inorganic substances

1. Alkali metals, especially potassium, rubidium, and cesium (see Chapter 6, Section III.D)
2. Metal amides (see Chapter 6, Section III.C.7)
3. Organometallic compounds with a metal atom bonded to carbon (see Chapter 6, Section IV)
4. Metal alkoxides

TABLE 8
Common Peroxide-Forming Chemicals

LIST A

Severe Peroxide Hazard on Storage with Exposure to Air

Discard within 3 months

- Diisopropyl ether (isopropyl ether)
- Divinylacetylene (DVA)[a]
- Potassium metal
- Potassium amide
- Sodium amide (sodamide)
- Vinylidene chloride (1,1–dichloroethylene)[a]

LIST B

Peroxide Hazard on Concentration; Do Not Distill or Evaporate Without First Testing for the Presence of Peroxides

Discard or test for peroxides after 6 months

- Acetaldehyde diethyl acetal (acetal)
- Cumene (isopropylbenzene)
- Cyclohexene
- Cyclopentene
- Decalin (decahydronaphthalene)
- Diacetylene
- Dicyclopentadiene
- Diethyl ether (ether)
- Diethylene glycol dimethyl ether (diglyme)
- Dioxane
- Ethylene glycol dimethyl ether (glyme)
- Ethylene glycol ether acetates
- Ethylene glycol monoethers (cellosolves)
- Furan
- Methylacetylene
- Methylcyclopentane
- Methyl isobutyl ketone
- Tetrahydrofuran (THF)
- Tetralin (tetrahydronaphthalene)
- Vinyl ethers[a]

LIST C

Hazard of Rapid Polymerization Initiated by Internally Formed Peroxides[a]

a. Normal Liquids; Discard or test for peroxides after 6 months[b]

- Chloroprene (2–chloro–1,3–butadiene)[c]
- Styrene
- Vinyl acetate
- Vinylpyridine

b. Normal Gases; Discard after 12 months[d]

- Butadiene[c]
- Tetrafluoroethylene (TFE)[c]
- Vinylacetylene (MVA)[c]
- Vinyl chloride

[a] Polymerizable monomers should be stored with a polymerization inhibitor from which the monomer can be separated by distillation just before use.

[b] Although common acrylic monomers such as acrylonitrile, acrylic acid, ethyl acrylate, and methyl methacrylate can form peroxides, they have not been reported to develop hazardous levels in normal use and storage.

[c] The hazard from peroxides in these compounds is substantially greater when they are stored in the liquid phase, and if so stored without an inhibitor they should be considered as in LIST A.

TABLE 8
Common Peroxide-Forming Chemicals (continued)

[d] Although air will not enter a gas cylinder in which gases are stored under pressure, these gases are sometimes transferred from the original cylinder to another in the laboratory, and it is difficult to be sure that there is no residual air in the receiving cylinder. An inhibitor should be put into any such secondary cylinder before one of these gases is transferred into it; the supplier can suggest inhibitors to be used. The hazard posed by these gases is much greater if there is a liquid phase in such a secondary container, and even inhibited gases that have been put into a secondary container under conditions that create a liquid phase should be discarded within 12 months.

Note: Laboratory workers should label all containers of peroxidizable solvents or reagents with one of the following:

[LIST A]

Peroxidizable compound
Received Opened
Date ______ ______
Discard 3 months after opening

[LISTS B AND C]

Peroxidizable compound
Received Opened
Date ______ ______
Discard or test for peroxides
6 months after opening

TABLE 9
Relative Toxicity of Cations

High toxic hazard	Precipitant[a]	Low toxic hazard	Precipitant[a]
Antimony	OH^-, S^{2-}	Aluminum	OH^-
Arsenic	S^{2-}	Bismuth	OH^-, S^{2-}
Barium	SO_4^{2-}, CO_3^{2-}	Calcium	SO_4^{2-}, CO_3^{2-}
Beryllium	OH^-	Cerium	OH^-
Cadmium	OH^-, S^{2-}	Cesium	
Chromium (III)[b]	OH^-	Copper[c]	OH^-, S^{2-}
Cobalt (II)[b]	OH^-, S^{2-}	Gold	OH^-, S^{2-}
Gallium	OH^-	Iron[c]	OH^-, S^{2-}
Germanium	OH^-, S^{2-}	Lanthanides	OH^-
Hafnium	OH^-	Lithium	
Indium	OH^-, S^{2-}	Magnesium	OH^-
Iridium	OH^-, S^{2-}	Molybdenum (VI)[b,d]	
Lead	OH^-, S^{2-}	Niobium (V)	OH^-
Manganese (II)[b]	OH^-, S^{2-}	Palladium	OH^-, S^{2-}
Mercury	OH^-, S^{2-}	Potassium	
Nickel	OH^-, S^{2-}	Rubidium	
Osmium (IV)[b,e]	OH^-, S^{2-}	Scandium	OH^-
Platinum (II)[b]	OH^-, S^{2-}	Sodium	
Rhenium (VII)[b]	S^{2-}	Strontium	SO_4^{2-}, CO_3^{2-}
Rhodium (III)[b]	OH^-, S^{2-}	Tantalum	OH^-
Ruthenium (III)[b]	OH^-, S^{2-}	Tin	OH^-, S^{2-}
Selenium	S^{2-}	Titanium	OH^-
Silver	Cl^-, OH^-, S^{2-}	Yttrium	OH^-
Tellurium	S^{2-}	Zinc[c]	OH^-, S^{2}
Thallium	OH^-, S^{2-}	Zirconium	OH^-
Tungsten (VI)[b,d]			
Vanadium	OH^-, S^{2-}		

TABLE 9
Relative Toxicity of Cations (continued)

[a] Precipitants are listed in order of preference:
OH^- = base (sodium hydroxide or sodium carbonate)
S^{2-} = sulfide
Cl^- = chloride
SO_4^{2-} = sulfate
CO_3^{2-} = carbonate

[b] The precipitant is for the indicated valence state.

[c] Maximum tolerance levels have been set for these low–toxicity ions by the U.S. Public Health Service, and large amounts should not be put into public sewer systems. The small amounts typically used in laboratories will not normally affect water supplies.

[d] These ions are best precipitated as calcium molybdate or calcium tungstate.

[e] CAUTION: OsO_4, a volatile, extremely poisonous substance, is formed from almost any osmium compound under acid conditions in the presence of air.

TABLE 10
Relative Hazard of Anions

High–hazard anions			
Ion	Hazard type[a]	Precipitant	Low-hazard anions
Aluminum hydride, AlH_4	F	—	Bisulfite, HSO_3^-
Amide, NH_2^-	F, E[b]	—	Borate, BO_3^{3-}, $B_4O_7^{2-}$
Arsenate, AsO_3^-, AsO_4^{3-}	T	Cu^{2+}, Fe^{2+}	Bromide, Br^-
Arsenite, AsO_2^-, AsO_3^{3-}	T	Pb^{2+}	Carbonate, CO_3^{2-}
Azide, N_3^-	E, T	—	Chloride, Cl^-
Borohydride, BH_4^-	F	—	Cyanate, OCN^-
Bromate, BrO_3^-	O, E	—	Hydroxide, OH^-
Chlorate, ClO_3^-	O, E	—	Iodide, I^-
Chromate, CrO_4^{2-}, $Cr_2O_7^{2-}$	T, O	[c]	Oxide, O^{2-}
Cyanide, CN^-	T	—	Phosphate, PO_4^{3-}
Ferricyanide, $Fe(CN)_6^{3-}$	T	Fe^{2+}	Sulfate, SO_4^{2}
Ferrocyanide, $Fe(CN)_6^{4-}$	T	Fe^{3+}	Sulfite, SO_3^{2-}
Fluoride, F^-	T	Ca^{2+}	Thiocyanate, SCN^-
Hydride, H^-	F	—	
Hydroperoxide, O_2H^-	O, E	—	
Hydrosulfide, SH^-	T	—	
Hypochlorite, OCl^-	O	—	
Iodate, IO_3^-	O, E	—	
Nitrate, NO_3^-	O	—	
Nitrite, NO_2^-	T, O	—	
Perchlorate, ClO_4^-	O, E	—	
Permanganate, MnO_4^-	T, O	[d]	
Peroxide, O_2^{2-}	O, E	—	
Persulfate, $S_2O_8^{2-}$	O	—	
Selenate, SeO_4^{2-}	T	Pb^{2+}	
Selenide, Se^{2-}	T	Cu^{2+}	
Sulfide, S^{2-}	T	[e]	

[a] Toxic, T: oxidant, O; flammable, F; explosive, E.

[b] Metal amides readily form explosive peroxides on exposure to air.

[c] Reduce and precipitate as Cr(III); see Table 9.

[d] Reduce and precipitate as Mn(II); see Table 9.

[e] See Table 11.

TABLE 11
Precipitation of Sulfides

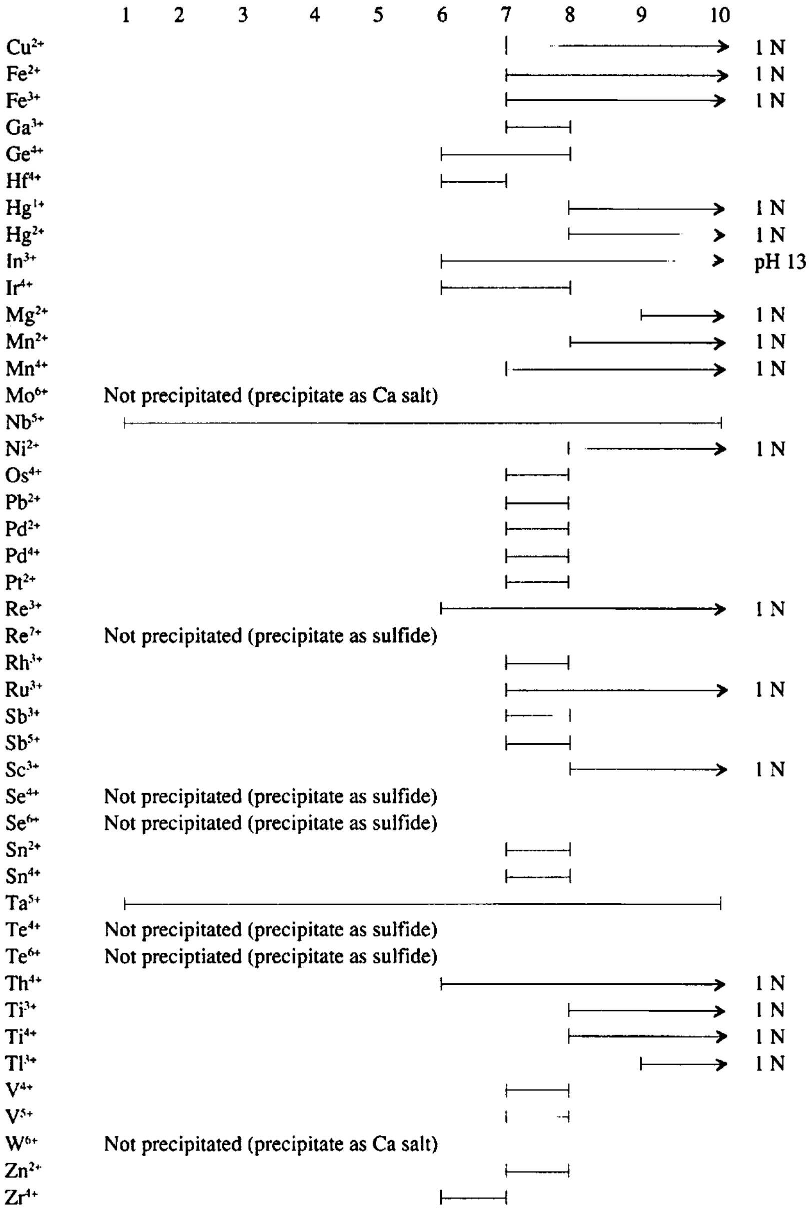
Precipitated at pH 7	Not precipitated at low pH	Forms a soluble complex at high pH
Ag^{+}		
As^{3+}[a]		X
Au^{+}[a]		X
Bi^{3+}		
Cd^{2+}		
Co^{2+}	X	
Cr^{3+}[a]		
Cu^{2+}		
Fe^{2+}[a]	X	
Ge^{2+}		X
Hg^{2+}		X
In^{3+}	X	
Ir^{4+}		X
Mn^{2+}[a]	X	
Mo^{3+}		X
Ni^{2+}	X	
Os^{4+}		
Pb^{2+}		
Pd^{2+}[a]		
Pt^{2+}[a]		X
Re^{4+}		
Rh^{2+}[a]		
Ru^{4+}		
Sb^{3+}[a]		X
Se^{2+}		X
Sn^{2+}		X
Te^{4+}		X
Tl^{+}[a]	X	
V^{4+}[a]		
Zn^{2+}	X	

[a] Higher oxidation states of this ion are reduced by sulfide ion and precipitated as this sulfide.

TABLE 12
pH Range for Precipitation of Metal Hydroxides and Oxides

Ion	pH range (scale 1–10)	
Ag^{1+}	9 ⟶	1 N
Al^{3+}	7 ├──┤ 8	
As^{3+}	Not precipitated (precipitate as sulfide)	
As^{5+}	Not precipitated (precipitate as sulfide)	
Au^{3+}	7 ├ ─┤ 8	
Be^{2+}	7 ├──┤ 8	
Bi^{3+}	7 ⟶	1 N
Cd^{2+}	7 ⟶	1 N
Co^{2+}	8 ⟶	1 N
Cr^{3+}	7 ⟶	1 N
Cu^{1+}	9 ⟶	1 N

TABLE 12
pH Range for Precipitation of Metal Hydroxides and Oxides (continued)



REFERENCES

L. Erdey, *Gravimetric Analysis*, Part II, Pergamon Press, New York, 1965.

D. T. Burns, A. Towsend, and A. H. Carter, *Inorganic Reaction Chemistry*, Vol. 2, Ellis Horwood, New York, 1981.

FIRE HAZARDS

Flammable solvents are a common source of laboratory fires. The relative ease with which some common laboratory solvents can be ignited is indicated by the following properties.

Flash Point — The lowest temperature, as determined by standard tests, at which a liquid emits vapor in sufficient concentration to form an ignitable mixture with air near the surface of the liquid in a test vessel. Note that many of these common chemicals have flash points below room temperature.

Ignition Temperature — The minimum temperature required to initiate self-sustained combustion, regardless of the heat source.

Flammable Limits — The lower flammable limit is the minimum concentration (percent by volume) of a vapor in air below which a flame is not propagated when an ignition source is present. Below this concentration the mixture is too lean to burn. The upper flammable limit is the maximum concentration (percent by volume) of the vapor in air above which a flame is not propagated. Above this concentration the mixture is too rich to burn. The flammable range comprises all concentrations between these two limits. This range becomes wider with increasing temperature and in oxygen–rich atmospheres. Table 13 lists these properties for a few common laboratory chemicals.

GLOVE MATERIALS

It is good safety practice (and mandated in some laboratories) to wear rubber gloves while handling chemicals that can cause injury when in contact with, or absorbed through, the skin. The various common rubbers are not equally resistant to all chemicals. Table 14 provides guidelines for selecting the best, and avoiding the poorest, glove material for handling a given chemical.

RESPIRATORS

In the event of a laboratory accident or spill, it will be necessary for someone to enter the contaminated area for cleanup. If significant quantities of a chemical are spilled, or even minor quantities of a known toxic material, it is essential to wear the correct kind of respirator equipment when entering the area. If it is not known whether the contamination is of a chemical "Immediately dangerous to life or health", the prudent course is to assume that it is, and to use the corresponding type of respirator. Guidelines are presented in Table 15.

TABLE 13
Flash Points, Boiling Points, Ignition Temperatures, and Flammable Limits of Some Common Laboratory Chemicals

Chemical	Flash point (°C)	Boiling point (°C)	Ignition temp. (°C)	Flammable limit (percent by volume in air) Lower	Upper
Acetaldehyde	–37.8	21.1	175.0	4.0	60.0
Acetone	–19.0	56.0	538.0	2.6	12.8
Benzene	–11.1	80.1	560.0	1.4	8.0
Carbon disulfide	–30.0	45.8	90.0	1.0	44.0
Cyclohexane	–18.0	80.7	260.0	1.3	8.0
Diethyl ether	–45.0	34.4	160.0	1.8	48.0
Ethanol	12.0	78.3	363.0	3.3	19.0
n–Heptane	–3.9	98.4	204.0	1.0	6.7
n–Hexane	–21.7	68.7	223.0	1.2	7.5
Isopropyl alcohol	11.7	82.2	398.9	2.0	12.0
Methanol	11.1	64.5	385.0	6.0	36.5
Methyl ethyl ketone	–6.1	79.6	515.6	1.9	11.0
Pentane	–40.0	36.1	260.0	1.4	7.8
Styrene	31.0	145.0	490.0	1.1	6.1
Toluene	4.4	110.6	530.0	1.3	7.0
p–Xylene	25.0	132.4	529.0	1.1	7.0

Note: For a more extensive listing, see the table "Properties of Common Solvents" in Section 15.

TABLE 14
Resistance to Chemicals of Common Glove Materials
(E = Excellent, G = Good, F = Fair, P = Poor)

Chemical	Natural rubber	Neoprene	Nitrile	Vinyl
Acetaldehyde	G	G	E	G
Acetic acid	E	E	E	E
Acetone	G	G	G	F
Acrylonitrile	P	G	—	F
Ammonium hydroxide (sat)	G	E	E	E
Aniline	F	G	E	G
Benzaldehyde	F	F	E	G
Benzene[a]	P	F	G	F
Benzyl chloride[a]	F	P	G	P
Bromine	G	G	—	G
Butane	P	E	—	P
Butyraldehyde	P	G	—	G
Calcium hypochlorite	P	G	G	G
Carbon disulfide	P	P	G	F
Carbon tetrachloride[a]	P	F	G	F
Chlorine	G	G	—	G
Chloroacetone	F	E	—	P
Chloroform[a]	P	F	G	P
Chromic acid	P	F	F	E
Cyclohexane	F	E	—	P
Dibenzyl ether	F	G	—	P
Dibutyl phthalate	F	G	—	P
Diethanolamine	F	E	—	E
Diethyl ether	F	G	E	P
Dimethyl sulfoxide[b]	—	—	—	—
Ethyl acetate	F	G	G	F
Ethylene dichloride[a]	P	F	G	
Ethylene glycol	G	G	E	E
Ethylene trichloride[a]	P	P	—	P
Fluorine	G	G	—	G
Formaldehyde	G	E	E	E
Formic acid	G	E	E	E
Glycerol	G	G	E	E
Hexane	P	E	—	P
Hydrobromic acid (40%)	G	E	—	E
Hydrochloric acid (conc)	G	G	G	E
Hydrofluoric acid (30%)	G	G	G	E
Hydrogen peroxide	G	G	G	E
Iodine	G	G	—	G
Methylamine	G	G	E	E
Methyl cellosolve	F	E	—	P
Methyl chloride[a]	P	E	—	P
Methyl ethyl ketone	F	G	G	P
Methylene chloride[a]	F	F	G	F
Monoethanolamine	F	E	—	E
Morpholine	F	E	—	E
Naphthalene[a]	G	G	E	G
Nitric acid (conc)	P	P	P	G
Perchloric acid	F	G	F	E
Phenol	G	E	—	E
Phosphoric acid	G	E	—	E
Potassium hydroxide (sat)	G	G	G	E

TABLE 14
Resistance to Chemicals of Common Glove Materials
(E = Excellent, G = Good, F = Fair, P = Poor) (continued)

Chemical	Natural rubber	Neoprene	Nitrile	Vinyl
Propylene dichloride[a]	P	F	—	P
Sodium hydroxide	G	G	G	E
Sodium hypochlorite	G	P	F	G
Sulfuric acid (conc)	G	G	F	G
Toluene[a]	P	F	G	F
Trichloroethylene[a]	P	F	G	F
Tricresyl phosphate	P	F	—	F
Triethanolamine	F	E	E	E
Trinitrotoluene	P	E	—	P

[a] Aromatic and halogenated hydrocarbons will attack all types of natural and synthetic glove materials. Should swelling occur, the user should change to fresh gloves and allow the swollen gloves to dry and return to normal.

[b] No data on the resistance to dimethyl sulfoxide of natural rubber, neoprene, nitrile rubber, or vinyl materials are available; the manufacturer of the substance recommends the use of butyl rubber gloves.

TABLE 15
Guide for Selection of Respirators

Type of hazard	Type of respirator
Oxygen deficiency	Self–contained breathing apparatus Hose mask with blower Combination of air–line respirator and auxiliary self–contained air supply or air–storage receiver with alarm
Gas and vapor contaminants Immediately dangerous to life or health	Self–contained breathing apparatus Hose mask with blower Air–purifying full–facepiece respirator with chemical canister (gas mask) Self–rescue mouthpiece respirator (for escape only) Combination of air–line respirator and auxiliary self–contained air supply or air–storage receiver with alarm
Not immediately dangerous to life or health	Air–line respirator Hose mask with blower Air–purifying half–mask or mouthpiece respirator with chemical cartridge
Particulate Contaminants Immediately dangerous to life or health	Self–contained breathing apparatus Hose mask with blower Air–purifying full–facepiece respirator with appropriate filter Self-rescue mouthpiece respirator (for escape only) Combination of air–line respirator and auxiliary self–contained air supply or air–storage receiver with alarm

TABLE 15
Guide for Selection of Respirators (continued)

Type of hazard	Type of respirator
Not immediately dangerous to life or health	Air–purifying half–mask or mouthpiece respirator with filter pad or cartridge Air–line respirator Air–line abrasive–blasting respirator Hose mask with blower
Combination of gas, vapor, and particulate contaminants Immediately dangerous to life or health	Self–contained breathing apparatus Hose mask with blower Air–purifying full–facepiece respirator with chemical canister and appropriate filter (gas mask with filter) Self–rescue mouthpiece respirator (for escape only) Combination of air–line respirator and auxiliary self–contained air supply or air–storage receiver with alarm
Not immediately dangerous to life or health	Air–line respirator Hose mask without blower Air–purifying half–mask or mouthpiece respirator with chemical cartridge and appropriate filter

Source: ANSI Standard Z88.2 (1969).

FLAMMABILITY OF CHEMICAL SUBSTANCES

This table gives properties related to the flammability of about 900 chemical substances. The properties listed are:

t_B : Normal boiling point in °C (at 101.325 kPa pressure).

FP: Flash point, which is the minimum temperature at which the vapor pressure of a liquid is sufficient to form an ignitable mixture with air near the surface of the liquid. Flash point is not an intrinsic physical property but depends on the conditions of measurement (see Reference 1).

Fl. Limits: Flammable limits (often called explosive limits), which specify the range of concentration of the vapor in air (in percent by volume) for which a flame can propagate. Below the lower flammable limit, the gas mixture is too lean to burn; above the upper flammable limit, the mixture is too rich. Values refer to ambient temperature and pressure and are dependent on the precise test conditions. A ? indicates that one of the limits is not known.

IT: Ignition temperature (sometimes called autoignition temperature), which is the minimum temperature required for self-sustained combustion in the absence of an external ignition source. As in the case of flash point, the value depends on specified test conditions.

Even in cases where very careful measurements of flash point have been replicated in several laboratories, observed values can differ by 3 to 6°C (Reference 4). For more typical measurements, larger uncertainties should be assumed in both flash points and autoignition temperatures. The absence of a flash point entry in this table does not mean that the substance is nonflammable, but only that no reliable value is available.

Compounds are listed by molecular formula following the Hill convention. Substances not containing carbon are listed first, followed by those that contain carbon. To locate an organic compound by name or CAS Registry Number when the molecular formula is not known, use the table "Physical Constants of Organic Compounds" in Section 3 and its indexes to determine the molecular formula.

REFERENCES

1. *Fire Protection Guide to Hazardous Materials, 11th Edition*, National Fire Protection Association, Quincy, MA, 1994.
2. Urben, P.G., Editor, *Bretherick's Handbook of Reactive Chemical Hazards*, *5th Edition*, Butterworth-Heinemann, Oxford, 1995.
3. Daubert, T.E., Danner, R.P., Sibul, H.M., and Stebbins, C.C., *Physical and Thermodynamic Properties of Pure Compounds: Data Compilation*, extant 1994 (core with 4 supplements), Taylor & Francis, Bristol, PA.
4. *Report of Investigation: Flash Point Reference Materials*, National Institute of Standards and Technology, Standard Reference Materials Program, Gaithersburg, MD, 1995.

Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
	Compounds not containing carbon				
B_2H_6	Diborane	-92.4	-90	1-98%	≈40
B_5H_9	Pentaborane(9)	60	30	0.4-?	35
BrH_3Si	Bromosilane	1.9	<0		≈20
Br_3HSi	Tribromosilane	109			≈20
Cl_2H_2Si	Dichlorosilane	8.3		4.1-99%	36
Cl_3HSi	Trichlorosilane	33	-50		104
GeH_4	Germane	-88.1			≈20
Ge_2H_6	Digermane	30.8			≈50
H_2	Hydrogen	-252.8		4-74%	
H_2S	Hydrogen sulfide	-59.55		4-44%	260
H_2S_2	Hydrogen disulfide	70.7	<22		
H_2Te	Hydrogen telluride	-2			-50
H_3N	Ammonia	-33.33		16-25%	
H_3P	Phosphine	-87.75		1.8-?	
H_4N_2	Hydrazine	113.55	38	5-100%	
H_4P_2	Diphosphine	63.5			≈20
H_4Si	Silane	-111.9	-112	1.4-?	≈20
H_6Si_2	Disilane	-14.3	-14		≈20
H_8Si_3	Trisilane	52.9	<0		≈20
P	Phosphorus (white)	280.5			38
	Compounds containing carbon				
CHN	Hydrogen cyanide	26	-18	6-40%	538
CH_2Cl_2	Dichloromethane	40		13-23%	556
CH_2N_2	Cyanamide		141		

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FLAMMABILITY OF CHEMICAL SUBSTANCES (continued)

Mol. Form	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
CH_2O	Formaldehyde	-19.1	85	7.0-73%	424
$(CH_2O)_x$	Paraformaldehyde		70	7.0-73%	300
CH_2O_2	Formic acid	101	50	18-57%	434
CH_3Br	Bromomethane	3.5		10-16%	537
CH_3Cl	Chloromethane	-24.0		8.1-17.4%	632
CH_3Cl_3Si	Methyltrichlorosilane	65.6	-9	7.6->20%	>404
CH_3NO	Formamide	220	154		
CH_3NO_2	Nitromethane	101.1	35	7.3-?	418
CH_4	Methane	-161.5		5.0-15.0%	537
CH_4Cl_2Si	Dichloromethylsilane	41	-9	6.0-55%	316
CH_4O	Methanol	64.6	11	6.0-36%	464
CH_4S	Methanethiol	5.9	-18	3.9-21.8%	
CH_5N	Methylamine	-6.3	0	4.9-20.7%	430
CH_6N_2	Methylhydrazine	87.5	-8	2.5-92%	194
CO	Carbon monoxide	-191.5		12.5-74%	609
COS	Carbon oxysulfide	-50		12-29%	
CS_2	Carbon disulfide	46	-30	1.3-50.0%	90
C_2ClF_3	Chlorotrifluoroethylene	-27.8		8.4-16.0%	
C_2F_4	Tetrafluoroethylene	-75.9		10.0-50.0%	200
C_2HCl_3	Trichloroethylene	87.2		8-10.5%	420
C_2HCl_3O	Dichloroacetyl chloride	108	66		
C_2H_2	Acetylene	-84.7		2.5-100%	305
$C_2H_2Cl_2$	1,1-Dichloroethylene	31.6	-28	6.5-15.5%	570
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethylene	60.1	6	3-15%	460
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethylene	48.7	2	6-13%	460
$C_2H_2F_2$	1,1-Difluoroethylene	-85.7		5.5-21.3%	
C_2H_3Br	Bromoethylene	15.8		9-15%	530
C_2H_3Cl	Chloroethylene	-13.3	-78	3.6-33.0%	472
$C_2H_3ClF_2$	1-Chloro-1,1-difluoroethane	-9.7		6-18%	632
C_2H_3ClO	Acetyl chloride	50.7	4		390
$C_2H_3Cl_2NO_2$	1,1-Dichloro-1-nitroethane	123.5	76		
$C_2H_3Cl_3$	1,1,1-Trichloroethane	74.0		8-10.5%	500
$C_2H_3Cl_3$	1,1,2-Trichloroethane	113.8	32	6-28%	460
$C_2H_3Cl_3Si$	Trichlorovinylsilane	91.5	21		
C_2H_3F	Fluoroethylene	-72		2.6-21.7%	
C_2H_3N	Acetonitrile	81.6	6	3.0-16.0%	524
C_2H_3NO	Methyl isocyanate	39.5	-7	5.3-26%	534
C_2H_4	Ethylene	-103.7		2.7-36%	450
$C_2H_4ClNO_2$	1-Chloro-1-nitroethane	124.5	56		
$C_2H_4Cl_2$	1,1-Dichloroethane	57.4	-17	5.4-11.4%	458
$C_2H_4Cl_2$	1,2-Dichloroethane	83.5	13	6.2-16%	413
C_2H_4O	Acetaldehyde	20.1	-39	4.0-60%	175
C_2H_4O	Ethylene oxide	10.6	-20	3.0-100%	429
$C_2H_4O_2$	Acetic acid	117.9	39	4.0-19.9%	463
$C_2H_4O_2$	Methyl formate	31.7	-19	4.5-23%	449
$C_2H_4O_3$	Ethaneperoxoic acid	110	41		
C_2H_5Br	Bromoethane	38.5		6.8-8.0%	511
C_2H_5Cl	Chloroethane	12.3	-50	3.8-15.4%	519
C_2H_5ClO	Ethylene chlorohydrin	128.6	60	4.9-15.9%	425
$C_2H_5Cl_3Si$	Trichloroethylsilane	100.5	22		
C_2H_5N	Ethyleneimine	56	-11	3.3-54.8%	320
$C_2H_5NO_2$	Nitroethane	114.0	28	3.4-17%	414
$C_2H_5NO_2$	Ethyl nitrite	18	-35	4.0-50%	90
$C_2H_5NO_3$	Ethyl nitrate	87.2	10	4-?	
C_2H_6	Ethane	-88.6		3.0-12.5%	472
$C_2H_6Cl_2Si$	Dichlorodimethylsilane	70.3	<21	3.4-9.5%	
C_2H_6O	Ethanol	78.2	13	3.3-19%	363
C_2H_6O	Dimethyl ether	-24.8	-41	3.4-27.0%	350
C_2H_6OS	2-Mercaptoethanol	158	74		
C_2H_6OS	Dimethyl sulfoxide	189	95	2.6-42%	215
$C_2H_6O_2$	Ethylene glycol	197.3	111	3.2-22%	398

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
$C_2H_6O_4S$	Dimethyl sulfate		83		188
C_2H_6S	Ethanethiol	35.1	-17	2.8-18.0%	300
C_2H_6S	Dimethyl sulfide	37.3	-37	2.2-19.7%	206
$C_2H_6S_2$	Dimethyl disulfide	109.8	24		
C_2H_7N	Ethylamine	16.5	-16	3.5-14%	385
C_2H_7N	Dimethylamine	6.8	20	2.8-14.4%	400
C_2H_7NO	Ethanolamine	171	86	3.0-23.5%	410
$C_2H_8N_2$	1,2-Ethanediamine	117	40	2.5-12.0%	385
$C_2H_8N_2$	1,1-Dimethylhydrazine	63.9	-15	2-95%	249
C_2N_2	Cyanogen	-21.1		6.6-32%	
C_3H_3Br	3-Bromo-1-propyne	89	10	3.0-?	324
C_3H_3N	2-Propenenitrile	77.3	0	3.0-17.0%	481
C_3H_4	Propyne	-23.2		2.1-12.5%	
C_3H_4ClN	3-Chloropropanenitrile	175.5	76		
$C_3H_4Cl_2$	2,3-Dichloropropene	94	15	2.6-7.8%	
C_3H_4O	Propargyl alcohol	113.6	36		
C_3H_4O	Acrolein	52.6	-26	2.8-31%	220
$C_3H_4O_2$	Propenoic acid	141	50	2.4-8.0%	438
$C_3H_4O_2$	2-Oxetanone	162	74	2.9-?	
$C_3H_4O_3$	Ethylene carbonate	248	143		
C_3H_5Br	3-Bromopropene	70.1	-1	4.4-7.3%	295
C_3H_5Cl	2-Chloropropene	22.6	-37	4.5-16%	
C_3H_5Cl	3-Chloropropene	45.1	-32	2.9-11.1%	485
C_3H_5ClO	Epichlorohydrin	118	31	3.8-21.0%	411
C_3H_5ClO	Propanoyl chloride	80	12		
$C_3H_5ClO_2$	2-Chloropropanoic acid	185	107		500
$C_3H_5ClO_2$	Ethyl chloroformate	95	16		500
$C_3H_5ClO_2$	Methyl chloroacetate	129.5	57	7.5-18.5%	
$C_3H_5Cl_2NO_2$	1,1-Dichloro-1-nitropropane	145	66		
$C_3H_5Cl_3$	1,2,3-Trichloropropane	157	71	3.2-12.6%	
$C_3H_5Cl_3Si$	Trichloro-2-propenylsilane	117.5	35		
C_3H_5N	Propanenitrile	97.1	2	3.1-14%	512
C_3H_5NO	3-Hydroxypropanenitrile	221	129		
$C_3H_5N_3O_9$	Trinitroglycerol				270
C_3H_6	Propene	-47.6		2.0-11.1%	455
C_3H_6	Cyclopropane	-32.8		2.4-10.4%	498
$C_3H_6ClNO_2$	1-Chloro-1-nitropropane	142	62		
$C_3H_6ClNO_2$	2-Chloro-2-nitropropane		57		
$C_3H_6Cl_2$	1,2-Dichloropropane	96.4	21	3.4-14.5%	557
$C_3H_6Cl_2O$	1,3-Dichloro-2-propanol	176	74		
$C_3H_6N_2$	Dimethylcyanamide	163.5	71		
C_3H_6O	Allyl alcohol	97.0	21	2.5-18.0%	378
C_3H_6O	Methyl vinyl ether	5.5			287
C_3H_6O	Propanal	48	-30	2.6-17%	207
C_3H_6O	Acetone	56.0	-20	2.5-12.8%	465
C_3H_6O	Methyloxirane	35	-37	3.1-27.5%	449
$C_3H_6O_2$	Propanoic acid	141.1	52	2.9-12.1%	465
$C_3H_6O_2$	Ethyl formate	54.4	-20	2.8-16.0%	455
$C_3H_6O_2$	Methyl acetate	56.8	-10	3.1-16%	454
$C_3H_6O_2$	1,3-Dioxolane	78	2		
$C_3H_6O_3$	Dimethyl carbonate	90.5	19		
$C_3H_6O_3$	1,3,5-Trioxane	114.5	45	3.6-29%	414
C_3H_7Br	1-Bromopropane	71.1			490
C_3H_7Cl	1-Chloropropane	46.5	<-18	2.6-11.1%	520
C_3H_7Cl	2-Chloropropane	35.7	-32	2.8-10.7%	593
C_3H_7ClO	2-Chloro-1-propanol	133.5	52		
C_3H_7ClO	1-Chloro-2-propanol	127	52		
$C_3H_7Cl_3Si$	Trichloropropylsilane	123.5	37		
C_3H_7N	Allylamine	53.3	-29	2.2-22%	374
C_3H_7NO	*N*,*N*-Dimethylformamide	153	58	2.2-15.2%	445
$C_3H_7NO_2$	1-Nitropropane	131.1	36	2.2-?	421

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
$C_3H_7NO_2$	2-Nitropropane	120.2	24	2.6-11.0%	428
$C_3H_7NO_3$	Propyl nitrate	110	20	2-100%	175
C_3H_8	Propane	-42.1	-104	2.1-9.5%	450
C_3H_8O	1-Propanol	97.2	23	2.2-13.7%	412
C_3H_8O	2-Propanol	82.3	12	2.0-12.7%	399
C_3H_8O	Ethyl methyl ether	7.4	-37	2.0-10.1%	190
$C_3H_8O_2$	1,2-Propylene glycol	187.6	99	2.6-12.5%	371
$C_3H_8O_2$	1,3-Propylene glycol	214.4			400
$C_3H_8O_2$	Ethylene glycol monomethyl ether	124.1	39	1.8-14%	285
$C_3H_8O_2$	Dimethoxymethane	42	-32	2.2-13.8%	237
$C_3H_8O_3$	Glycerol	290	199	3-19%	370
$C_3H_9BO_3$	Trimethyl borate	67.5	-8		
C_3H_9ClSi	Trimethylchlorosilane	60	-28		395
C_3H_9N	Propylamine	47.2	-37	2.0-10.4%	318
C_3H_9N	Isopropylamine	31.7	-37		402
C_3H_9N	Trimethylamine	2.8	-5	2.0-11.6%	190
C_3H_9NO	3-Amino-1-propanol	187.5	80		
C_3H_9NO	1-Amino-2-propanol	159.4	77		374
C_3H_9NO	*N*-Methyl-2-ethanolamine	158	74		
$C_3H_9O_3P$	Trimethyl phosphite	111.5	54		
$C_3H_9O_4P$	Trimethyl phosphate	197.2	107		
$C_3H_{10}N_2$	1,3-Propanediamine	139.8	24		
C_4Cl_6	Hexachloro-1,3-butadiene	215			610
$C_4H_2O_3$	Maleic anhydride	202	102	1.4-7.1%	477
C_4H_4	1-Buten-3-yne	5.1		21-100%	
$C_4H_4N_2$	Succinonitrile	266	132		
C_4H_4O	Furan	31.5	-36	2.3-14.3%	
$C_4H_4O_2$	Diketene	126.1	34		
C_4H_4S	Thiophene	84.0	-1		
C_4H_5Cl	2-Chloro-1,3-butadiene	59.4	-20	4.0-20.0%	
C_4H_5N	2-Butenenitrile	120.5	16		
C_4H_5N	Methylacrylonitrile	90.3	1	2-6.8%	
C_4H_5N	Pyrrole	129.7	39		
C_4H_6	1,3-Butadiene	-4.4		2.0-12.0%	420
C_4H_6	2-Butyne	26.9	-31	1.4-?	
C_4H_6O	Divinyl ether	28.3	<-30	1.7-27%	360
C_4H_6O	Ethoxyacetylene	50	<-7		
C_4H_6O	*trans*-2-Butenal	102.2	13	2.1-15.5%	232
C_4H_6O	3-Buten-2-one	81.4	-7	2.1-15.6%	491
C_4H_6O	Vinyloxirane	68	<-50		
$C_4H_6O_2$	Methacrylic acid	162.5	77	1.6-8.8%	68
$C_4H_6O_2$	Vinyl acetate	72.5	-8	2.6-13.4%	402
$C_4H_6O_2$	Methyl acrylate	80.7	-3	2.8-25%	468
$C_4H_6O_2$	2,3-Butanedione	88	27		
$C_4H_6O_2$	gamma-Butyrolactone	204	98		
$C_4H_6O_3$	Acetic anhydride	139.5	49	2.7-10.3%	316
$C_4H_6O_3$	Propylene carbonate	242	135		
$C_4H_6O_6$	*L*-Tartaric acid		210		425
C_4H_7Br	1-Bromo-2-butene	104.5		4.6-12.0%	
$C_4H_7BrO_2$	Ethyl bromoacetate	168.5	48		
C_4H_7Cl	2-Chloro-1-butene	58.5	-19	2.3-9.3%	
C_4H_7Cl	3-Chloro-2-methylpropene	71.5	-12	3.2-8.1%	
C_4H_7ClO	2-Chloroethyl vinyl ether	108	27		
$C_4H_7ClO_2$	Ethyl chloroacetate	144.3	64		
C_4H_7N	Butanenitrile	117.6	24	1.6-?	501
C_4H_7N	2-Methylpropanenitrile	103.9	8		482
C_4H_7NO	Acetone cyanohydrin		74	2.2-12.0%	688
C_4H_7NO	2-Pyrrolidone	251	129		
C_4H_8	1-Butene	-6.2		1.6-10.0%	385
C_4H_8	*cis*-2-Butene	3.7		1.7-9.0%	325
C_4H_8	*trans*-2-Butene	0.8		1.8-9.7%	324

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FLAMMABILITY OF CHEMICAL SUBSTANCES (continued)

Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
C_4H_8	Isobutene	-6.9		1.8-9.6%	465
C_4H_8	Cyclobutane	12.6	<10	1.8-?	
$C_4H_8Cl_2$	1,2-Dichlorobutane	124.1			275
$C_4H_8Cl_2$	1,4-Dichlorobutane	161	52		
$C_4H_8Cl_2O$	Bis(2-chloroethyl) ether	178.5	55	2.7-?	369
C_4H_8O	2-Buten-1-ol	121.5	27	4.2-35.3%	349
C_4H_8O	2-Methyl-2-propenol	114.5	33		
C_4H_8O	Ethyl vinyl ether	35.5	<-46	1.7-28%	202
C_4H_8O	1,2-Epoxybutane	63.4	-22	1.7-19%	439
C_4H_8O	Butanal	74.8	-22	1.9-12.5%	218
C_4H_8O	Isobutanal	64.5	-18	1.6-10.6%	196
C_4H_8O	2-Butanone	79.5	-9	1.4-11.4%	404
C_4H_8O	Tetrahydrofuran	65	-14	2-11.8%	321
C_4H_8OS	1,4-Oxathiane	147	42		
$C_4H_8O_2$	Butanoic acid	163.7	72	2.0-10.0%	443
$C_4H_8O_2$	2-Methylpropanoic acid	154.4	56	2.0-9.2%	481
$C_4H_8O_2$	Propyl formate	80.9	-3		455
$C_4H_8O_2$	Isopropyl formate	68.2	-6		485
$C_4H_8O_2$	Ethyl acetate	77.1	-4	2.0-11.5%	426
$C_4H_8O_2$	Methyl propanoate	79.8	-2	2.5-13%	469
$C_4H_8O_2$	3-Hydroxybutanal		66		250
$C_4H_8O_2$	1,4-Dioxane	101.5	12	2.0-22%	180
$C_4H_8O_2S$	Sulfolane	287.3	177		
$C_4H_8O_3$	Methyl lactate	144.8	49	2.2-?	385
$C_4H_8O_3$	Ethylene glycol monoacetate	188	102		
C_4H_9Br	1-Bromobutane	101.6	18	2.6-6.6%	265
C_4H_9Br	2-Bromobutane	91.2	21		
C_4H_9Cl	1-Chlorobutane	78.6	-12	1.9-10.1%	240
C_4H_9Cl	2-Chlorobutane	68.2	-10		
C_4H_9Cl	1-Chloro-2-methylpropane	68.5	-6	2.0-8.7%	
C_4H_9Cl	2-Chloro-2-methylpropane	50.9	0		
$C_4H_9Cl_3Si$	Butyltrichlorosilane	148.5	54		
C_4H_9N	Pyrrolidine	86.5	3		
C_4H_9NO	*N*-Ethylacetamide	205	110		
C_4H_9NO	*N*,*N*-Dimethylacetamide	165	70	1.8-11.5%	490
C_4H_9NO	Butanal oxime	154	58		
C_4H_9NO	2-Butanone oxime	152.5	≈70		
C_4H_9NO	Morpholine	128	37	1.4-11.2%	290
$C_4H_9NO_2$	*N*-Acetylethanolamine		179		460
$C_4H_9NO_3$	Butyl nitrate	133	36		
C_4H_{10}	Butane	-0.5	-60	1.9-8.5%	287
C_4H_{10}	Isobutane	-11.7	-87	1.8-8.4%	460
$C_4H_{10}N_2$	Piperazine	146	81		
$C_4H_{10}O$	1-Butanol	117.7	37	1.4-11.2%	343
$C_4H_{10}O$	2-Butanol	99.5	24	1.7-9.8%	405
$C_4H_{10}O$	2-Methyl-1-propanol	107.8	28	1.7-10.6%	415
$C_4H_{10}O$	2-Methyl-2-propanol	82.4	11	2.4-8.0%	478
$C_4H_{10}O$	Diethyl ether	34.5	-45	1.9-36.0%	180
$C_4H_{10}O$	Methyl propyl ether	39.1	-20	2.0-14.8%	
$C_4H_{10}O_2$	1,2-Butanediol	190.5	40		
$C_4H_{10}O_2$	1,3-Butanediol	207.5	121		395
$C_4H_{10}O_2$	1,4-Butanediol	235	121		
$C_4H_{10}O_2$	2,3-Butanediol	182.5			402
$C_4H_{10}O_2$	Ethylene glycol monoethyl ether	135	43	3-18%	235
$C_4H_{10}O_2$	Ethylene glycol dimethyl ether	85	-2		202
$C_4H_{10}O_2$	*tert*-Butyl hydroperoxide		27		
$C_4H_{10}O_2S$	2,2′-Thiodiethanol	282	160		298
$C_4H_{10}O_3$	Diethylene glycol	245.8	124	2-17%	224
$C_4H_{10}O_4S$	Diethyl sulfate	208	104		436
$C_4H_{10}S$	1-Butanethiol	98.5	2		
$C_4H_{10}S$	2-Butanethiol	85	-23		

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
$C_4H_{10}S$	2-Methyl-1-propanethiol	88.5	2		
$C_4H_{10}S$	2-Methyl-2-propanethiol	64.3	<-29		
$C_4H_{10}Se$	Diethyl selenide	108		2.5-?	
$C_4H_{11}N$	Butylamine	77.0	-12	1.7-9.8%	312
$C_4H_{11}N$	*sec*-Butylamine	63.5	-9		
$C_4H_{11}N$	*tert*-Butylamine	44.0	-9	1.7-8.9%	380
$C_4H_{11}N$	Isobutylamine	67.7	-9	2-12%	378
$C_4H_{11}N$	Diethylamine	55.5	-23	1.8-10.1%	312
$C_4H_{11}NO$	2-Amino-1-butanol	178	74		
$C_4H_{11}NO$	2-Amino-2-methyl-1-propanol	165.5	67		
$C_4H_{11}NO_2$	Diethanolamine	268.8	172	2-13%	662
$C_4H_{12}Sn$	Tetramethylstannane	78	-12	1.9-?	
$C_4H_{13}N_3$	Diethylenetriamine	207	98	2-6.7%	358
$C_5H_4O_2$	Furfural	161.7	60	2.1-19.3%	316
C_5H_5N	Pyridine	115.2	20	1.8-12.4%	482
C_5H_6	2-Methyl-1-buten-3-yne	32	<-7		
$C_5H_6N_2$	2-Methylpyrazine	137	50		
C_5H_6O	3-Methylfuran	66	-30		
$C_5H_6O_2$	Furfuryl alcohol	171	75	1.8-16.3%	491
C_5H_7N	1-Methylpyrrole	115	16		
C_5H_7NO	2-Furanmethanamine	145.5	37		
$C_5H_7NO_2$	Ethyl cyanoacetate	205	110		
C_5H_8	2-Methyl-1,3-butadiene	34.0	-54	1.5-8.9%	395
C_5H_8	1-Pentyne	40.1	<-20		
C_5H_8	Cyclopentene	44.2	-29		395
C_5H_8O	3-Methyl-3-buten-2-one	98		1.8-9.0%	
C_5H_8O	Cyclopentanone	130.5	26		
C_5H_8O	3,4-Dihydro-2H-pyran	86	-18		
$C_5H_8O_2$	Allyl acetate	103.5	22		374
$C_5H_8O_2$	Isopropenyl acetate	94	26		432
$C_5H_8O_2$	Vinyl propanoate	91.2	1		
$C_5H_8O_2$	Ethyl acrylate	99.4	10	1.4-14%	372
$C_5H_8O_2$	Methyl methacrylate	100.5	10	1.7-8.2%	
$C_5H_8O_2$	2,4-Pentanedione	138	34		340
$C_5H_8O_3$	Methyl acetoacetate	171.7	77		280
C_5H_9NO	*N*-Methyl-2-pyrrolidone	202	96	1-10%	346
C_5H_{10}	1-Pentene	29.9	-18	1.5-8.7%	275
C_5H_{10}	*cis*-2-Pentene	36.9	<-20		
C_5H_{10}	*trans*-2-Pentene	36.3	<-20		
C_5H_{10}	2-Methyl-1-butene	31.2	-20		
C_5H_{10}	3-Methyl-1-butene	20.1	-7	1.5-9.1%	365
C_5H_{10}	2-Methyl-2-butene	38.5	-20		
C_5H_{10}	Cyclopentane	49.3	-25	1.5-?	361
$C_5H_{10}Cl_2$	1,5-Dichloropentane	179	>27		
$C_5H_{10}N_2$	3-(Dimethylamino)propanenitrile	173	65		
$C_5H_{10}O$	Cyclopentanol	140.4	51		
$C_5H_{10}O$	Pentanal	103	12		222
$C_5H_{10}O$	2-Pentanone	102.2	7	1.5-8.2%	452
$C_5H_{10}O$	3-Pentanone	101.9	13	1.6-?	450
$C_5H_{10}O$	Tetrahydropyran	88	-20		
$C_5H_{10}O$	2-Methyltetrahydrofuran	78	-11		
$C_5H_{10}O_2$	Pentanoic acid	186.1	96		400
$C_5H_{10}O_2$	3-Methylbutanoic acid	176.5			416
$C_5H_{10}O_2$	Butyl formate	106.1	18	1.7-8.2%	322
$C_5H_{10}O_2$	Isobutyl formate	98.2	5	2-9%	320
$C_5H_{10}O_2$	Propyl acetate	101.5	13	1.7-8%	450
$C_5H_{10}O_2$	Isopropyl acetate	88.6	2	1.8-8%	460
$C_5H_{10}O_2$	Ethyl propanoate	99.1	12	1.9-11%	440
$C_5H_{10}O_2$	Methyl butanoate	102.8	14		
$C_5H_{10}O_2$	3-Ethoxypropanal	135.2	38		
$C_5H_{10}O_2$	Tetrahydrofurfuryl alcohol	178	75	1.5-9.7%	282

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FLAMMABILITY OF CHEMICAL SUBSTANCES (continued)

Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
$C_5H_{10}O_3$	Diethyl carbonate	126	25		
$C_5H_{10}O_3$	Ethylene glycol monomethyl ether acetate	143	49	1.5-12.3%	392
$C_5H_{10}O_3$	Ethyl lactate	154.5	46	1.5-?	400
$C_5H_{11}Br$	1-Bromopentane	129.8	32		
$C_5H_{11}Cl$	1-Chloropentane	107.8	13	1.6-8.6%	260
$C_5H_{11}Cl$	2-Chloro-2-methylbutane	85.6		1.5-7.4%	345
$C_5H_{11}Cl$	1-Chloro-3-methylbutane	98.9	<21	1.5-7.4%	
$C_5H_{11}Cl_3Si$	Trichloropentylsilane	172	63		
$C_5H_{11}N$	Piperidine	106.2	16		
$C_5H_{11}N$	*N*-Methylpyrrolidine	81	-14		
$C_5H_{11}NO$	4-Methylmorpholine	116	24		
$C_5H_{11}NO_2$	Isopentyl nitrite	99.2			210
C_5H_{12}	Pentane	36.0	-40	1.4-8.0%	260
C_5H_{12}	Isopentane	27.8	-51	1.4-7.6%	420
C_5H_{12}	Neopentane	9.4	-65	1.4-7.5%	450
$C_5H_{12}N_2$	1-Methylpiperazine	138	42		
$C_5H_{12}N_2O$	Tetramethylurea	176.5	77		
$C_5H_{12}O$	1-Pentanol	137.9	33	1.2-10.0%	300
$C_5H_{12}O$	2-Pentanol	119.3	34	1.2-9.0%	343
$C_5H_{12}O$	3-Pentanol	116.2	41	1.2-9.0%	435
$C_5H_{12}O$	2-Methyl-1-butanol	128	50		385
$C_5H_{12}O$	3-Methyl-1-butanol	131.1	43	1.2-9.0%	350
$C_5H_{12}O$	2-Methyl-2-butanol	102.4	19	1.2-9.0%	437
$C_5H_{12}O$	3-Methyl-2-butanol	112.9	38		
$C_5H_{12}O$	2,2-Dimethyl-1-propanol	113.5	37		
$C_5H_{12}O$	Ethyl propyl ether	63.2	<-20	1.7-9.0%	
$C_5H_{12}O_2$	1,5-Pentanediol	239	129		335
$C_5H_{12}O_2$	2-Isopropoxyethanol	145	33		
$C_5H_{12}O_2$	2,2-Dimethyl-1,3-propanediol	208	129		399
$C_5H_{12}O_3$	Diethylene glycol monomethyl ether	193	96	1.38-22.7%	240
$C_5H_{12}S$	1-Pentanethiol	126.6	18		
$C_5H_{12}S$	3-Methyl-2-butanethiol		3		
$C_5H_{13}N$	Pentylamine	104.3	-1	2.2-22%	
$C_5H_{13}N$	Butylmethylamine	91	13		
$C_6H_2Cl_4$	1,2,4,5-Tetrachlorobenzene	244.5	155		
$C_6H_3ClN_2O_4$	1-Chloro-2,4-dinitrobenzene	315	194	2.0-22%	
$C_6H_3Cl_3$	1,2,4-Trichlorobenzene	213.5	105	2.5-6.6%	571
$C_6H_4ClNO_2$	1-Chloro-4-nitrobenzene	242	127		
$C_6H_4Cl_2$	*o*-Dichlorobenzene	180	66	2.2-9.2%	648
$C_6H_4Cl_2$	*m*-Dichlorobenzene	173	72		
$C_6H_4Cl_2$	*p*-Dichlorobenzene	174	66		
$C_6H_4Cl_2O$	2,4-Dichlorophenol	210	114		
C_6H_5Br	Bromobenzene	156.0	51		565
C_6H_5Cl	Chlorobenzene	131.7	28	1.3-9.6%	593
C_6H_5ClO	*o*-Chlorophenol	174.9	64		
C_6H_5ClO	*p*-Chlorophenol	220	121		
$C_6H_5Cl_2N$	3,4-Dichloroaniline	272	166		
$C_6H_5Cl_3Si$	Trichlorophenylsilane	201	91		
C_6H_5F	Fluorobenzene	84.7	-15		
$C_6H_5NO_2$	Nitrobenzene	210.8	88	1.8-?	482
$C_6H_5N_3O_4$	2,4-Dinitroaniline		224		
C_6H_6	1,5-Hexadien-3-yne	85	<-20	1.5-?	
C_6H_6	Benzene	80.0	-11	1.2-7.8%	498
$C_6H_6N_2O_2$	*p*-Nitroaniline	332	199		
C_6H_6O	Phenol	181.8	79	1.8-8.6%	715
$C_6H_6O_2$	1,2-Benzenediol	245	127		
$C_6H_6O_2$	Resorcinol		127	1.4-?	608
$C_6H_6O_2$	*p*-Hydroquinone	287	165		516
C_6H_7N	Aniline	184.1	70	1.3-11%	615
C_6H_7N	2-Methylpyridine	129.3	39		538
C_6H_7N	4-Methylpyridine	145.3	57		

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
C_6H_8ClN	Aniline, hydrochloride		193		
$C_6H_8Cl_2O_2$	Hexanedioyl dichloride		72		
$C_6H_8N_2$	Adiponitrile	295	93	1.0-?	550
$C_6H_8N_2$	*o*-Phenylenediamine	257	156	1.5-?	
$C_6H_8N_2$	Phenylhydrazine	243.5	88		
$C_6H_8N_2$	2,5-Dimethylpyrazine	155	64		
C_6H_8O	2,5-Dimethylfuran	93.5	7		
$C_6H_8O_4$	Dimethyl maleate	202	113		
C_6H_{10}	1,4-Hexadiene	65	-21	2.0-6.1%	
C_6H_{10}	2-Methyl-1,3-pentadiene	75.8	-12		
C_6H_{10}	4-Methyl-1,3-pentadiene	76.5	-34		
C_6H_{10}	2-Hexyne	84.5	-10		
C_6H_{10}	Cyclohexene	82.9	-12	1.2-?	310
$C_6H_{10}O$	Diallyl ether	94	-7		
$C_6H_{10}O$	Cyclohexanone	155.4	44	1.1-9.4%	420
$C_6H_{10}O$	Mesityl oxide	130	31	1.4-7.2%	344
$C_6H_{10}O_2$	Vinyl butanoate	116.7	20	1.4-8.8%	
$C_6H_{10}O_2$	Ethyl 2-butenoate	136.5	2		
$C_6H_{10}O_2$	Ethyl methacrylate	117	20		
$C_6H_{10}O_2$	2,5-Hexanedione	194	79		499
$C_6H_{10}O_3$	Ethyl acetoacetate	180.8	57	1.4-9.5%	295
$C_6H_{10}O_3$	Propanoic anhydride	170	63	1.3-9.5%	285
$C_6H_{10}O_4$	Adipic acid	337.5	196		420
$C_6H_{10}O_4$	Diethyl oxalate	185.7	76		
$C_6H_{10}O_4$	Ethylene glycol diacetate	190	88	1.6-8.4%	482
$C_6H_{11}Cl$	Chlorocyclohexane	142	32		
$C_6H_{11}NO$	Caprolactam	270	125		
$C_6H_{11}NO_2$	Nitrocyclohexane	205	88		
$C_6H_{11}NO_2$	4-Acetylmorpholine		113		
C_6H_{12}	1-Hexene	63.4	-26	1.2-6.9%	253
C_6H_{12}	*cis*-2-Hexene	68.8	-21		
C_6H_{12}	2-Methyl-1-pentene	62.1	-28		300
C_6H_{12}	4-Methyl-1-pentene	53.9	-7		300
C_6H_{12}	4-Methyl-*cis*-2-pentene	56.3	-32		
C_6H_{12}	4-Methyl-*trans*-2-pentene	58.6	-29		
C_6H_{12}	2-Ethyl-1-butene	64.7	<-20		315
C_6H_{12}	2,3-Dimethyl-1-butene	55.6	<-20		360
C_6H_{12}	2,3-Dimethyl-2-butene	73.3	<-20		401
C_6H_{12}	Cyclohexane	80.7	-20	1.3-8%	245
C_6H_{12}	Methylcyclopentane	71.8	-29	1.0-8.35%	258
C_6H_{12}	Ethylcyclobutane	70.8	-15	1.2-7.7%	210
C_6H_{12}	2-Methyl-2-pentene	67.3	<-7		
$C_6H_{12}Cl_2O_2$	1,2-Bis(2-chloroethoxy)ethane	232	121		
$C_6H_{12}O$	*cis*-3-Hexen-1-ol	156.5	54		
$C_6H_{12}O$	Butyl vinyl ether	94	-9		255
$C_6H_{12}O$	Isobutyl vinyl ether	83	-9		
$C_6H_{12}O$	Hexanal	131	32		
$C_6H_{12}O$	2-Ethylbutanal		21	1.2-7.7%	
$C_6H_{12}O$	2-Methylpentanal	117	17		199
$C_6H_{12}O$	2-Hexanone	127.6	25	1-8%	423
$C_6H_{12}O$	3-Hexanone	123.5	35	1-8%	
$C_6H_{12}O$	4-Methyl-2-pentanone	116.5	18	1.2-8.0%	448
$C_6H_{12}O$	Cyclohexanol	160.8	68	1-9%	300
$C_6H_{12}O_2$	Hexanoic acid	205.2	102		380
$C_6H_{12}O_2$	2-Methylpentanoic acid	195.6	107		378
$C_6H_{12}O_2$	Diethylacetic acid	194	99		400
$C_6H_{12}O_2$	Pentyl formate	130.4	26		
$C_6H_{12}O_2$	Butyl acetate	126.1	22	1.7-7.6%	425
$C_6H_{12}O_2$	*sec*-Butyl acetate	112	31	1.7-9.8%	
$C_6H_{12}O_2$	Isobutyl acetate	116.5	18	1.3-10.5%	421
$C_6H_{12}O_2$	Propyl propanoate	122.5	79		

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
$C_6H_{12}O_2$	Ethyl butanoate	121.5	24		463
$C_6H_{12}O_2$	Ethyl 2-methylpropanoate	110.1	13		
$C_6H_{12}O_2$	Diacetone alcohol	167.9	58	1.8-6.9%	643
$C_6H_{12}O_3$	Ethylene glycol monoethyl ether acetate	156.4	56	2-8%	379
$C_6H_{12}O_3$	Paraldehyde	124.3	36	1.3-?	238
$C_6H_{12}S$	Cyclohexanethiol	158.9	43		
$C_6H_{13}Cl$	1-Chlorohexane	135	35		
$C_6H_{13}N$	Cyclohexylamine	134	31	1.9-9.4%	293
$C_6H_{13}NO$	*N*-Butylacetamide	229	116		
$C_6H_{13}NO$	2,6-Dimethylmorpholine	146.6	44		
$C_6H_{13}NO$	*N*-Ethylmorpholine	138.5	32		
$C_6H_{13}NO_2$	4-Morpholineethanol	227	99		
C_6H_{14}	Hexane	68.7	-22	1.1-7.5%	225
C_6H_{14}	2-Methylpentane	60.2	<-29	1.0-7.0%	264
C_6H_{14}	3-Methylpentane	63.2	-7	1.2-7.0%	278
C_6H_{14}	2,2-Dimethylbutane	49.7	-48	1.2-7.0%	405
C_6H_{14}	2,3-Dimethylbutane	57.9	-29	1.2-7.0%	405
$C_6H_{14}N_2O$	1-Piperazineethanol	246	124		
$C_6H_{14}O$	1-Hexanol	157.6	63		
$C_6H_{14}O$	2-Methyl-1-pentanol	149	54	1.1-9.65%	310
$C_6H_{14}O$	4-Methyl-2-pentanol	131.6	41	1.0-5.5%	
$C_6H_{14}O$	2-Ethyl-1-butanol	147	57		
$C_6H_{14}O$	Dipropyl ether	90.0	21	1.3-7.0%	188
$C_6H_{14}O$	Diisopropyl ether	68.5	-28	1.4-7.9%	443
$C_6H_{14}O$	Butyl ethyl ether	92.3	4		
$C_6H_{14}O_2$	2,5-Hexanediol	218	110		
$C_6H_{14}O_2$	2-Methyl-2,4-pentanediol	197.1	102	1-9%	306
$C_6H_{14}O_2$	Ethylene glycol monobutyl ether	168.4	69	4-13%	238
$C_6H_{14}O_2$	1,1-Diethoxyethane	102.2	-21	1.6-10.4%	230
$C_6H_{14}O_2$	Ethylene glycol diethyl ether	119.4	27		205
$C_6H_{14}O_3$	1,2,6-Hexanetriol		191		
$C_6H_{14}O_3$	Diethylene glycol monoethyl ether	196	96		
$C_6H_{14}O_3$	Diethylene glycol dimethyl ether	162	67		
$C_6H_{14}O_3$	Trimethylolpropane		149		
$C_6H_{14}O_4$	Triethylene glycol	285	177	0.9-9.2%	371
$C_6H_{15}N$	Hexylamine	132.8	29		
$C_6H_{15}N$	Butylethylamine	107.5	18		
$C_6H_{15}N$	Dipropylamine	109.3	17		299
$C_6H_{15}N$	Diisopropylamine	83.9	-1	1.1-7.1%	316
$C_6H_{15}N$	Triethylamine	89	-7	1.2-8.0%	249
$C_6H_{15}NO_2$	Diisopropanolamine	250	127		374
$C_6H_{15}NO_3$	Triethanolamine	335.4	179	1-10%	
$C_6H_{15}N_3$	1-Piperazineethanamine	220	93		
$C_6H_{15}O_4P$	Triethyl phosphate	215.5	115		454
$C_6H_{16}N_2$	*N*,*N*-Diethylethylenediamine	144	46		
$C_7H_3ClF_3NO_2$	1-Chloro-4-nitro-2-(trifluoromethyl)benzene	232	135		
$C_7H_4ClF_3$	1-Chloro-2-(trifluoromethyl)benzene	152.2	59		
$C_7H_4F_3NO_2$	1-Nitro-3-(trifluoromethyl)benzene	202.8	103		
C_7H_5ClO	Benzoyl chloride	197.2	72		
C_7H_5ClO	4-Chlorobenzaldehyde	213.5	88		
$C_7H_5Cl_3$	(Trichloromethyl)benzene	221	127		211
$C_7H_5F_3$	(Trifluoromethyl)benzene	102.1	12		
$C_7H_6N_2O_4$	1-Methyl-2,4-dinitrobenzene		207		
C_7H_6O	Benzaldehyde	179.0	63		192
$C_7H_6O_2$	Benzoic acid	249.2	121		570
$C_7H_6O_2$	Salicylaldehyde	197	78		
$C_7H_6O_3$	Salicylic acid		157	1.1-?	540
C_7H_7Br	*o*-Bromotoluene	181.7	79		
C_7H_7Br	*p*-Bromotoluene	184.3	85		
C_7H_7Cl	(Chloromethyl)benzene	179	67	1.1-?	585
$C_7H_7NO_2$	*o*-Nitrotoluene	222	106		

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
$C_7H_7NO_2$	*m*-Nitrotoluene	232	106		
$C_7H_7NO_2$	*p*-Nitrotoluene	238.3	106		
C_7H_8	Toluene	110.6	4	1.1-7.1%	480
C_7H_8	Bicyclo[2.2.1]hepta-2,5-diene	89.5	-21		
C_7H_8O	*o*-Cresol	191.0	81	1.4-?	599
C_7H_8O	*m*-Cresol	202.2	86	1.1-?	558
C_7H_8O	*p*-Cresol	201.9	86	1.1-?	558
C_7H_8O	Benzyl alcohol	205.3	93		436
C_7H_8O	Anisole	153.7	52		475
$C_7H_8O_2$	4-Methoxyphenol	243	132		421
$C_7H_8O_3S$	*p*-Toluenesulfonic acid		184		
C_7H_9N	*o*-Methylaniline	200.3	85		482
C_7H_9N	*p*-Methylaniline	200.4	87		482
C_7H_9NO	*o*-Anisidine	224	118		
$C_7H_{10}O$	3-Cyclohexene-1-carboxaldehyde	105	57		
$C_7H_{10}O_4$	3,3-Diacetoxy-1-propene	180	82		
C_7H_{12}	4-Methylcyclohexene	102.7	-1		
$C_7H_{12}O_2$	Butyl acrylate	145	29	1.7-9.9%	292
$C_7H_{12}O_2$	Isobutyl acrylate	132	30		427
$C_7H_{12}O_2$	Cyclohexyl formate	162	51		
$C_7H_{12}O_4$	Diethyl malonate	200	93		
C_7H_{14}	1-Heptene	93.6	-1		260
C_7H_{14}	*trans*-2-Heptene	98	<0		
C_7H_{14}	Cycloheptane	118.4	<21	1.1-6.7%	
C_7H_{14}	Methylcyclohexane	100.9	-4	1.2-6.7%	250
C_7H_{14}	Ethylcyclopentane	103.5	<21	1.1-6.7%	260
$C_7H_{14}O$	2-Heptanone	151.0	39	1.1-7.9%	393
$C_7H_{14}O$	3-Heptanone	147	46		
$C_7H_{14}O$	4-Heptanone	144	49		
$C_7H_{14}O$	5-Methyl-2-hexanone	144	36	1.0-8.2%	191
$C_7H_{14}O$	*cis*-2-Methylcyclohexanol	165	65		296
$C_7H_{14}O$	*trans*-2-Methylcyclohexanol	167.5	65		296
$C_7H_{14}O$	*cis*-3-Methylcyclohexanol	174.5	70		295
$C_7H_{14}O$	*trans*-3-Methylcyclohexanol	174.5	70		295
$C_7H_{14}O$	*cis*-4-Methylcyclohexanol	173	70		295
$C_7H_{14}O$	*trans*-4-Methylcyclohexanol	174	70		295
$C_7H_{14}O_2$	Pentyl acetate	149.2	16	1.1-7.5%	360
$C_7H_{14}O_2$	Isopentyl acetate	142.5	25	1.0-7.5%	360
$C_7H_{14}O_2$	*sec*-Pentyl acetate	130.5	32		
$C_7H_{14}O_2$	Butyl propanoate	146.8	32		426
$C_7H_{14}O_2$	Propyl butanoate	143.0	37		
$C_7H_{15}NO_2$	Ethyl *N*-butylcarbamate	202	92		
C_7H_{16}	Heptane	98.5	-4	1.05-6.7%	204
C_7H_{16}	2-Methylhexane	90.0	-1	1.0-6.0%	280
C_7H_{16}	3-Methylhexane	92	-4		280
C_7H_{16}	2,3-Dimethylpentane	89.7	-56	1.1-6.7%	335
C_7H_{16}	2,4-Dimethylpentane	80.4	-12		
C_7H_{16}	2,2,3-Trimethylbutane	80.8	<0		412
$C_7H_{16}N_2O$	4-Morpholinepropanamine	220	104		
$C_7H_{16}O$	2-Heptanol	159	71		
$C_7H_{16}O$	3-Heptanol	157	60		
$C_7H_{16}O$	2,4-Dimethyl-3-pentanol	138.7	49		
$C_7H_{16}O$	2,3,3-Trimethyl-2-butanol	131	<0		375
$C_7H_{17}N$	Heptylamine	156	54		
$C_7H_{18}N_2$	*N*,*N*-Diethyl-1,3-propanediamine	168.5	59		
$C_8H_4O_3$	Phthalic anhydride	295	152	1.7-10.5%	570
$C_8H_6O_4$	Phthalic acid		168		
$C_8H_6O_4$	Terephthalic acid		260		496
C_8H_7ClO	α-Chloroacetophenone	247	118		
C_8H_7N	Benzeneacetonitrile	233.5	113		
C_8H_8	Styrene	145	31	0.9-6.8%	490

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
C_8H_8O	Phenyloxirane	194.1	74		498
C_8H_8O	Benzeneacetaldehyde	195	71		
C_8H_8O	Acetophenone	202	77		570
$C_8H_8O_2$	Benzeneacetic acid	265.5	>100		
$C_8H_8O_2$	Phenyl acetate	196	80		
$C_8H_8O_2$	Methyl benzoate	199	83		
$C_8H_8O_2$	2-Methoxybenzaldehyde	243.5	118		
$C_8H_8O_3$	Methyl salicylate	222.9	96		454
C_8H_9Cl	1-Chloro-4-ethylbenzene	184.4	64		
C_8H_9NO	Acetanilide	304	169		530
$C_8H_9NO_2$	Methyl 2-aminobenzoate	256	>100		
C_8H_{10}	Ethylbenzene	136.1	21	0.8-6.7%	432
C_8H_{10}	*o*-Xylene	144.5	32	0.9-6.7%	463
C_8H_{10}	*m*-Xylene	139.1	27	1.1-7.0%	527
C_8H_{10}	*p*-Xylene	138.3	27	1.1-7.0%	528
$C_8H_{10}O$	*p*-Ethylphenol	217.9	104		
$C_8H_{10}O$	Benzeneethanol	218.2	96		
$C_8H_{10}O$	α-Methylbenzyl alcohol	205	93		
$C_8H_{10}O$	Phenetole	169.8	63		
$C_8H_{10}O$	Benzyl methyl ether	170	135		
$C_8H_{10}O$	4-Methylanisole	175.5	60		
$C_8H_{10}O_2$	2-Phenoxyethanol	245	121		
$C_8H_{11}N$	*N*-Ethylaniline	203.0	85		
$C_8H_{11}N$	*N*,*N*-Dimethylaniline	194.1	63		371
$C_8H_{11}N$	2,3-Xylidine	221.5	97	1.0-?	
$C_8H_{11}N$	2,6-Xylidine	215	96		
$C_8H_{11}N$	α-Methylbenzylamine	187	79		
$C_8H_{11}N$	5-Ethyl-2-picoline	178.3	68	1.1-6.6%	
$C_8H_{11}NO$	*N*-Phenylethanolamine	279.5	152		
$C_8H_{11}NO$	*o*-Phenetidine	232.5	115		
$C_8H_{11}NO$	*p*-Phenetidine	254	116		
C_8H_{12}	1,5-Cyclooctadiene	150.8	35		
C_8H_{12}	4-Vinylcyclohexene	128	16		269
$C_8H_{12}O_4$	Diethyl maleate	223	121		350
$C_8H_{12}O_4$	Diethyl fumarate	214	104		
$C_8H_{14}O_2$	Cyclohexyl acetate	173	58		335
$C_8H_{14}O_2$	Butyl methacrylate	160	52		
$C_8H_{14}O_3$	Butanoic anhydride	200	54	0.9-5.8%	279
$C_8H_{14}O_3$	2-Methylpropanoic anhydride	183	59	1.0-6.2%	329
$C_8H_{14}O_3$	Butyl acetoacetate		85		
$C_8H_{14}O_4$	Ethyl succinate	217.7	90		
$C_8H_{14}O_5$	Diethylene glycol diacetate	200	135		
$C_8H_{14}O_6$	Diethyl tartrate	281	93		
$C_8H_{15}ClO$	Octanoyl chloride	195.6	82		
C_8H_{16}	1-Octene	121.2	21		230
C_8H_{16}	2,4,4-Trimethyl-1-pentene	101.4	-5	0.8-4.8%	391
C_8H_{16}	2,4,4-Trimethyl-2-pentene	104.9	2		305
C_8H_{16}	Ethylcyclohexane	131.9	35	0.9-6.6%	238
C_8H_{16}	*cis*-1,2-Dimethylcyclohexane	129.8	16		304
C_8H_{16}	*trans*-1,2-Dimethylcyclohexane	123.5	11		304
C_8H_{16}	*cis*-1,4-Dimethylcyclohexane	124.4	16		
C_8H_{16}	Propylcyclopentane	131			269
$C_8H_{16}O$	Octanal	171	52		
$C_8H_{16}O$	2-Ethylhexanal	163	44	0.85-7.2%	190
$C_8H_{16}O$	2-Octanone	172.5	52		
$C_8H_{16}O_2$	Hexyl acetate	171.5	45		
$C_8H_{16}O_2$	sec-Hexyl acetate	147.5	45		
$C_8H_{16}O_2$	2-Ethylbutyl acetate	162.5	54		
$C_8H_{16}O_2$	Pentyl propanoate	168.6	41		378
$C_8H_{16}O_2$	Butyl butanoate	166	53		

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
$C_8H_{16}O_2$	Isobutyl butanoate	156.9	50		
$C_8H_{16}O_2$	Isobutyl isobutanoate	148.6	38	0.96-7.59%	432
$C_8H_{16}O_2$	Ethyl hexanoate	167	49		
$C_8H_{16}O_2$	1,4-Cyclohexanedimethanol	283	167		316
$C_8H_{16}O_3$	Pentyl lactate		79		
$C_8H_{16}O_4$	Diethylene glycol monoethyl ether acetate	218.5	110		425
$C_8H_{17}Cl$	1-Chlorooctane	181.5	70		
$C_8H_{17}Cl$	3-(Chloromethyl)heptane	172	60		
C_8H_{18}	Octane	125.6	13	1.0-6.5%	206
C_8H_{18}	2,3-Dimethylhexane	115.6	7		438
C_8H_{18}	2,4-Dimethylhexane	109.5	10		
C_8H_{18}	3-Ethyl-2-methylpentane	115.6	<21		460
C_8H_{18}	2,2,3-Trimethylpentane	110	<21		346
C_8H_{18}	2,2,4-Trimethylpentane	99.2	-12		418
C_8H_{18}	2,3,3-Trimethylpentane	114.8	<21		425
$C_8H_{18}O$	1-Octanol	195.1	81		
$C_8H_{18}O$	2-Octanol	180	88		
$C_8H_{18}O$	2-Ethyl-1-hexanol	184.6	73	0.88-9.7%	231
$C_8H_{18}O$	Dibutyl ether	140.2	25	1.5-7.6%	194
$C_8H_{18}O_2$	2-Ethyl-1,3-hexanediol	244	127		360
$C_8H_{18}O_2$	2,2,4-Trimethyl-1,3-pentanediol	235	113		346
$C_8H_{18}O_2$	Di-*tert*-butyl peroxide	111	18		
$C_8H_{18}O_3$	Diethylene glycol diethyl ether	188	82		
$C_8H_{18}O_4$	2,5,8,11-Tetraoxadodecane	216	111		
$C_8H_{18}O_5$	Tetraethylene glycol	328	182		
$C_8H_{18}S$	1-Octanethiol	199.1	69		
$C_8H_{18}S$	Dibutyl sulfide	185	76		
$C_8H_{19}N$	Octylamine	179.6	60		
$C_8H_{19}N$	Dibutylamine	159.6	47	1.1-6%	
$C_8H_{19}N$	Diisobutylamine	139.6	29		
$C_8H_{19}N$	2-Ethylhexylamine	169.2	60		
$C_8H_{20}O_4Si$	Ethyl silicate	168.8	52		
$C_8H_{23}N_5$	Tetraethylenepentamine	341.5	163		321
$C_9H_6N_2O_2$	Toluene-2,4-diisocyanate	251	127	0.9-9.5%	
C_9H_7N	Quinoline	237.1			480
C_9H_{10}	*o*-Methylstyrene	169.8	53	0.8-11.0%	538
C_9H_{10}	*m*-Methylstyrene	164	53	0.8-11.0%	538
C_9H_{10}	*p*-Methylstyrene	172.8	53	0.8-11.0%	538
C_9H_{10}	Isopropenylbenzene	165.4	54	1.9-6.1%	574
$C_9H_{10}O$	1-Phenyl-1-propanone	217.5	99		
$C_9H_{10}O$	4-Methylacetophenone	226	96		
$C_9H_{10}O_2$	Ethyl benzoate	212	88		490
$C_9H_{10}O_2$	Benzyl acetate	213	90		460
$C_9H_{10}O_2$	Methyl 2-phenylacetate	216.5	91		
$C_9H_{11}NO$	4-Methylacetanilide	307	168		
C_9H_{12}	Propylbenzene	159.2	30	0.8-6.0%	450
C_9H_{12}	Isopropylbenzene	152.4	36	0.9-6.5%	424
C_9H_{12}	*o*-Ethyltoluene	165.2			440
C_9H_{12}	*m*-Ethyltoluene	161.3			480
C_9H_{12}	*p*-Ethyltoluene	162			475
C_9H_{12}	1,2,3-Trimethylbenzene	176.1	44	0.8-6.6%	470
C_9H_{12}	1,2,4-Trimethylbenzene	169.3	44	0.9-6.4%	500
C_9H_{12}	1,3,5-Trimethylbenzene	164.7	50	1-5%	559
$C_9H_{12}O$	α–Ethylbenzyl alcohol	219	100		
$C_9H_{12}O_2$	Ethylene glycol monobenzyl ether	256	129		352
$C_9H_{12}O_3S$	Ethyl *p*-toluenesulfonate		158		
$C_9H_{13}N$	Amphetamine	203	<100		
$C_9H_{14}O$	Phorone	197.5	85		
$C_9H_{14}O$	Isophorone	215.2	84	0.8-3.8%	460
$C_9H_{14}O_6$	Triacetin	259	138	1.0-?	433
C_9H_{16}	Octahydroindene	167			296

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
$C_9H_{16}O_2$	Allyl hexanoate	186	66		
C_9H_{18}	1-Nonene	146.9	26		
C_9H_{18}	Propylcyclohexane	156.7			248
C_9H_{18}	Isopropylcyclohexane	154.8			283
C_9H_{18}	Butylcyclopentane	156.6			250
$C_9H_{18}O$	2-Nonanone	195.3	60	0.9-5.9%	360
$C_9H_{18}O$	Diisobutyl ketone	169.4	49	0.8-7.1%	396
$C_9H_{18}O_2$	Pentyl butanoate	186.4	57		
$C_9H_{18}O_2$	Isopentyl butanoate	179	59		
$C_9H_{18}O_2$	Butyl 3-methylbutanoate		53		
C_9H_{20}	Nonane	150.8	31	0.8-2.9%	205
C_9H_{20}	3-Ethyl-4-methylhexane	140	24		
C_9H_{20}	4-Ethyl-2-methylhexane	133.8	<21	0.7-?	280
C_9H_{20}	2,2,5-Trimethylhexane	124.0	13		
C_9H_{20}	3,3-Diethylpentane	146.3		0.7-5.7%	290
C_9H_{20}	3-Ethyl-2,4-dimethylpentane	136.7	390		
C_9H_{20}	2,2,3,3-Tetramethylpentane	140.2	<21	0.8-4.9%	430
C_9H_{20}	2,2,3,4-Tetramethylpentane	133.0	<21		
$C_9H_{21}BO_3$	Triisopropyl borate	140	28		
$C_9H_{21}N$	Tripropylamine	156	41		
$C_9H_{21}NO_3$	Triisopropanolamine		160		320
$C_{10}H_7Cl$	1-Chloronaphthalene	259	121		>558
$C_{10}H_8$	Naphthalene	217.9	79	0.9-5.9%	526
$C_{10}H_8O$	2-Naphthol	285	153		
$C_{10}H_9N$	1-Naphthalenamine	300.8	157		
$C_{10}H_{10}O_2$	Safrole	234.5	100		
$C_{10}H_{10}O_4$	Dimethyl phthalate	283.7	146	0.9-?	490
$C_{10}H_{10}O_4$	Dimethyl isophthalate	282	138		
$C_{10}H_{10}O_4$	Dimethyl terephthalate	288	153		518
$C_{10}H_{11}NO_2$	Acetoacetanilide		185		
$C_{10}H_{12}$	1,2,3,4-Tetrahydronaphthalene	207.6	71	0.8-5.0%	385
$C_{10}H_{12}O_2$	Isopropyl benzoate	216	99		
$C_{10}H_{12}O_2$	Ethyl phenylacetate	227	99		
$C_{10}H_{14}$	Butylbenzene	183.3	71	0.8-5.8%	410
$C_{10}H_{14}$	*sec*-Butylbenzene	173.3	52	0.8-6.9%	418
$C_{10}H_{14}$	*tert*-Butylbenzene	169.1	60	0.7-5.7%	450
$C_{10}H_{14}$	Isobutylbenzene	172.7	55	0.8-6.0%	427
$C_{10}H_{14}$	*p*-Cymene	177.1	47	0.7-5.6%	436
$C_{10}H_{14}$	1,2,3,4-Tetramethylbenzene	205	74		427
$C_{10}H_{14}$	1,2,3,5-Tetramethylbenzene	198	71		427
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene	196.8	54		
$C_{10}H_{14}$	*o*-Diethylbenzene	184	57		395
$C_{10}H_{14}$	*m*-Diethylbenzene	181.1	56		450
$C_{10}H_{14}$	*p*-Diethylbenzene	183.7	55	0.7-6.0%	430
$C_{10}H_{14}O$	Butyl phenyl ether	210	82		
$C_{10}H_{14}O_2$	4-*tert*-Butyl-1,2-benzenediol	285	130		
$C_{10}H_{15}N$	*N*-Butylaniline	243.5	107		
$C_{10}H_{15}N$	*N*,*N*-Diethylaniline	216.3	85		630
$C_{10}H_{15}NO_2$	*N*-Phenyl-*N*,*N*-diethanolamine		196	0.7-?	387
$C_{10}H_{16}$	Dipentene	178	45		237
$C_{10}H_{16}$	*d*-Limonene	178	45	0.7-6.1%	237
$C_{10}H_{16}$	α-Pinene	156.2	33		255
$C_{10}H_{16}$	β-Pinene	166	38		275
$C_{10}H_{16}$	β-Phellandrene	171.5	49		
$C_{10}H_{16}O$	Camphor	207.4	66	0.6-3.5%	466
$C_{10}H_{18}$	*trans*-Decahydronaphthalene	187.3	54	0.7-5.4%	255
$C_{10}H_{18}O$	Borneol		66		
$C_{10}H_{18}O$	Linalol	198	71		
$C_{10}H_{18}O$	α-Terpineol	220	90		
$C_{10}H_{18}O$	Cineole	176.4	48		

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
$C_{10}H_{18}O$	*trans*-Geraniol	230	>100		
$C_{10}H_{18}O_4$	Dibutyl oxalate	241	104		
$C_{10}H_{19}NO_2$	*N*-*tert*-Butylaminoethyl methacrylate		96		
$C_{10}H_{20}$	1-Decene	170.5	<55		235
$C_{10}H_{20}$	Butylcyclohexane	180.9			246
$C_{10}H_{20}$	Isobutylcyclohexane	171.3			274
$C_{10}H_{20}$	*tert*-Butylcyclohexane	171.5			342
$C_{10}H_{20}O$	Citronellol	224	96		
$C_{10}H_{20}O_2$	2-Ethylhexyl acetate	199	71	0.76-8.14%	268
$C_{10}H_{20}O_2$	Ethyl octanoate	208.5	79		
$C_{10}H_{21}N$	*N*-Butylcyclohexanamine		93		
$C_{10}H_{22}$	Decane	174.1	51	0.8-5.4%	210
$C_{10}H_{22}$	2-Methylnonane	167.1			210
$C_{10}H_{22}$	3-Ethyloctane	166.5			230
$C_{10}H_{22}$	4-Ethyloctane	163.7			229
$C_{10}H_{22}O$	1-Decanol	231.1	82		288
$C_{10}H_{22}O$	Dipentyl ether	190	57		170
$C_{10}H_{22}O_2$	Ethylene glycol dibutyl ether	203.3	85		
$C_{10}H_{22}O_5$	Tetraethylene glycol dimethyl ether	275.3	141		
$C_{10}H_{22}S$	Dipentyl sulfide		85		
$C_{10}H_{23}N$	Decylamine	220.5	99		
$C_{10}H_{23}N$	Dipentylamine	202.5	51		
$C_{11}H_{10}$	1-Methylnaphthalene	244.7			529
$C_{11}H_{12}O_3$	Ethyl benzoylacetate		141		
$C_{11}H_{14}O_2$	Butyl benzoate	250.3	107		
$C_{11}H_{16}$	*p*-*tert*-Butyltoluene	190	68		
$C_{11}H_{16}$	Pentylbenzene	205.4	66		
$C_{11}H_{16}$	1,3-Diethyl-5-methylbenzene	205			455
$C_{11}H_{16}$	Pentamethylbenzene	232	93		427
$C_{11}H_{16}O$	4-*tert*-Butyl-2-methylphenol	237	118		
$C_{11}H_{17}N$	*p*-*tert*-Pentylaniline	260.5	102		
$C_{11}H_{20}O_2$	2-Ethylhexyl acrylate		82		252
$C_{11}H_{22}$	Pentylcyclohexane	203.7			239
$C_{11}H_{22}O$	2-Undecanone	231.5	89		
$C_{11}H_{22}O_2$	Nonyl acetate	210	68		
$C_{11}H_{24}$	Undecane	195.9	69		
$C_{11}H_{24}$	2-Methyldecane	189.3			225
$C_{11}H_{24}O$	2-Undecanol	228	113		
$C_{12}H_9Br$	4-Bromo-1,1'-Biphenyl	310	144		
$C_{12}H_{10}$	Biphenyl	256.1	113	0.6-5.8%	540
$C_{12}H_{10}Cl_2Si$	Dichlorodiphenylsilane	305	142		
$C_{12}H_{10}O$	*o*-Phenylphenol	286	124		530
$C_{12}H_{10}O$	Diphenyl ether	258.0	112	0.8-1.5%	618
$C_{12}H_{11}N$	2-Aminobiphenyl	299			450
$C_{12}H_{11}N$	Diphenylamine	302	153		634
$C_{12}H_{12}$	1-Ethylnaphthalene	258.6			480
$C_{12}H_{14}O_4$	Diethyl phthalate	295	161	0.7-?	457
$C_{12}H_{14}O_4$	Diethyl terephthalate	302	117		
$C_{12}H_{16}$	Cyclohexylbenzene	240.1	99		
$C_{12}H_{16}O_3$	Pentyl salicylate	270	132		
$C_{12}H_{17}NO$	*N*-Butyl-*N*-phenylacetamide	281	141		
$C_{12}H_{18}$	1,5,9-Cyclododecatriene	240	71		
$C_{12}H_{20}O_4$	Dibutyl maleate	280	141		
$C_{12}H_{22}O_4$	Dimethyl sebacate		145		
$C_{12}H_{22}O_6$	Dibutyl tartrate	320	91		284
$C_{12}H_{23}N$	Dicyclohexylamine		>99		
$C_{12}H_{24}$	1-Dodecene	213.8	79		
$C_{12}H_{24}O_2$	Ethyl decanoate	241.5	>100		
$C_{12}H_{25}Br$	1-Bromododecane	276	144		
$C_{12}H_{26}$	Dodecane	216.3	74	0.6-?	203
$C_{12}H_{26}O$	1-Dodecanol	259	127		275

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
$C_{12}H_{26}O$	2-Butyl-1-octanol	246.5	110		
$C_{12}H_{26}O_3$	Diethylene glycol dibutyl ether	256	118		310
$C_{12}H_{26}S$	1-Dodecanethiol	277	128		
$C_{12}H_{27}BO_3$	Tributyl borate	234	93		
$C_{12}H_{27}N$	Tributylamine	216.5	63		
$C_{12}H_{27}O_4P$	Tributyl phosphate	289	146		
$C_{13}H_{12}$	2-Methylbiphenyl	255.5	137		502
$C_{13}H_{12}$	Diphenylmethane	265.0	130		485
$C_{13}H_{14}N_2$	*p,p′*-Diaminodiphenylmethane	398	220		
$C_{13}H_{26}$	1-Tridecene	232.8	79		
$C_{13}H_{26}O$	2-Tridecanone	263	107		
$C_{13}H_{28}$	Tridecane	235.4	79		
$C_{13}H_{28}O$	1-Tridecanol		121		
$C_{14}H_8O_2$	9,10-Anthracenedione	377	185		
$C_{14}H_{10}$	Anthracene	339.9	121	0.6-?	540
$C_{14}H_{10}$	Phenanthrene	340	171		
$C_{14}H_{12}O_2$	Benzyl benzoate	323.5	148		480
$C_{14}H_{12}O_3$	Benzyl salicylate	320	>100		
$C_{14}H_{14}$	1,1-Diphenylethane	272.6	>100		440
$C_{14}H_{14}O$	Dibenzyl ether	298	135		
$C_{14}H_{16}$	1-Butylnaphthalene	289.3	360		
$C_{14}H_{16}N_2O_2$	*o*-Dianisidine		206		
$C_{14}H_{23}N$	*N,N*-Dibutylaniline	274.8	110		
$C_{14}H_{28}$	1-Tetradecene	233	110		235
$C_{14}H_{30}$	Tetradecane	253.5	112	0.5-?	200
$C_{14}H_{30}O$	1-Tetradecanol	289	141		
$C_{15}H_{18}$	1-Pentylnaphthalene	307	124		
$C_{15}H_{24}$	Nonylbenzene	280.5	99		
$C_{15}H_{24}O$	2,6-Di-*tert*-butyl-4-methylphenol	265	127		
$C_{15}H_{26}O_6$	Tributyrin	307.5	180	0.5-?	407
$C_{15}H_{33}N$	Tripentylamine	242.5	102		
$C_{16}H_{14}O$	1,3-Diphenyl-2-buten-1-one	342.5	177		
$C_{16}H_{18}$	2-Butyl-1,1'-biphenyl		>100		430
$C_{16}H_{22}O_4$	Dibutyl phthalate	340	157	0.5-?	402
$C_{16}H_{26}$	Decylbenzene	298	107		
$C_{16}H_{34}$	Hexadecane	286.8	136		202
$C_{16}H_{34}O$	Dioctyl ether	283	>100		205
$C_{16}H_{35}N$	Bis(2-ethylhexyl)amine		132		
$C_{17}H_{20}N_2O$	*N,N′*-Diethylcarbanilide		150		
$C_{17}H_{34}O$	2-Heptadecanone	320	120		
$C_{17}H_{36}O$	1-Heptadecanol	333	154		
$C_{18}H_{14}$	*o*-Terphenyl	332	163		
$C_{18}H_{14}$	*m*-Terphenyl	363	191		
$C_{18}H_{15}O_3P$	Triphenyl phosphite	360	218		
$C_{18}H_{15}O_4P$	Triphenyl phosphate		220		
$C_{18}H_{15}P$	Triphenylphosphine		180		
$C_{18}H_{30}$	Dodecylbenzene	328	140		
$C_{18}H_{32}O_7$	Butyl citrate		157		368
$C_{18}H_{34}O_2$	Oleic acid	360	189		363
$C_{18}H_{34}O_4$	Dibutyl sebacate	344.5	178	0.4-?	365
$C_{18}H_{36}O_2$	Stearic acid		196		395
$C_{18}H_{37}Cl_3Si$	Trichlorooctadecylsilane		89		
$C_{18}H_{38}$	Octadecane	316.3	>100		227
$C_{18}H_{38}O$	1-Octadecanol				450
$C_{19}H_{16}$	Triphenylmethane	359	>100		
$C_{19}H_{38}O$	2-Nonadecanone		124		
$C_{19}H_{38}O_2$	Methyl stearate	443	153		
$C_{19}H_{40}$	Nonadecane	329.9	>100		230
$C_{20}H_{14}O_4$	Diphenyl phthalate		224		
$C_{20}H_{28}$	1-Decylnaphthalene	379	177		
$C_{20}H_{42}$	Eicosane	343	>100		232

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Mol. Form.	Name	t_B/°C	FP/°C	Fl. Limits	IT/°C
$C_{21}H_{21}O_4P$	Tri-*o*-cresyl phosphate	410	225		385
$C_{21}H_{26}O_3$	4-Octylphenyl salicylate		216		416
$C_{21}H_{32}O_2$	Methyl abietate		180		
$C_{22}H_{42}O_2$	Butyl oleate		180		
$C_{22}H_{42}O_4$	Bis(2-ethylhexyl) adipate		206	0.4-?	377
$C_{22}H_{44}O_2$	Butyl stearate	343	160		355
$C_{23}H_{46}O_2$	Pentyl stearate		185		
$C_{24}H_{20}Sn$	Tetraphenylstannane	420	232		
$C_{24}H_{38}O_4$	Bis(2-ethylhexyl) phthalate	384	218		
$C_{25}H_{48}O_4$	Bis(2-ethylhexyl) azelate		227	0.3-?	374

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THRESHOLD LIMITS FOR AIRBORNE CONTAMINANTS

Several organizations recommend limits of exposure to airborne contaminants in the workplace. These include the Occupational Safety and Health Administration (OSHA), the National Institute for Occupational Safety and Health (NIOSH), and the non-governmental organization, American Conference of Governmental Industrial Hygienists (ACGIH). The threshold limit value (TLV) for a substance is defined as the concentration level under which the majority of workers may be repeatedly exposed, day after day, without adverse effects. The TLV recommendations are given in two forms:

- Time-weighted average (TWA) concentration for a normal 8-h workday and 40-h workweek.
- Short-term exposure limit (STEL), which should not be exceeded for more than 15 min.

Both kinds of limits are specified for some substances.

The following table gives threshold limit values for a number of substances that may be encountered in the atmosphere of a chemical laboratory or industrial facility. All values refer to the concentration in air at 25°C and normal atmospheric pressure. Data for gases are given both in parts per million by volume (ppm) and in mass concentration (mg/m^3). Values for liquids refer to mists or aerosols, and those for solids to dusts or fumes; both are stated in mg/m^3. A "C" following a value indicates a ceiling limit which should not be exceeded even for very brief periods because of acute toxic effects of the substance.

Substances are listed by systematic name, which is followed by molecular formula in the Hill format and Chemical Abstracts Service Registry Number. Common synonyms are given in brackets [ ] for some compounds.

REFERENCES

1. *2000 TLV's and BEI's,* American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634, 2000.
2. *NIOSH Pocket Guide to Chemical Hazards*, U.S. Department of Health and Human Services, National Institute for Occupational Health and Safety, U.S. Government Printing Office, Washington, DC, 1994.
3. *Chemical Information Manual*, U.S. Department of Labor, Occupational Safety and Health Administration, Washington, DC, 1991.

Substance	Molecular Formula	CAS Reg. No.	Time-Weighted Average		Short-Term Exposure Limit	
			ppm	mg/m^3	ppm	mg/m^3
Abate [Temephos]	$C_{16}H_{20}O_6P_2S_3$	3383-96-8		10		
Acetaldehyde	C_2H_4O	75-07-0			25 C	45 C
Acetic acid	$C_2H_4O_2$	64-19-7	10	25	15	37
Acetic anhydride	$C_4H_6O_3$	108-24-7	5	21		
Acetone	C_3H_6O	67-64-1	500	1188	750	1780
Acetone cyanohydrin	C_4H_7NO	75-86-5			4.7 C	5 C
Acetonitrile	C_2H_3N	75-05-8	40	67	60	101
Acetophenone	C_8H_8O	98-86-2	10	49		
2-(Acetyloxy)benzoic acid [Aspirin]	$C_9H_8O_4$	50-78-2		5		
Acrolein [2-Propenal]	C_3H_4O	107-02-8			0.1 C	0.23 C
Acrylamide	C_3H_5NO	79-06-1		0.03		
Acrylic acid [2-Propenoic acid]	$C_3H_4O_2$	79-10-7	2	5.9		
Acrylonitrile [Propenenitrile]	C_3H_3N	107-13-1	2	4.3		
Adipic acid	$C_6H_{10}O_4$	124-04-9		5		
Adiponitrile	$C_6H_8N_2$	111-69-3	2	9		
Aldrin	$C_{12}H_8Cl_6$	309-00-2		0.25		
Allyl alcohol [2-Propen-1-ol]	C_3H_6O	107-18-6	0.5	1.2		
Allyl glycidyl ether	$C_6H_{10}O_2$	106-92-3	1	5		
Allyl propyl disulfide	$C_6H_{12}S_2$	2179-59-1	2	12	3	18
Aluminum (metal dust)	Al	7429-90-5		10		
Aluminum oxide	Al_2O_3	1344-28-1		10		
4-Amino-3,5,6-trichloropyridinecarboxlic acid [Picloram]	$C_6H_3Cl_3N_2O_2$	1918-02-1		10		
Ammonia	H_3N	7664-41-7	25	17	35	24
Ammonium chloride	ClH_4N	12125-02-9		10		20
Ammonium perfluorooctanoate	$C_8H_4F_{15}NO_2$	3825-26-1		0.01		
Ammonium sulfamate	$H_6N_2O_3S$	7773-06-0		10		
Aniline	C_6H_7N	62-53-3	2	7.6		
Antimony	Sb	7440-36-0		0.5		
Arsenic	As	7440-38-2		0.01		
Arsine	AsH_3	7784-42-1	0.05	0.16		

Substance	Molecular Formula	CAS Reg. No.	Time-Weighted Average		Short-Term Exposure Limit	
			ppm	mg/m^3	ppm	mg/m^3
Atrazine	$C_8H_{14}ClN_5$	1912-24-9		5		
Azinphos-methyl	$C_{10}H_{12}N_3O_3PS_2$	86-50-0		0.2		
Barium	Ba	7440-39-3		0.5		
Barium sulfate	BaO_4S	7727-43-7		10		
Benomyl	$C_{14}H_{18}N_4O_3$	17804-35-2	0.84	10		
Benzene	C_6H_6	71-43-2	0.5	1.6	2.5	8
1,3-Benzenedimethanamine [*m*-Xylene diamine]	$C_8H_{12}N_2$	1477-55-0				0.1 C
Benzenethiol [Phenyl mercaptan]	C_6H_6S	108-98-5	0.5	2.3		
p-Benzoquinone [Quinone]	$C_6H_4O_2$	106-51-4	0.1	0.44		
Benzoyl chloride	C_7H_5ClO	98-88-4			0.5 C	2.8 C
Benzoyl peroxide	$C_{14}H_{10}O_4$	94-36-0		5		
Benzyl acetate	$C_9H_{10}O_2$	140-11-4	10	61		
Beryllium	Be	7440-41-7		0.002		0.01
Biphenyl	$C_{12}H_{10}$	92-52-4	0.2	1.3		
Bis(4-amino-3-chlorophenyl)methane [4,4-Methylene bis(2-chloroaniline)]	$C_{13}H_{12}Cl_2N_2$	101-14-4	0.01	0.11		
Bis(2-chloroethyl) ether [2,2'-Dichlorethyl ether]	$C_4H_8Cl_2O$	111-44-4	5	29	10	58
Bis(chloromethyl) ether	$C_2H_4Cl_2O$	542-88-1	0.001	0.0047		
Bis(2-dimethylaminoethyl) ether [DMAEE]	$C_8H_{20}N_20$	3033-62-3	0.05	0.33	0.15	1.0
Bis(2-ethylhexyl) phthalate [Di-*sec*-octyl phthalate]	$C_{24}H_{38}O_4$	117-81-7		5		10
Bismuth telluride	Bi_2Te_3	1304-82-1		10		
Boron oxide	B_2O_3	1303-86-2		10		
Boron tribromide	BBr_3	10294-33-4			1 C	10 C
Boron trifluoride	BF_3	7637-07-2			1 C	2.8 C
Bromacil	$C_9H_{13}BrN_2O_2$	314-40-9		10		
Bromine	Br_2	7726-95-6	0.1	0.66	0.2	1.3
Bromine pentafluoride	BrF_5	7789-30-2	0.1	0.72		
Bromochloromethane [Halon 1011]	CH_2BrCl	74-97-5	200	1060		
2-Bromo-2-chloro-1,1,1-trifluoroethane [Halothane]	$C_2HBrClF_3$	151-67-7	50	404		
Bromoethane [Ethyl bromide]	C_2H_5Br	74-96-4	5	22		
Bromoethene [Vinyl bromide]	C_2H_3Br	593-60-2	0.5	2.2		
Bromomethane [Methyl bromide]	CH_3Br	74-83-9	1	3.9		
Bromotrifluoromethane	$CBrF_3$	75-63-8	1000	6090		
1,3-Butadiene	C_4H_6	106-99-0	2	4.4		
Butane	C_4H_{10}	106-97-8	800	1900		
1-Butanethiol [Butyl mercaptan]	$C_4H_{10}S$	109-79-5	0.5	1.8		
1-Butanol	$C_4H_{10}O$	71-36-3			50 C	152 C
2-Butanol [*sec*-Butyl alcohol]	$C_4H_{10}O$	78-92-2	100	303		
2-Butanone [Methyl ethyl ketone]	C_4H_8O	78-93-3	200	590	300	885
trans-2-Butenal [Crotonaldehyde]	C_4H_6O	4170-30-3			0.3 C	0.9 C
3-Buten-2-one	C_4H_6O	78-94-4			0.2 C	0.6 C
Butyl acetate	$C_6H_{12}O_2$	123-86-4	150	713	200	950
sec-Butyl acetate	$C_6H_{12}O_2$	105-46-4	200	950		
tert-Butyl acetate	$C_6H_{12}O_2$	540-88-5	200	950		
Butyl acrylate	$C_7H_{12}O_2$	141-32-2	2	10		
Butylamine	$C_4H_{11}N$	109-73-9			5 C	15 C
tert-Butyl chromate	$C_8H_{18}CrO_4$	1189-85-1				0.1 C
Butyl glycidyl ether	$C_7H_{14}O_2$	2426-08-6	25	133		
Butyl lactate	$C_7H_{14}O_3$	138-22-7	5	30		
o-*sec*-Butylphenol	$C_{10}H_{14}O$	89-72-5	5	31		
p-*tert*-Butyltoluene	$C_{11}H_{16}$	98-51-1	1	6.1		
Cadmium	Cd	7440-43-9		0.01		
Calcium carbonate	$CCaO_3$	1317-65-3		10		

Substance	Molecular Formula	CAS Reg. No.	Time-Weighted Average ppm	Time-Weighted Average mg/m³	Short-Term Exposure Limit ppm	Short-Term Exposure Limit mg/m³
Calcium chromate	$CaCrO_4$	13765-19-0		0.003		
Calcium cyanamide	$CCaN_2$	156-62-7		0.5		
Calcium hydroxide	CaH_2O_2	1305-62-0		5		
Calcium metasilicate	CaO_3Si	1344-95-2		10		
Calcium oxide	CaO	1305-78-8		2		
Calcium sulfate	CaO_4S	7778-18-9		10		
Camphor	$C_{10}H_{16}O$	76-22-2	2	12	4	24
Caprolactam	$C_6H_{11}NO$	105-60-2	5 (gas)	1 (solid)	10 (gas)	3 (solid)
Captafol	$C_{10}H_9Cl_4NO_2S$	2425-06-1		0.1		
Captan	$C_9H_8Cl_3NO_2S$	133-06-2		5		
Carbaryl	$C_{12}H_{11}NO_2$	63-25-2		5		
Carbofuran	$C_{12}H_{15}NO_3$	1563-66-2		0.1		
Carbon black	C	1333-86-4		3.5		
Carbon dioxide	CO_2	124-38-9	5000	9000	30,000	54,000
Carbon disulfide	CS_2	75-15-0	10	31		
Carbon monoxide	CO	630-08-0	25	29		
Carbonyl chloride [Phosgene]	CCl_2O	75-44-5	0.1	0.40		
Carbonyl fluoride	CF_2O	353-50-4	2	5.4	5	13
Cesium hydroxide	CsHO	21351-79-1		2		
Chlordane	$C_{10}H_6Cl_8$	57-74-9		0.5		
Chlorine	Cl_2	7782-50-5	0.5	1.5	1	2.9
Chlorine dioxide	ClO_2	10049-04-4	0.1	0.28	0.3	0.83
Chlorine trifluoride	ClF_3	7790-91-2			0.1 C	0.38 C
Chloroacetaldehyde	C_2H_3ClO	107-20-0			1 C	3.2 C
Chloroacetone	C_3H_5ClO	78-95-5			1 C	3.8 C
α-Chloroacetophenone	C_8H_7ClO	532-27-4	0.05	0.32		
Chloroacetyl chloride	$C_2H_2Cl_2O$	79-04-9	0.05	0.23	0.15	0.69
Chlorobenzene	C_6H_5Cl	108-90-7	10	46		
o-Chlorobenzylidene malononitrile	$C_{10}H_5ClN_2$	2698-41-1			0.05 C	0.39 C
2-Chloro-1,3-butadiene [Chloroprene]	C_4H_5Cl	126-99-8	10	36		
Chlorodifluoromethane	$CHClF_2$	75-45-6	1000	3540		
Chloroethane [Ethyl chloride]	C_2H_5Cl	75-00-3	100	264		
2-Chloroethanol [Ethylene chlorohydrin]	C_2H_5ClO	107-07-3			1 C	3.3 C
Chloroethene [Vinyl chloride]	C_2H_3Cl	75-01-4	1	2.5		
Chloromethane [Methyl chloride]	CH_3Cl	74-87-3	50	103	100	207
(Chloromethyl)benzene [Benzyl chloride]	C_7H_7Cl	100-44-7	1	5.2		
1-Chloro-4-nitrobenzene	$C_6H_4ClNO_2$	100-00-5	0.1	0.64		
1-Chloro-1-nitropropane	$C_3H_6ClNO_2$	600-25-9	2	10		
Chloropentafluoroethane	C_2ClF_5	76-15-3	1000	6320		
2-Chloropropanoic acid	$C_3H_5ClO_2$	598-78-7	0.1	0.44		
3-Chloropropene [Allyl chloride]	C_3H_5Cl	107-05-1	1	3	2	6
2-Chlorostyrene	C_8H_7Cl	2039-87-4	50	283	75	425
o-Chlorotoluene	C_7H_7Cl	95-49-8	50	259		
Chlorpyrifos	$C_9H_{11}Cl_3NO_3PS$	2921-88-2		0.2		
Chromium	Cr	7440-47-3		0.5		
Chromyl chloride	Cl_2CrO_2	14977-61-8	0.025	0.16		
Clopidol	$C_7H_7Cl_2NO$	2971-90-6		10		
Cobalt	Co	7440-48-4		0.02		
Cobalt carbonyl	$C_8Co_2O_8$	10210-68-1		0.1		
Cobalt hydrocarbonyl	C_4HCoO_4	16842-03-8		0.1		
Copper	Cu	7440-50-8		0.2		
Cresol (all isomers)	C_7H_8O	1319-77-3	5	22		
Crufomate	$C_{12}H_{19}ClNO_3P$	299-86-5		5		
Cyanamide	CH_2N_2	420-04-2		2		
Cyanogen	C_2N_2	460-19-5	10	21		
Cyanogen chloride	CClN	506-77-4			0.3 C	0.75 C
Cyclohexane	C_6H_{12}	110-82-7	300	1030		

THRESHOLD LIMITS FOR AIRBORNE CONTAMINANTS (continued)

Substance	Molecular Formula	CAS Reg. No.	Time-Weighted Average ppm	Time-Weighted Average mg/m^3	Short-Term Exposure Limit ppm	Short-Term Exposure Limit mg/m^3
Cyclohexanol	$C_6H_{12}O$	108-93-0	50	206		
Cyclohexanone	$C_6H_{10}O$	108-94-1	25	100		
Cyclohexene	C_6H_{10}	110-83-8	300	1010		
Cyclohexylamine	$C_6H_{13}N$	108-91-8	10	41		
Cyclonite [Hexahydro-1,3,5-trinitro-1,3,5-triazine]	$C_3H_6N_6O_6$	121-82-4		0.5		
1,3-Cyclopentadiene	C_5H_6	542-92-7	75	203		
Cyclopentane	C_5H_{10}	287-92-3	600	1720		
Cyhexatin	$C_{18}H_{34}OSn$	13121-70-5		5		
Decaborane(14)	$B_{10}H_{14}$	17702-41-9	0.05	0.25	0.15	0.75
Diacetone alcohol	$C_6H_{12}O_2$	123-42-2	50	238		
4,4'-Diaminodiphenylmethane [4,4-Methylene dianiline]	$C_{13}H_{14}N_2$	101-77-9	0.1	0.81		
Diazinon	$C_{12}H_{21}N_2O_3PS$	333-41-5		0.1		
Diazomethane	CH_2N_2	334-88-3	0.2	0.34		
Diborane	B_2H_6	19287-45-7	0.1	0.11		
Dibromodifluoromethane	CBr_2F_2	75-61-6	100	858		
2-Dibutylaminoethanol	$C_{10}H_{23}NO$	102-81-8	0.5	3.5		
2,6-Di-*tert*-butyl-4-methylphenol	$C_{15}H_{24}O$	128-37-0		10		
Dibutylphenyl phosphate	$C_{14}H_{23}O_4P$	2528-36-1	0.3	3.5		
Dibutyl phosphate	$C_8H_{19}O_4P$	107-66-4	1	8.6	2	17
Dibutyl phthalate	$C_{16}H_{22}O_4$	84-74-2		5		
Dichloroacetylene	C_2Cl_2	7572-29-4			0.1 C	0.39 C
o-Dichlorobenzene	$C_6H_4Cl_2$	95-50-1	25	150	50	301
p-Dichlorobenzene	$C_6H_4Cl_2$	106-46-7	10	60		
1,4-Dichloro-2-butene (unspecified isomer)	$C_4H_6Cl_2$	764-41-0	0.005	0.026		
Dichlorodifluoromethane	CCl_2F_2	75-71-8	1000	4950		
1,3-Dichloro-5,5-dimethyl hydantoin	$C_5H_6Cl_2N_2O_2$	118-52-5		0.2		0.4
Dichlorodiphenyltrichloroethane [DDT]	$C_{14}H_9Cl_5$	50-29-3		1		
1,1-Dichloroethane [Ethylidene dichloride]	$C_2H_4Cl_2$	75-34-3	100	405		
1,2-Dichloroethane [Ethylene dichloride]	$C_2H_4Cl_2$	107-06-2	10	40		
1,1-Dichloroethene [Vinylidene chloride]	$C_2H_2Cl_2$	75-35-4	5	20		
1,2-Dichloroethylene (both isomers)	$C_2H_2Cl_2$	540-59-0	200	793		
Dichlorofluoromethane	$CHCl_2F$	75-43-4	10	42		
Dichloromethane [Methylene chloride]	CH_2Cl_2	75-09-2	50	174		
1,1-Dichloro-1-nitroethane	$C_2H_3Cl_2NO_2$	594-72-9	2	12		
(2,4-Dichlorophenoxy)acetic acid	$C_8H_6Cl_2O_3$	94-75-7		10		
1,2-Dichloropropane	$C_3H_6Cl_2$	78-87-5	75	347	110	508
2,2-Dichloropropanoic acid	$C_3H_4Cl_2O_2$	75-99-0		5		
1,3-Dichloropropene (both isomers)	$C_3H_4Cl_2$	542-75-6	1	4.5		
1,2-Dichloro-1,1,2,2-tetrafluoroethane	$C_2Cl_2F_4$	76-14-2	1000	7000		
Dichlorvos	$C_4H_7Cl_2O_4P$	62-73-7	0.1	0.90		
Dicrotophos	$C_8H_{16}NO_5P$	141-66-2		0.25		
m-Dicyanobenzene [*m*-Phthalodinitrile]	$C_8H_4N_2$	626-17-5		5		
Dicyclopentadiene	$C_{10}H_{12}$	77-73-6	5	27		
Dieldrin	$C_{12}H_8Cl_6O$	60-57-1		0.25		
Diethanolamine	$C_4H_{11}NO_2$	111-42-2	0.46	2		
Diethylamine	$C_4H_{11}N$	109-89-7	5	15	15	45
2-Diethylaminoethanol	$C_6H_{15}NO$	100-37-8	2	9.6		
Diethylenetriamine [Bis(2-amimoethyl)amine]	$C_4H_{13}N_3$	111-40-0	1	4.2		
Diethyl ether	$C_4H_{10}O$	60-29-7	400	1210	500	1520
Diethyl phthalate	$C_{12}H_{14}O_4$	84-66-2		5		
1,1-Difluoroethene	$C_2H_2F_2$	75-38-7	500	1310		
Diglycidyl ether	$C_6H_{10}O_3$	2238-07-5	0.1	0.53		
Diisopropylamine	$C_6H_{15}N$	108-18-9	5	21		
Diisopropyl ether	$C_6H_{14}O$	108-20-3	250	1040	310	1300
Dimethoxymethane [Methylal]	$C_3H_8O_2$	109-87-5	1000	3110		

			Time-Weighted Average		Short-Term Exposure Limit	
Substance	**Molecular Formula**	**CAS Reg. No.**	**ppm**	**mg/m^3**	**ppm**	**mg/m^3**
Dimethyl mercury	C_2H_6Hg	593-74-8		0.01		0.03
N,*N*-Dimethylacetamide	C_4H_9NO	127-19-5	10	36		
Dimethylamine	C_2H_7N	124-40-3	5	9.2	15	27.6
N,*N*-Dimethylaniline	$C_8H_{11}N$	121-69-7	5	25	10	50
2,2-Dimethylbutane	C_6H_{14}	75-83-2	500	1760	1000	3500
2,3-Dimethylbutane	C_6H_{14}	79-29-8	500	1760	1000	3500
N,*N*-Dimethylformamide	C_3H_7NO	68-12-2	10	30		
2,6-Dimethyl-4-heptanone [Diisobutyl ketone]	$C_9H_{18}O$	108-83-8	25	145		
1,1-Dimethylhydrazine	$C_2H_8N_2$	57-14-7	0.01	0.025		
Dimethyl phthalate	$C_{10}H_{10}O_4$	131-11-3		5		
Dimethyl sulfate	$C_2H_6O_4S$	77-78-1	0.1	0.52		
Dinitrobenzene (all isomers)	$C_6H_4N_2O_4$	25154-54-5	0.15	1.0		
Dinitrotoluene (all isomers)	$C_7H_6N_2O_4$	25321-14-6		0.2		
1,4-Dioxane	$C_4H_8O_2$	123-91-1	20	72		
Dioxathion	$C_{12}H_{26}O_6P_2S_4$	78-34-2		0.2		
Diphenylamine	$C_{12}H_{11}N$	122-39-4		10		
Diphenyl ether	$C_{12}H_{10}O$	101-84-8	1	7	2	14
4,4'-Diphenylmethane diisocyanate	$C_{15}H_{10}N_2O_2$	101-68-8	0.005	0.051		
Dipropylene glycol monomethyl ether	$C_7H_{16}O_3$	34590-94-8	100	600	150	900
Diquat	$C_{12}H_{12}N_2$	231-36-7		0.5		
Disulfiram	$C_{10}H_{20}N_2S_4$	97-77-8		2		
Disulfoton	$C_8H_{19}O_2PS_3$	298-04-4		0.1		
Diuron	$C_9H_{10}Cl_2N_2O$	330-54-1		10		
Divinyl benzene (all isomers)	$C_{10}H_{10}$	1321-74-0	10	53		
Endosulfan	$C_9H_6Cl_6O_3S$	115-29-7		0.1		
Endrin	$C_{12}H_8Cl_6O$	72-20-8		0.1		
Enflurane	$C_3H_2ClF_5O$	13838-16-9	75	566		
Epichlorohydrin [(Chloromethyl)oxirane]	C_3H_5ClO	106-89-8	0.5	1.9		
1,2-Epoxy-4-(epoxyethyl)cyclohexane [Vinylcyclohexene dioxide]	$C_8H_{12}O_2$	106-87-6	0.1	0.57		
1,2-Ethanediamine [Ethylenediamine]	$C_2H_8N_2$	107-15-3	10	25		
Ethanethiol [Ethyl mercaptan]	C_2H_6S	75-08-1	0.5	1.3		
Ethanol	C_2H_6O	64-17-5	1000	1880		
Ethanolamine	C_2H_7NO	141-43-5	3	7.5	6	15
Ethion	$C_9H_{22}O_4P_2S_4$	563-12-2		0.4		
Ethoxydimethylsilane	$C_4H_{12}OSi$	14857-34-2	0.5	2.1	1.5	6.4
Ethyl acetate	$C_4H_8O_2$	141-78-6	400	1440		
Ethyl acrylate	$C_5H_8O_2$	140-88-5	5	20	15	61
Ethylamine	C_2H_7N	75-04-7	5	9.2	15	27.6
Ethylbenzene	C_8H_{10}	100-41-4	100	434	125	543
Ethyl *tert*-butyl ether [ETBE]	$C_6H_{14}O$	637-92-3	5	20		
Ethylene glycol	$C_2H_6O_2$	107-21-1				100 C
Ethylene glycol dinitrate	$C_2H_4N_2O_6$	628-96-6	0.05	0.31		
Ethylene glycol monobutyl ether [2-Butoxyethanol]	$C_6H_{14}O_2$	111-76-2	20	97		
Ethylene glycol monoethyl ether [2-Ethoxyethanol]	$C_4H_{10}O_2$	110-80-5	5	18		
Ethylene glycol monoethyl ether acetate [2-Ethoxyethyl acetate]	$C_6H_{12}O_3$	111-15-9	5	27		
Ethylene glycol monomethyl ether [2-Methoxyethanol]	$C_3H_8O_2$	109-86-4	5	16		
Ethylene glycol monomethyl ether acetate [2-Methoxyethyl acetate]	$C_5H_{10}O_3$	110-49-6	5	24		
Ethyleneimine	C_2H_5N	151-56-4	0.5	0.88		
Ethylene oxide [Oxirane]	C_2H_4O	75-21-8	1	1.8		
Ethyl formate	$C_3H_6O_2$	109-94-4	100	303		
Ethylidene norbornene	C_9H_{12}	16219-75-3			5 C	25 C

Substance	Molecular Formula	CAS Reg. No.	Time-Weighted Average ppm	Time-Weighted Average mg/m^3	Short-Term Exposure Limit ppm	Short-Term Exposure Limit mg/m^3
N-Ethylmorpholine	$C_6H_{13}NO$	100-74-3	5	24		
Ethyl *p*-nitrophenyl benzenethiophosphate [EPN]	$C_{14}H_{14}NO_4PS$	2104-64-5		0.1		
Ethyl silicate	$C_8H_{20}O_4Si$	78-10-4	10	85		
Fenamiphos	$C_{13}H_{22}NO_3PS$	22224-92-6		0.1		
Fensulfothion	$C_{11}H_{17}O_4PS_2$	115-90-2		0.1		
Fenthion	$C_{10}H_{15}O_3PS_2$	55-38-9		0.2		
Ferbam	$C_9H_{18}FeN_3S_6$	14484-64-1		10		
Ferrocene [Dicyclopentadienyl iron]	$C_{10}H_{10}Fe$	102-54-5		10		
Fluorine	F_2	7782-41-4	1	1.6	2	3.1
Fluorine monoxide [Oxygen difluoride]	F_2O	7783-41-7			0.05 C	0.11 C
Fonofos	$C_{10}H_{15}OPS_2$	944-22-9		0.1		
Formaldehyde	CH_2O	50-00-0			0.3 C	0.37 C
Formamide	CH_3NO	75-12-7	10	18		
Formic acid	CH_2O_2	64-18-6	5	9.4	10	19
Furfural [2-Furaldehyde]	$C_5H_4O_2$	98-01-1	2	7.9		
Furfuryl alcohol [2-Furanmethanol]	$C_5H_6O_2$	98-00-0	10	40	15	60
Germane [Germanium tetrahydride]	GeH_4	7782-65-2	0.2	0.63		
Glycerol	$C_3H_8O_3$	56-81-5		10		
Graphite	C	7440-44-0		2		
Hafnium	Hf	7440-58-6		0.5		
Heptachlor	$C_{10}H_5Cl_7$	76-44-8		0.05		
Heptane	C_7H_{16}	142-82-5	400	1640	500	2050
2-Heptanone [Methyl pentyl ketone]	$C_7H_{14}O$	110-43-0	50	233		
3-Heptanone [Ethyl butyl ketone]	$C_7H_{14}O$	106-35-4	50	233	75	350
4-Heptanone [Dipropyl ketone]	$C_7H_{14}O$	123-19-3	50	233		
Hexachlorobenzene	C_6Cl_6	118-74-1		0.002		
Hexachloro-1,3-butadiene	C_4Cl_6	87-68-3	0.02	0.21		
1,2,3,4,5,6-Hexachlorocyclohexane [Lindane]	$C_6H_6Cl_6$	58-89-9		0.5		
Hexachloro-1,3-cyclopentadiene	C_5Cl_6	77-47-4	0.01	0.11		
Hexachloroethane [Perchloroethane]	C_2Cl_6	67-72-1	1	9.7		
Hexachloronaphthalene (all isomers)	$C_{10}H_2Cl_6$	1335-87-1		0.2		
Hexamethylene diisocyanate	$C_8H_{12}N_2O_2$	822-06-0	0.005	0.034		
Hexane	C_6H_{14}	110-54-3	50	176		
1,6-Hexanediamine [Hexamethylenediamine]	$C_6H_{16}N_2$	124-09-4	0.5	2.3		
2-Hexanone [Butyl methyl ketone]	$C_6H_{12}O$	591-78-6	5	20	10	40
1-Hexene	C_6H_{12}	592-41-6	30	103		
sec-Hexyl acetate	$C_8H_{16}O_2$	108-84-9	50	295		
Hydrazine	H_4N_2	302-01-2	0.01	0.013		
Hydrazoic acid	HN_3	7782-79-8			0.11 C	0.19 C
Hydrogen bromide	BrH	10035-10-6			3 C	9.9 C
Hydrogen chloride	ClH	7647-01-0			5 C	7.5 C
Hydrogen cyanide	CHN	74-90-8			4.7 C	5 C
Hydrogen fluoride	FH	7664-39-3			3 C	2.3 C
Hydrogen peroxide	H_2O_2	7722-84-1	1	1.4		
Hydrogen selenide	H_2Se	7783-07-5	0.05	0.16		
Hydrogen sulfide	H_2S	7783-06-4	10	14	15	21
p-Hydroquinone [1,4-Benzenediol]	$C_6H_6O_2$	123-31-9		2		
2-Hydroxypropyl acrylate	$C_6H_{10}O_3$	999-61-1	0.5	2.8		
Indene	C_9H_8	95-13-6	10	48		
Indium	In	7440-74-6		0.1		
Iodine	I_2	7553-56-2			0.1 C	1.0 C
Iodomethane [Methyl iodide]	CH_3I	74-88-4	2	12		
Iron(III) oxide	Fe_2O_3	1309-37-1		5		
Iron pentacarbonyl	C_5FeO_5	13463-40-6	0.1	0.23	0.2	0.45
Isobutyl acetate	$C_6H_{12}O_2$	110-19-0	150	713		
Isopentane	C_5H_{12}	78-78-4	600	1770		

Substance	Molecular Formula	CAS Reg. No.	Time-Weighted Average ppm	Time-Weighted Average mg/m^3	Short-Term Exposure Limit ppm	Short-Term Exposure Limit mg/m^3
Isopentyl acetate [Isoamyl acetate]	$C_7H_{14}O_2$	123-92-2	100	532		
Isophorone	$C_9H_{14}O$	78-59-1			5 C	28 C
Isophorone diisocyanate	$C_{12}H_{18}N_2O_2$	4098-71-9	0.005	0.045		
Isopropenylbenzene [α-Methyl styrene]	C_9H_{10}	98-83-9	50	242	100	483
2-Isopropoxyethanol	$C_5H_{12}O_2$	109-59-1	25	106		
Isopropyl acetate	$C_5H_{10}O_2$	108-21-4	250	1040	310	1290
Isopropylamine	C_3H_9N	75-31-0	5	12	10	24
N-Isopropylaniline	$C_9H_{13}N$	768-52-5	2	11		
Isopropylbenzene [Cumene]	C_9H_{12}	98-82-8	50	246		
Isopropyl glycidyl ether	$C_6H_{12}O_2$	4016-14-2	50	238	75	356
Kaolin		1332-58-7		2		
Ketene	C_2H_2O	463-51-4	0.5	0.86	1.5	2.6
Lead	Pb	7439-92-1		0.05		
Lead(II) arsenate	$As_2O_8Pb_3$	7784-40-9		0.15		
Lead(II) chromate	CrO_4Pb	7758-97-6		0.075		
Lithium hydride	HLi	7580-67-8		0.025		
Magnesium carbonate [Magnesite]	$CMgO_3$	546-93-0		10		
Magnesium oxide	MgO	1309-48-4		10		
Malathion	$C_{10}H_{19}O_6PS_2$	121-75-5		10		
Maleic anhydride	$C_4H_2O_3$	108-31-6	0.1	4		
Manganese	Mn	7439-96-5		0.2		
Manganese cyclopentadienyl tricarbonyl	$C_8H_5MnO_3$	12079-65-1		0.4		
Mercury	Hg	7439-97-6		0.025		
Mesityl oxide	$C_6H_{10}O$	141-79-7	15	60	25	100
Methacrylic acid [2-Methylpropenoic acid]	$C_4H_6O_2$	79-41-4	20	70		
Methanethiol [Methyl mercaptan]	CH_4S	74-93-1	0.5	0.98		
Methanol	CH_4O	67-56-1	200	262	250	328
Methomyl	$C_5H_{10}N_2O_2S$	16752-77-5		2.5		
o-Methoxyaniline [*o*-Anisidine]	C_7H_9NO	90-04-0	0.1	0.5		
p-Methoxyaniline [*p*-Anisidine]	C_7H_9NO	104-94-9	0.1	0.5		
Methoxychlor	$C_{16}H_{15}Cl_3O_2$	72-43-5		10		
4-Methoxyphenol	$C_7H_8O_2$	150-76-5		5		
Methyl acetate	$C_3H_6O_2$	79-20-9	200	606	250	757
Methyl acrylate	$C_4H_6O_2$	96-33-3	2	7		
2-Methylacrylonitrile	C_4H_5N	126-98-7	1	2.7		
Methylamine	CH_5N	74-89-5	5	6.4	15	19
o-Methylaniline [*o*-Toluidine]	C_7H_9N	95-53-4	2	8.8		
m-Methylaniline [*m*-Toluidine]	C_7H_9N	108-44-1	2	8.8		
p-Methylaniline [*p*-Toluidine]	C_7H_9N	106-49-0	2	8.8		
N-Methylaniline	C_7H_9N	100-61-8	0.5	2.2		
3-Methyl-1-butanol [Isoamyl alcohol]	$C_5H_{12}O$	123-51-3	100	361	125	452
3-Methyl-2-butanone [Methyl isopropyl ketone]	$C_5H_{10}O$	563-80-4	200	705		
Methyl *tert*-butyl ether [MTBE]	$C_5H_{12}O$	1634-04-4	40	144		
Methyl 2-cyanoacrylate	$C_5H_5NO_2$	137-05-3	0.2	0.9		
Methylcyclohexane	C_7H_{14}	108-87-2	400	1610		
Methylcyclohexanol (all isomers)	$C_7H_{14}O$	25639-42-3	50	234		
2-Methylcyclohexanone	$C_7H_{12}O$	583-60-8	50	229	75	344
2-Methylcyclopentadienyl manganese tricarbonyl	$C_9H_7MnO_3$	12108-13-3		0.8		
Methyl demeton	$C_6H_{15}O_3PS_2$	8022-00-2		0.5		
2-Methyl-3,5-dinitrobenzamide [Dinitolmide]	$C_8H_7N_3O_5$	148-01-6		5		
2-Methyl-4,6-dinitrophenol [Dinitro-*o*-cresol]	$C_7H_6N_2O_5$	534-52-1		0.2		
Methylene bis(4-cyclohexylisocyanate)	$C_{15}H_{22}N_2O_2$	5124-30-1	0.005	0.054		
Methyl ethyl ketone peroxide	$C_8H_{18}O_2$	1338-23-4			0.2 C	1.5 C
Methyl formate	$C_2H_4O_2$	107-31-3	100	246	150	368
6-Methyl-1-heptanol [Isooctyl alcohol]	$C_8H_{18}O$	26952-21-6	50	266		
5-Methyl-3-heptanone	$C_8H_{16}O$	541-85-5	25	131		

Substance	Molecular Formula	CAS Reg. No.	Time-Weighted Average ppm	Time-Weighted Average mg/m³	Short-Term Exposure Limit ppm	Short-Term Exposure Limit mg/m³
5-Methyl-2-hexanone [Methyl isopentyl ketone]	$C_7H_{14}O$	110-12-3	50	234		
Methylhydrazine	CH_6N_2	60-34-4	0.01	0.019		
Methyl isocyanate	C_2H_3NO	624-83-9	0.02	0.047		
Methyl methacrylate	$C_5H_8O_2$	80-62-6	50	205	100	410
Methyloxirane [1,2-Propylene oxide]	C_3H_6O	75-56-9	20	48		
Methyl parathion	$C_8H_{10}NO_5PS$	298-00-0		0.2		
2-Methylpentane	C_6H_{14}	107-83-5	500	1760	1000	3500
3-Methylpentane	C_6H_{14}	96-14-0	500	1760	1000	3500
2-Methyl-2,4-pentanediol [Hexylene glycol]	$C_6H_{14}O_2$	107-41-5			25 C	121 C
4-Methyl-2-pentanol [Methyl isobutyl carbinol]	$C_6H_{14}O$	108-11-2	25	104	40	167
4-Methyl-2-pentanone [Isobutyl methyl ketone]	$C_6H_{12}O$	108-10-1	50	205	75	307
2-Methyl-1-propanol [Isobutyl alcohol]	$C_4H_{10}O$	78-83-1	50	152		
2-Methyl-2-propanol [*tert*-Butyl alcohol]	$C_4H_{10}O$	75-65-0	100	303		
Methylstyrene (all isomers)	C_9H_{10}	25013-15-4	50	242	100	483
N-Methyl-*N*,2,4,6-tetranitroaniline [Tetryl]	$C_7H_5N_5O_8$	479-45-8		1.5		
Metribuzin	$C_8H_{14}N_4OS$	21087-64-9		5		
Mevinphos	$C_7H_{13}O_6P$	7786-34-7	0.01	0.092	0.03	0.27
Mica		12001-26-2		3		
Molybdenum	Mo	7439-98-7		10		
Monocrotophos	$C_7H_{14}NO_5P$	6923-22-4		0.25		
Morpholine	C_4H_9NO	110-91-8	20	71		
Naled	$C_4H_7Br_2Cl_2O_4P$	300-76-5		3		
Naphthalene	$C_{10}H_8$	91-20-3	10	52	15	79
1-Naphthalenylthiourea [ANTU]	$C_{11}H_{10}N_2S$	86-88-4		0.3		
Neopentane	C_5H_{12}	463-82-1	600	1770		
Nickel	Ni	7440-02-0		1.5		
Nickel carbonyl	C_4NiO_4	13463-39-3	0.05	0.12		
Nickel(III) sulfide	Ni_3S_2	12035-72-2		0.14		
Nicotine	$C_{10}H_{14}N_2$	54-11-5		0.5		
Nitrapyrin	$C_6H_3Cl_4N$	1929-82-4		10		20
Nitric acid	HNO_3	7697-37-2	2	5.2	4	10
Nitric oxide	NO	10102-43-9	25	31		
p-Nitroaniline	$C_6H_6N_2O_2$	100-01-6		3		
Nitrobenzene	$C_6H_5NO_2$	98-95-3	1	5		
Nitroethane	$C_2H_5NO_2$	79-24-3	100	307		
Nitrogen dioxide	NO_2	10102-44-0	3	5.6	5	9.4
Nitrogen trifluoride	F_3N	7783-54-2	10	29		
Nitromethane	CH_3NO_2	75-52-5	20	50		
1-Nitropropane	$C_3H_7NO_2$	108-03-2	25	91		
2-Nitropropane	$C_3H_7NO_2$	79-46-9	10	36		
Nitrotoluene (all isomers)	$C_7H_7NO_2$	1321-12-6	2	11		
Nitrous oxide	N_2O	10024-97-2	50	90		
Nonane (all isomers)	C_9H_{20}	111-84-2	200	1050		
Octachloronaphthalene	$C_{10}Cl_8$	2234-13-1		0.1		0.3
Octane (all isomers)	C_8H_{18}	111-65-9	300	1400	375	1750
Osmium(VIII) oxide [Osmium tetroxide]	O_4Os	20816-12-0	0.0002	0.0016	0.0006	0.0047
Oxalic acid	$C_2H_2O_4$	144-62-7		1		2
2-Oxetanone [β-Propiolactone]	$C_3H_4O_2$	57-57-8	0.5	1.5		
Oxiranemethanol [Glycidol]	$C_3H_6O_2$	556-52-5	2	6.1		
Ozone	O_3	10028-15-6	0.1	0.2		
Paraquat	$C_{12}H_{14}N_2$	4685-14-7		0.5		
Parathion	$C_{10}H_{14}NO_5PS$	56-38-2		0.1		
Pentaborane(9)	B_5H_9	19624-22-7	0.005	0.013	0.015	0.039
Pentachloronaphthalene (unspecified isomer)	$C_{10}H_3Cl_5$	1321-64-8		0.5		
Pentachloronitrobenzene	$C_6Cl_5NO_2$	82-68-8		0.5		
Pentachlorophenol	C_6HCl_5O	87-86-5		0.5		
Pentaerythritol	$C_5H_{12}O_4$	115-77-5		10		

Substance	Molecular Formula	CAS Reg. No.	Time-Weighted Average ppm	Time-Weighted Average mg/m^3	Short-Term Exposure Limit ppm	Short-Term Exposure Limit mg/m^3
Pentanal [Valeraldehyde]	$C_5H_{10}O$	110-62-3	50	176		
Pentane	C_5H_{12}	109-66-0	600	1770	750	2210
Pentanedial [Glutaraldehyde]	$C_5H_8O_2$	111-30-8			0.05 C	0.2 C
2-Pentanone [Methyl propyl ketone]	$C_5H_{10}O$	107-87-9	200	705	250	881
3-Pentanone [Diethyl ketone]	$C_5H_{10}O$	96-22-0	200	700	300	1050
Pentyl acetate (all isomers)	$C_7H_{14}O_2$	628-63-7	50	265	100	530
Perchloromethyl mercaptan	CCl_4S	594-42-3	0.1	0.76		
Perchloryl fluoride	$ClFO_3$	7616-94-6	3	13	6	25
Perfluoroacetone [Hexafluoroacetone]	C_3F_6O	684-16-2	0.1	0.68		
Perfluoroisobutene	C_4F_8	382-21-8			0.01 C	0.082 C
Phenol	C_6H_6O	108-95-2	5	19		
10*H*-Phenothiazine	$C_{12}H_9NS$	92-84-2		5		
Phenylenediamine (all isomers)	$C_6H_8N_2$	25265-76-3		0.1		
Phenyl glycidyl ether	$C_9H_{10}O_2$	122-60-1	0.1	0.6		
Phenylhydrazine	$C_6H_8N_2$	100-63-0	0.1	0.44		
Phenylphosphine	C_6H_7P	638-21-1			0.05 C	0.23 C
Phorate	$C_7H_{17}O_2PS_3$	298-02-2		0.05		0.2
Phosphine	H_3P	7803-51-2	0.3	0.42	1	1.4
Phosphoric acid	H_3O_4P	7664-38-2		1		3
Phosphorus (white)	P	7723-14-0	0.02	0.1		
Phosphorus(III) chloride [Phosphorus trichloride]	Cl_3P	7719-12-2	0.2	1.1	0.5	2.8
Phosphorus(V) chloride [Phosphorus pentachloride]	Cl_5P	10026-13-8	0.1	0.85		
Phosphorus(V) oxychloride [Phosphoryl chloride]	Cl_3OP	10025-87-3	0.1	0.63		
Phosphorus(V) sulfide	P_2S_5	1314-80-3		1		3
Phthalic anhydride	$C_8H_4O_3$	85-44-9	1	6.1		
Piperazine dihydrochloride	$C_4H_{12}Cl_2N_2$	142-64-3		5		
2-Pivaloyl-1,3-indandione [Pindone]	$C_{14}H_{14}O_3$	83-26-1		0.1		
Platinum	Pt	7440-06-4		1		
Potassium hydroxide	HKO	1310-58-3		2 C		
Propane	C_3H_8	74-98-6	2500	4500		
Propanoic acid	$C_3H_6O_2$	79-09-4	10	30		
1-Propanol	C_3H_8O	71-23-8	200	492	250	614
2-Propanol [Isopropyl alcohol]	C_3H_8O	67-63-0	400	983	500	1230
Propargyl alcohol [2-Propyn-1-ol]	C_3H_4O	107-19-7	1	2.3		
Propoxur	$C_{11}H_{15}NO_3$	114-26-1		0.5		
Propyl acetate	$C_5H_{10}O_2$	109-60-4	200	835	250	1040
1,2-Propylene glycol dinitrate	$C_3H_6N_2O_6$	6423-43-4	0.05	0.34		
Propylene glycol monomethyl ether	$C_4H_{10}O_2$	107-98-2	100	369	150	553
Propyleneimine	C_3H_7N	75-55-8	2	4.7		
Propyl nitrate	$C_3H_7NO_3$	627-13-4	25	107	40	172
Propyne [Methylacetylene]	C_3H_4	74-99-7	1000	1640		
2-Pyridinamine [2-Aminopyridine]	$C_5H_6N_2$	504-29-0	0.5	1.9		
Pyridine	C_5H_5N	110-86-1	5	16		
Pyrocatechol [Catechol]	$C_6H_6O_2$	120-80-9	5	23		
Resorcinol	$C_6H_6O_2$	108-46-3	10	45	20	90
Rhodium	Rh	7440-16-6		1		
Ronnel	$C_8H_8Cl_3O_3PS$	299-84-3		10		
Rotenone	$C_{23}H_{22}O_6$	83-79-4		5		
Selenium	Se	7782-49-2		0.2		
Selenium hexafluoride	F_6Se	7783-79-1	0.12	0.95		
Sesone	$C_8H_7Cl_2NaO_5S$	136-78-7		10		
Silane	H_4Si	7803-62-5	5	6.6		
Silicon	Si	7440-21-3		10		
Silicon carbide	CSi	409-21-2		10		

THRESHOLD LIMITS FOR AIRBORNE CONTAMINANTS (continued)

Substance	Molecular Formula	CAS Reg. No.	Time-Weighted Average ppm	Time-Weighted Average mg/m^3	Short-Term Exposure Limit ppm	Short-Term Exposure Limit mg/m^3
Silicon dioxide (α-quartz)	O_2Si	14808-60-7		0.05		
Silicon dioxide (tridymite)	O_2Si	15468-32-3		0.05		
Silicon dioxide (cristobalite)	O_2Si	14464-46-1		0.05		
Silicon dioxide (vitreous)	O_2Si	60676-86-0		0.1		
Silver	Ag	7440-22-4		0.1		
Sodium azide	N_3Na	26628-22-8				0.29 C
Sodium fluoroacetate	$C_2H_2FNaO_2$	62-74-8		0.05		
Sodium hydrogen sulfite	$HNaO_3S$	7631-90-5		5		
Sodium hydroxide	HNaO	1310-73-2				2 C
Sodium metabisulfite	$Na_2O_5S_2$	7681-57-4		5		
Sodium pyrophosphate	$Na_4O_7P_2$	7722-88-5		5		
Sodium tetraborate decahydrate	$B_4H_{20}Na_2O_{17}$	1303-96-4		5		
Stibine	H_3Sb	7803-52-3	0.1	0.51		
Strontium chromate	CrO_4Sr	7789-06-2		0.002		
Strychnine	$C_{21}H_{22}N_2O_2$	57-24-9		0.15		
Styrene	C_8H_8	100-42-5	20	85	40	170
Sucrose	$C_{12}H_{22}O_{11}$	57-50-1		10		
Sulfotep	$C_8H_{20}O_5P_2S_2$	3689-24-5		0.2		
Sulfur chloride	Cl_2S_2	10025-67-9			1 C	5.5 C
Sulfur decafluoride	$F_{10}S_2$	5714-22-7			0.01 C	0.10 C
Sulfur dioxide	O_2S	7446-09-5	2	5.2	5	13
Sulfur hexafluoride	F_6S	2551-62-4	1000	6000		
Sulfur tetrafluoride	F_4S	7783-60-0			0.1 C	0.44 C
Sulfuric acid	H_2O_4S	7664-93-9		1		3
Sulfuryl fluoride	F_2O_2S	2699-79-8	5	21	10	42
Sulprofos	$C_{12}H_{19}O_2PS_3$	35400-43-2		1		
Talc		14807-96-6		2		
Tantalum	Ta	7440-25-7		5		
Tantalum(V) oxide	O_5Ta_2	1314-61-0		5		
Tellurium	Te	13494-80-9		0.1		
Tellurium hexafluoride	F_6Te	7783-80-4	0.02	0.10		
Terephthalic acid	$C_8H_6O_4$	100-21-0		10		
Terphenyl (all isomers)	$C_{18}H_{14}$	26140-60-3			0.53 C	5 C
1,1,2,2-Tetrabromoethane [Acetylene tetrabromide]	$C_2H_2Br_4$	79-27-6	1	14		
Tetrabromomethane [Carbon tetrabromide]	CBr_4	558-13-4	0.1	1.4	0.3	4.1
1,1,1,2-Tetrachloro-2,2-difluoroethane	$C_2Cl_4F_2$	76-11-9	500	4170		
1,1,2,2-Tetrachloro-1,2-difluoroethane	$C_2Cl_4F_2$	76-12-0	500	4170		
1,1,2,2-Tetrachloroethane	$C_2H_2Cl_4$	79-34-5	1	6.9		
Tetrachloroethene [Perchloroethylene]	C_2Cl_4	127-18-4	25	170	100	685
Tetrachloromethane [Carbon tetrachloride]	CCl_4	56-23-5	5	31	10	63
Tetrachloronaphthalene (all isomers)	$C_{10}H_4Cl_4$	1335-88-2		2		
Tetraethyl lead	$C_8H_{20}Pb$	78-00-2		0.1		
Tetraethyl pyrophosphate [TEPP]	$C_8H_{20}O_7P_2$	107-49-3		0.05		
Tetrahydrofuran [Oxolane]	C_4H_8O	109-99-9	200	590	250	737
Tetramethyl lead	$C_4H_{12}Pb$	75-74-1		0.15		
Tetramethyl silicate	$C_4H_{12}O_4Si$	681-84-5	1	6		
Tetramethyl succinonitrile	$C_8H_{12}N_2$	3333-52-6	0.5	2.8		
Tetranitromethane	CN_4O_8	509-14-8	0.005	0.04		
Thallium	Tl	7440-28-0		0.1		
4,4'-Thiobis(6-*tert*-butyl-*m*-cresol)	$C_{22}H_{30}O_2S$	96-69-5		10		
Thioglycolic acid	$C_2H_4O_2S$	68-11-1	1	3.8		
Thionyl chloride	Cl_2OS	7719-09-7			1 C	4.9 C
Thiram	$C_6H_{12}N_2S_4$	137-26-8		1		
Tin	Sn	7440-31-5		2		
Titanium(IV) oxide [Titanium dioxide]	O_2Ti	13463-67-7		10		
Toluene	C_7H_8	108-88-3	50	188		

Substance	Molecular Formula	CAS Reg. No.	Time-Weighted Average ppm	Time-Weighted Average mg/m^3	Short-Term Exposure Limit ppm	Short-Term Exposure Limit mg/m^3
Toluene-2,4-diisocyanate	$C_9H_6N_2O_2$	584-84-9	0.005	0.036	0.02	0.14
1*H*-1,2,4-Triazol-3-amine	$C_2H_4N_4$	61-82-5		0.2		
Tribromomethane [Bromoform]	$CHBr_3$	75-25-2	0.5	5.2		
Tributyl phosphate	$C_{12}H_{27}O_4P$	126-73-8	0.2	2.2		
Trichloroacetic acid	$C_2HCl_3O_2$	76-03-9	1	6.7		
1,2,4-Trichlorobenzene	$C_6H_3Cl_3$	120-82-1			5 C	37 C
1,1,1-Trichloroethane [Methyl chloroform]	$C_2H_3Cl_3$	71-55-6	350	1910	450	2460
1,1,2-Trichloroethane	$C_2H_3Cl_3$	79-00-5	10	55		
Trichloroethene	C_2HCl_3	79-01-6	50	269	100	537
Trichlorofluoromethane	CCl_3F	75-69-4			1000 C	5620 C
Trichloromethane [Chloroform]	$CHCl_3$	67-66-3	10	49		
(Trichloromethyl)benzene [Benzotrichloride]	$C_7H_5Cl_3$	98-07-7			0.01 C	0.08 C
Trichloronaphthalene (all isomers)	$C_{10}H_5Cl_3$	1321-65-9		5		
Trichloronitromethane [Chloropicrin]	CCl_3NO_2	76-06-2	0.1	0.67		
2,4,5-Trichlorophenoxyacetic acid	$C_8H_5Cl_3O_3$	93-76-5		10		
1,2,3-Trichloropropane	$C_3H_5Cl_3$	96-18-4	10	60		
1,1,2-Trichloro-1,2,2-trifluoroethane	$C_2Cl_3F_3$	76-13-1	1000	7670	1250	9590
Tri-*o*-cresyl phosphate	$C_{21}H_{21}O_4P$	78-30-8		0.1		
Triethanolamine	$C_6H_{15}NO_3$	102-71-6		5		
Triethylamine	$C_6H_{15}N$	121-44-8	1	4.1	3	12
Triiodomethane [Iodoform]	CHI_3	75-47-8	0.6	10		
Trimellitic anhydride [1,2,4-Benzenetricarboxylic anhydride]	$C_9H_4O_5$	552-30-7				0.04 C
Trimethylamine	C_3H_9N	75-50-3	5	12	15	36
Trimethylbenzene (all isomers)	C_9H_{12}	25551-13-7	25	123		
Trimethyl phosphite	$C_3H_9O_3P$	121-45-9	2	10		
Trinitroglycerol [Nitroglycerin]	$C_3H_5N_3O_9$	55-63-0	0.05	0.46		
2,4,6-Trinitrophenol [Picric acid]	$C_6H_3N_3O_7$	88-89-1		0.1		
2,4,6-Trinitrotoluene [TNT]	$C_7H_5N_3O_6$	118-96-7		0.1		
Triphenylamine	$C_{18}H_{15}N$	603-34-9		5		
Triphenyl phosphate	$C_{18}H_{15}O_4P$	115-86-6		3		
Tungsten	W	7440-33-7		5		10
Uranium	U	7440-61-1		0.2		0.6
Vanadium(V) oxide	O_5V_2	1314-62-1		0.05		
Vinyl acetate	$C_4H_6O_2$	108-05-4	10	35	15	53
4-Vinylcyclohexene	C_8H_{12}	100-40-3	0.1	0.44		
Warfarin	$C_{19}H_{16}O_4$	81-81-2		0.1		
Xylene (all isomers)	C_8H_{10}	1330-20-7	100	434	150	651
Xylidine (all isomers)	$C_8H_{11}N$	1300-73-8	0.5	2.5		
Yttrium	Y	7440-65-5		1		
Zinc chloride	Cl_2Zn	7646-85-7		1		2
Zinc chromate, basic	CrH_2O_4Zn	13530-65-9		0.045		
Zinc oxide	OZn	1314-13-2		5		10
Zirconium	Zr	7440-67-7		5		10

OCTANOL-WATER PARTITION COEFFICIENTS

The octanol-water partition coefficient, *P*, is a widely used parameter for correlating biological effects of organic substances. It is a property of the two-phase system in which water and 1-octanol are in equilibrium at a fixed temperature and the substance is distributed between the water-rich and octanol-rich phases. *P* is defined as the ratio of the equilibrium concentration of the substance in the octanol-rich phase to that in the water-rich phase, in the limit of zero concentration. In general, *P* tends to be large for compounds with extended non-polar structures (such as long chain or multi-ring hydrocarbons) and small for compounds with highly polar groups. Thus *P* (or, in its more common form of expression, log *P*) provides a measure of the lipophilic vs. hydrophilic nature of a compound, which is an important consideration in assessing the potential toxicity. A discussion of methods of measurement and accuracy considerations for log *P* may be found in Reference 1.

This table gives selected values of log *P* for about 450 organic compounds, including many of environmental importance. All values refer to a nominal temperature of 25°C. The source of each value is indicated in the last column. These references contain data on many more compounds than are included here.

Compounds are listed by molecular formula following the Hill convention. To locate a compound by name or CAS Registry Number when the molecular formula is not known, use the table "Physical Constants of Organic Compounds" in Section 3 and its indexes to determine the molecular formula.

REFERENCES

1. Sangster, J., *J. Phys. Chem. Ref. Data*, 18, 1111, 1989.
2. Mackay, D., Shiu, W.Y., and Ma, K.C., *Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals*, Lewis Publishers/CRC Press, Boca Raton, FL, 1992.
3. Shiu, W.Y., and Mackay, D., *J. Phys. Chem. Ref. Data*, 15, 911, 1986.
4. Pinsuwan, S., Li, L., and Yalkowsky, S.H., *J. Chem. Eng. Data*, 40, 623, 1995.
5. *Solubility Data Series, International Union of Pure and Applied Chemistry, Vol. 20*, Pergamon Press, Oxford, 1985.
6. *Solubility Data Series, International Union of Pure and Applied Chemistry, Vol. 38*, Pergamon Press, Oxford, 1985.
7. Miller, M.M., Ghodbane, S., Wasik, S.P., Tewari, Y.B., and Martire, D.E., *J. Chem. Eng. Data*, 29, 184, 1984.

Mol. Form.	Name	log *P*	Ref.
CCl_2F_2	Dichlorodifluoromethane	2.16	2
CCl_3F	Trichlorofluoromethane	2.53	2
CCl_4	Tetrachloromethane	2.64	2
$CHBr_3$	Tribromomethane	2.38	2
$CHCl_3$	Trichloromethane	1.97	2
CH_2BrCl	Bromochloromethane	1.41	2
CH_2Br_2	Dibromomethane	2.3	2
CH_2Cl_2	Dichloromethane	1.25	2
CH_2F_2	Difluoromethane	0.20	1
CH_2I_2	Diiodomethane	2.5	2
CH_2O	Formaldehyde	0.35	1
CH_2O_2	Formic acid	-0.54	1
CH_3Br	Bromomethane	1.19	2
CH_3Cl	Chloromethane	0.91	2
CH_3F	Fluoromethane	0.51	1
CH_3I	Iodomethane	1.5	2
CH_3NO	Formamide	-1.51	1
CH_3NO_2	Nitromethane	-0.33	1
CH_4O	Methanol	-0.74	1
CH_5N	Methylamine	-0.57	1
$C_2Cl_3F_3$	1,1,2-Trichlorotrifluoroethane	3.16	2
C_2Cl_4	Tetrachloroethylene	2.88	2
C_2Cl_6	Hexachloroethane	4.00	4
C_2HCl_3	Trichloroethylene	2.53	2
C_2HCl_5	Pentachloroethane	2.89	2
$C_2H_2Cl_2$	1,1-Dichloroethylene	2.13	2
$C_2H_2Cl_2$	*cis*-1,2-Dichloroethylene	1.86	2
$C_2H_2Cl_2$	*trans*-1,2-Dichloroethylene	1.93	2
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane	2.39	2
C_2H_3Cl	Chloroethylene	1.38	2
$C_2H_3Cl_3$	1,1,1-Trichloroethane	2.49	2
$C_2H_3Cl_3$	1,1,2-Trichloroethane	2.38	2
C_2H_3N	Acetonitrile	-0.34	1
$C_2H_4Cl_2$	1,1-Dichloroethane	1.79	2
$C_2H_4Cl_2$	1,2-Dichloroethane	1.48	2
C_2H_4O	Acetaldehyde	0.45	1
C_2H_4O	Ethylene oxide	-0.30	1
$C_2H_4O_2$	Acetic acid	-0.17	1
C_2H_5Br	Bromoethane	1.6	2
C_2H_5Cl	Chloroethane	1.43	2
C_2H_5I	Iodoethane	2	2
C_2H_5NO	Acetamide	-1.26	1
$C_2H_5NO_2$	Nitroethane	0.18	1
C_2H_6O	Ethanol	-0.30	1
C_2H_6O	Dimethyl ether	0.10	1
C_2H_6OS	Dimethyl sulfoxide	-1.35	1
$C_2H_6O_2S$	Dimethyl sulfone	-1.41	1
C_2H_7N	Ethylamine	-0.13	1
C_2H_7N	Dimethylamine	-0.38	1
C_3H_3N	2-Propenenitrile	0.25	1
$C_3H_4Cl_2$	*cis*-1,3-Dichloropropene	2.03	2
C_3H_4O	Propargyl alcohol	-0.38	1
C_3H_4O	Acrolein	-0.01	1
C_3H_5Br	3-Bromopropene	1.79	1
C_3H_5ClO	Epichlorohydrin	0.30	2
$C_3H_5Cl_3$	1,2,3-Trichloropropane	2.63	2
C_3H_5N	Propanenitrile	0.16	1
C_3H_5NO	Acrylamide	-0.78	1
$C_3H_6Cl_2$	1,2-Dichloropropane	2.0	2
C_3H_6O	Allyl alcohol	0.17	1
C_3H_6O	Propanal	0.59	1
C_3H_6O	Acetone	-0.24	1
C_3H_6O	Methyloxirane	0.03	1
$C_3H_6O_2$	Propanoic acid	0.33	1
$C_3H_6O_2$	Methyl acetate	0.18	1
C_3H_7Br	1-Bromopropane	2.1	2
C_3H_7Br	2-Bromopropane	1.9	2
C_3H_7Cl	1-Chloropropane	2.04	1
C_3H_7Cl	2-Chloropropane	1.90	1
C_3H_7I	1-Iodopropane	2.5	2

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Mol. Form.	Name	log *P*	Ref.
C_3H_7N	Allylamine	0.03	1
C_3H_7NO	*N,N*-Dimethylformamide	-1.01	1
C_3H_7NO	*N*-Methylacetamide	-1.05	1
$C_3H_7NO_2$	1-Nitropropane	0.87	1
C_3H_8O	1-Propanol	0.25	1
C_3H_8O	2-Propanol	0.05	1
C_3H_8S	1-Propanethiol	1.81	1
C_3H_9N	Propylamine	0.48	1
C_3H_9N	Isopropylamine	0.26	1
C_3H_9N	Ethylmethylamine	0.15	1
C_3H_9N	Trimethylamine	0.16	1
C_4H_4O	Furan	1.34	1
C_4H_4S	Thiophene	1.81	1
C_4H_5N	Pyrrole	0.75	1
C_4H_6	1,3-Butadiene	1.99	1
C_4H_6	2-Butyne	1.46	1
C_4H_6O	2,5-Dihydrofuran	0.46	1
$C_4H_6O_2$	Methacrylic acid	0.93	1
$C_4H_6O_2$	Vinyl acetate	0.73	1
$C_4H_6O_2$	Methyl acrylate	0.80	1
C_4H_7N	Butanenitrile	0.60	1
C_4H_8	*cis*-2-Butene	2.33	1
C_4H_8	*trans*-2-Butene	2.31	1
C_4H_8	Isobutene	2.35	1
$C_4H_8Cl_2O$	Bis(2-chloroethyl) ether	1.12	2
C_4H_8O	Ethyl vinyl ether	1.04	1
C_4H_8O	Butanal	0.88	1
C_4H_8O	2-Butanone	0.29	1
C_4H_8O	Tetrahydrofuran	0.46	1
$C_4H_8O_2$	Butanoic acid	0.79	1
$C_4H_8O_2$	Propyl formate	0.83	1
$C_4H_8O_2$	Ethyl acetate	0.73	1
C_4H_9Br	1-Bromobutane	2.75	1
C_4H_9Cl	1-Chlorobutane	2.64	2
C_4H_9F	1-Fluorobutane	2.58	1
C_4H_9I	1-Iodobutane	3	2
C_4H_9N	Pyrrolidine	0.46	1
C_4H_9NO	Butanamide	-0.21	1
C_4H_9NO	*N,N*-Dimethylacetamide	-0.77	1
$C_4H_9NO_2$	1-Nitrobutane	1.47	1
C_4H_{10}	Isobutane	2.8	2
$C_4H_{10}O$	1-Butanol	0.84	1
$C_4H_{10}O$	2-Butanol	0.65	1
$C_4H_{10}O$	2-Methyl-1-propanol	0.76	1
$C_4H_{10}O$	2-Methyl-2-propanol	0.35	1
$C_4H_{10}O$	Diethyl ether	0.89	1
$C_4H_{10}S$	1-Butanethiol	2.28	1
$C_4H_{10}S$	Diethyl sulfide	1.95	1
$C_4H_{11}N$	Butylamine	0.86	1
$C_4H_{11}N$	*tert*-Butylamine	0.40	1
$C_4H_{11}N$	Diethylamine	0.58	1
C_5H_5N	Pyridine	0.65	1
C_5H_6O	2-Methylfuran	1.85	1
C_5H_7N	1-Methylpyrrole	1.21	1
C_5H_8	1,4-Pentadiene	2.48	1
C_5H_8	1-Pentyne	1.98	1
$C_5H_8O_2$	Methyl methacrylate	1.38	1
$C_5H_8O_2$	Ethyl acrylate	1.32	1
C_5H_9N	Pentanenitrile	0.94	1
C_5H_{10}	1-Pentene	2.2	2
C_5H_{10}	Cyclopentane	3.00	1
$C_5H_{10}O$	2-Pentanone	0.84	1
$C_5H_{10}O$	3-Pentanone	0.82	1
$C_5H_{10}O$	3-Methyl-2-butanone	0.56	1
$C_5H_{10}O$	Tetrahydropyran	0.82	1
$C_5H_{10}O$	2-Methyltetrahydrofuran	1.85	2
$C_5H_{10}O_2$	Pentanoic acid	1.39	1
$C_5H_{10}O_2$	Propyl acetate	1.24	1
$C_5H_{10}O_2$	Ethyl propanoate	1.21	1
$C_5H_{10}O_3$	Diethyl carbonate	1.21	1
$C_5H_{11}Br$	1-Bromopentane	3.37	1
$C_5H_{11}F$	1-Fluoropentane	2.33	1
$C_5H_{11}N$	Piperidine	0.84	1
$C_5H_{11}NO_2$	1-Nitropentane	2.01	1
C_5H_{12}	Pentane	3.45	1
C_5H_{12}	Neopentane	3.11	1
$C_5H_{12}O$	1-Pentanol	1.51	1
$C_5H_{12}O$	2-Pentanol	1.25	1
$C_5H_{12}O$	3-Pentanol	1.21	1
$C_5H_{12}O$	3-Methyl-1-butanol	1.28	1
$C_5H_{12}O$	2-Methyl-2-butanol	0.89	1
$C_5H_{12}O$	3-Methyl-2-butanol	1.28	1
$C_5H_{12}O$	2,2-Dimethyl-1-propanol	1.31	1
$C_5H_{12}O$	Methyl *tert*-butyl ether	0.94	1
$C_5H_{13}N$	Pentylamine	1.49	1
C_6Cl_6	Hexachlorobenzene	5.47	5
C_6HCl_5	Pentachlorobenzene	5.03	5
C_6HCl_5O	Pentachlorophenol	5.07	4
$C_6H_2Cl_4$	1,2,3,4-Tetrachlorobenzene	4.55	5
$C_6H_2Cl_4$	1,2,3,5-Tetrachlorobenzene	4.65	5
$C_6H_2Cl_4$	1,2,4,5-Tetrachlorobenzene	4.51	5
$C_6H_3Cl_3$	1,2,3-Trichlorobenzene	4.04	5
$C_6H_3Cl_3$	1,2,4-Trichlorobenzene	3.98	5
$C_6H_3Cl_3$	1,3,5-Trichlorobenzene	4.02	5
$C_6H_4Cl_2$	*o*-Dichlorobenzene	3.38	5
$C_6H_4Cl_2$	*m*-Dichlorobenzene	3.48	5
$C_6H_4Cl_2$	*p*-Dichlorobenzene	3.38	5
$C_6H_4Cl_2O$	2,4-Dichlorophenol	3.23	4
C_6H_5Br	Bromobenzene	2.99	2
C_6H_5Cl	Chlorobenzene	2.84	1
C_6H_5F	Fluorobenzene	2.27	2
C_6H_5I	Iodobenzene	3.28	2
$C_6H_5NO_2$	Nitrobenzene	1.85	1
C_6H_6	Benzene	2.13	1
C_6H_6O	Phenol	1.48	4
C_6H_6S	Benzenethiol	2.52	1
C_6H_7N	Aniline	0.90	1
C_6H_7N	2-Methylpyridine	1.11	1
C_6H_7N	3-Methylpyridine	1.20	1
C_6H_7N	4-Methylpyridine	1.22	1
C_6H_8	1,4-Cyclohexadiene	2.3	2
C_6H_8O	5-Hexyn-2-one	0.58	1
C_6H_8O	2-Cyclohexen-1-one	0.61	1
C_6H_8O	2-Ethylfuran	2.40	1
C_6H_{10}	1,5-Hexadiene	2.8	2
C_6H_{10}	1-Hexyne	2.73	2
C_6H_{10}	Cyclohexene	2.86	1
$C_6H_{10}O$	5-Hexen-2-one	1.02	1
$C_6H_{10}O$	Cyclohexanone	0.81	1
$C_6H_{10}O_2$	Ethyl methacrylate	1.94	1

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OCTANOL-WATER PARTITION COEFFICIENTS (continued)

Mol. Form.	Name	log *P*	Ref.
$C_6H_{11}Br$	Bromocyclohexane	3.20	1
$C_6H_{11}N$	Hexanenitrile	1.66	1
C_6H_{12}	1-Hexene	3.40	1
C_6H_{12}	4-Methyl-1-pentene	2.5	2
C_6H_{12}	Cyclohexane	3.44	1
C_6H_{12}	Methylcyclopentane	3.37	2
$C_6H_{12}O$	Cyclohexanol	1.23	1
$C_6H_{12}O$	Hexanal	1.78	1
$C_6H_{12}O$	2-Hexanone	1.38	1
$C_6H_{12}O$	4-Methyl-2-pentanone	1.31	1
$C_6H_{12}O_2$	Hexanoic acid	1.92	1
$C_6H_{12}O_2$	Butyl acetate	1.82	1
$C_6H_{13}Br$	1-Bromohexane	3.80	1
$C_6H_{13}N$	Cyclohexylamine	1.49	1
C_6H_{14}	Hexane	4.00	1
C_6H_{14}	3-Methylpentane	3.60	2
C_6H_{14}	2,2-Dimethylbutane	3.82	1
C_6H_{14}	2,3-Dimethylbutane	3.85	2
$C_6H_{14}O$	1-Hexanol	2.03	1
$C_6H_{14}O$	2-Hexanol	1.76	1
$C_6H_{14}O$	3-Hexanol	1.65	1
$C_6H_{14}O$	3,3-Dimethyl-2-butanol	1.48	1
$C_6H_{14}O$	Dipropyl ether	2.03	1
$C_6H_{14}O$	Diisopropyl ether	1.52	1
$C_6H_{15}N$	Hexylamine	2.06	1
$C_6H_{15}N$	Dipropylamine	1.67	1
$C_6H_{15}N$	Triethylamine	1.45	1
$C_7H_5BrO_2$	2-Bromobenzoic acid	2.20	4
$C_7H_5BrO_2$	3-Bromobenzoic acid	2.87	4
$C_7H_5BrO_2$	4-Bromobenzoic acid	2.86	4
C_7H_5N	Benzonitrile	1.56	1
C_7H_6O	Benzaldehyde	1.48	1
$C_7H_6O_2$	Benzoic acid	1.88	4
$C_7H_6O_2$	Phenyl formate	1.26	1
$C_7H_6O_3$	Salicylic acid	2.20	4
C_7H_7Br	(Bromomethyl)benzene	2.92	1
C_7H_7Cl	o-Chlorotoluene	3.42	1
C_7H_7Cl	*m*-Chlorotoluene	3.28	1
C_7H_7Cl	*p*-Chlorotoluene	3.33	1
C_7H_7Cl	(Chloromethyl)benzene	2.30	1
$C_7H_7NO_2$	*p*-Nitrotoluene	2.42	1
C_7H_8	Toluene	2.73	1
C_7H_8	1,3,5-Cycloheptatriene	2.63	2
C_7H_8O	*o*-Cresol	1.98	1
C_7H_8O	*m*-Cresol	1.98	1
C_7H_8O	*p*-Cresol	1.97	1
C_7H_8O	Benzyl alcohol	1.05	1
C_7H_8O	Anisole	2.11	1
C_7H_9N	Benzylamine	1.09	1
C_7H_9N	*o*-Methylaniline	1.32	1
C_7H_9N	*m*-Methylaniline	1.40	1
C_7H_9N	*p*-Methylaniline	1.39	1
C_7H_9N	*N*-Methylaniline	1.66	1
C_7H_{14}	1-Heptene	3.99	1
C_7H_{14}	Methylcyclohexane	3.88	1
$C_7H_{14}O$	2-Heptanone	1.98	1
$C_7H_{14}O$	5-Methyl-2-hexanone	1.88	1
$C_7H_{15}Br$	1-Bromoheptane	4.36	1
$C_7H_{15}Cl$	1-Chloroheptane	4.15	1
$C_7H_{15}I$	1-Iodoheptane	4.70	1
C_7H_{16}	Heptane	4.50	1
$C_7H_{16}O$	1-Heptanol	2.62	1
$C_7H_{16}O$	2-Heptanol	2.31	1
$C_7H_{16}O$	3-Heptanol	2.24	1
$C_7H_{16}O$	4-Heptanol	2.22	1
$C_7H_{17}N$	Heptylamine	2.57	1
C_8H_6	Phenylacetylene	2.40	1
C_8H_6O	Benzofuran	2.67	1
C_8H_6S	Benzo[b]thiophene	3.12	1
C_8H_7N	Benzeneacetonitrile	1.56	1
C_8H_7N	Indole	2.14	1
C_8H_8	Styrene	3.05	1
C_8H_8O	Acetophenone	1.63	1
C_8H_8O	2-Methylbenzaldehyde	2.26	1
C_8H_8O	Benzeneacetaldehyde	1.78	1
C_8H_8O	2,3-Dihydrobenzofuran	2.14	1
C_8H_8O	Phenyloxirane	1.61	1
$C_8H_8O_2$	*o*-Toluic acid	2.32	4
$C_8H_8O_2$	*m*-Toluic acid	2.37	1
$C_8H_8O_2$	*p*-Toluic acid	2.34	1
$C_8H_8O_2$	Benzeneacetic acid	1.41	1
$C_8H_8O_2$	Phenyl acetate	1.49	1
$C_8H_8O_2$	Methyl benzoate	2.20	1
C_8H_{10}	Ethylbenzene	3.15	1
C_8H_{10}	*o*-Xylene	3.12	1
C_8H_{10}	*m*-Xylene	3.20	1
C_8H_{10}	*p*-Xylene	3.15	1
$C_8H_{10}O$	*o*-Ethylphenol	2.47	1
$C_8H_{10}O$	*m*-Ethylphenol	2.50	1
$C_8H_{10}O$	*p*-Ethylphenol	2.50	1
$C_8H_{10}O$	2,4-Xylenol	2.35	1
$C_8H_{10}O$	2,5-Xylenol	2.34	1
$C_8H_{10}O$	2,6-Xylenol	2.36	1
$C_8H_{10}O$	3,4-Xylenol	3.23	1
$C_8H_{10}O$	3,5-Xylenol	2.35	1
$C_8H_{10}O$	Benzeneethanol	1.36	1
$C_8H_{10}O$	α-Methylbenzyl alcohol	1.42	1
$C_8H_{10}O$	3-Methylbenzenemethanol	1.60	1
$C_8H_{10}O$	4-Methylbenzenemethanol	1.58	1
$C_8H_{10}O$	Phenetole	2.51	1
$C_8H_{10}O$	Benzyl methyl ether	1.35	1
$C_8H_{10}O$	2-Methylanisole	2.74	1
$C_8H_{10}O$	3-Methylanisole	2.66	1
$C_8H_{10}O$	4-Methylanisole	2.81	1
$C_8H_{11}N$	*p*-Ethylaniline	1.96	1
$C_8H_{11}N$	*N*,*N*-Dimethylaniline	2.31	1
$C_8H_{11}N$	Benzeneethanamine	1.41	1
$C_8H_{14}O_2$	Butyl methacrylate	2.88	1
$C_8H_{15}N$	Octanenitrile	2.75	1
C_8H_{16}	1-Octene	4.57	1
C_8H_{16}	Cyclooctane	4.45	2
$C_8H_{16}O$	2-Octanone	2.37	1
$C_8H_{16}O_2$	Octanoic acid	3.05	1
$C_8H_{17}Br$	1-Bromooctane	4.89	1
C_8H_{18}	Octane	5.15	1
$C_8H_{18}O$	1-Octanol	3.07	1
$C_8H_{18}O$	2-Octanol	2.90	1
$C_8H_{18}O$	4-Octanol	2.68	1
$C_8H_{18}O$	Dibutyl ether	3.21	1
C_9H_7N	Quinoline	2.03	1

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OCTANOL-WATER PARTITION COEFFICIENTS (continued)

Mol. Form.	Name	log *P*	Ref.
C_9H_7N	Isoquinoline	2.08	1
C_9H_8	Indene	2.92	1
$C_9H_8O_2$	*trans*-Cinnamic acid	2.13	1
C_9H_9N	Benzenepropanenitrile	1.72	1
C_9H_{10}	Indan	3.33	1
$C_9H_{10}O$	1-Phenyl-1-propanone	2.19	1
$C_9H_{10}O$	1-Phenyl-2-propanone	1.44	1
$C_9H_{10}O$	4-Methylacetophenone	2.19	1
$C_9H_{10}O_2$	2-Phenylpropanoic acid	1.80	1
$C_9H_{10}O_2$	Benzyl acetate	1.96	1
$C_9H_{10}O_2$	4-Methylphenyl acetate	2.11	1
$C_9H_{10}O_2$	Ethyl benzoate	2.64	1
C_9H_{12}	Propylbenzene	3.69	1
C_9H_{12}	Isopropylbenzene	3.66	1
C_9H_{12}	*o*-Ethyltoluene	3.53	1
C_9H_{12}	*p*-Ethyltoluene	3.63	2
C_9H_{12}	1,2,3-Trimethylbenzene	3.60	1
C_9H_{12}	1,2,4-Trimethylbenzene	3.63	1
C_9H_{12}	1,3,5-Trimethylbenzene	3.42	1
$C_9H_{12}O$	2-Propylphenol	2.93	1
$C_9H_{12}O$	4-Propylphenol	3.20	1
$C_9H_{12}O$	2,3,6-Trimethylphenol	2.67	1
$C_9H_{12}O$	2,4,6-Trimethylphenol	2.46	1
$C_9H_{12}O$	Benzenepropanol	1.88	1
$C_9H_{13}N$	*N,N*-Dimethylbenzylamine	1.98	1
$C_9H_{13}N$	Amphetamine	1.76	1
C_9H_{18}	1-Nonene	5.15	1
$C_9H_{18}O$	2-Nonanone	3.16	1
$C_9H_{18}O$	5-Methyl-2-octanone	2.92	1
C_9H_{20}	Nonane	5.65	1
$C_9H_{20}O$	1-Nonanol	4.02	1
$C_9H_{21}N$	Tripropylamine	2.79	1
$C_{10}H_7Cl$	1-Chloronaphthalene	3.90	1
$C_{10}H_7Cl$	2-Chloronaphthalene	3.98	1
$C_{10}H_8$	Naphthalene	3.34	4
$C_{10}H_8$	Azulene	3.22	1
$C_{10}H_8O$	1-Naphthol	2.84	1
$C_{10}H_8O$	2-Naphthol	2.70	1
$C_{10}H_{12}O_2$	Isopropyl benzoate	3.18	1
$C_{10}H_{14}$	Butylbenzene	4.26	1
$C_{10}H_{14}$	*tert*-Butylbenzene	4.11	1
$C_{10}H_{14}$	Isobutylbenzene	4.01	2
$C_{10}H_{14}$	*p*-Cymene	4.10	1
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene	4.10	2
$C_{10}H_{14}$	1,2,3,4-Tetramethylbenzene	4.00	1
$C_{10}H_{14}$	1,2,3,5-Tetramethylbenzene	4.10	1
$C_{10}H_{14}O$	4-Butylphenol	3.65	1
$C_{10}H_{20}O$	2-Decanone	3.77	1
$C_{10}H_{20}O_2$	Decanoic acid	4.09	1
$C_{10}H_{22}$	Decane	6.25	1
$C_{10}H_{22}O$	1-Decanol	4.57	1
$C_{11}H_9N$	4-Phenylpyridine	2.59	1
$C_{11}H_{10}$	1-Methylnaphthalene	3.87	1
$C_{11}H_{10}$	2-Methylnaphthalene	4.00	1
$C_{11}H_{16}$	Pentylbenzene	4.90	1
$C_{11}H_{16}$	Pentamethylbenzene	4.56	1
$C_{11}H_{22}O$	2-Undecanone	4.09	1
$C_{11}H_{22}O_2$	Methyl decanoate	4.41	1
$C_{12}Cl_{10}$	Decachlorobiphenyl	8.26	3
$C_{12}HCl_9$	2,2′,3,3′,4,5,5′,6,6′-Nonachlorobiphenyl	8.16	3
$C_{12}H_2Cl_8$	2,2′,3,3′,5,5′,6,6′-Octachlorobiphenyl	7.10	3
$C_{12}H_3Cl_7$	2,2′,3,3′,4,4′,6-Heptachlorobiphenyl	6.70	3
$C_{12}H_4Cl_6$	2,2′,3,3′,4,4′-Hexachlorobiphenyl	7.00	3
$C_{12}H_4Cl_6$	2,2′,4,4′,6,6′-Hexachlorobiphenyl	7.00	3
$C_{12}H_4Cl_6$	2,2′,3,3′,6,6′-Hexachlorobiphenyl	6.70	3
$C_{12}H_5Cl_5$	2,3,4,5,6-Pentachlorobiphenyl	6.30	3
$C_{12}H_5Cl_5$	2,2′,4,5,5′-Pentachlorobiphenyl	6.40	3
$C_{12}H_6Cl_4$	2,3,4,5-Tetrachlorobiphenyl	5.72	3
$C_{12}H_6Cl_4$	2,2′,4′,5-Tetrachlorobiphenyl	5.73	7
$C_{12}H_7Cl_3$	2,4,5-Trichlorobiphenyl	5.60	3
$C_{12}H_7Cl_3$	2,4,6-Trichlorobiphenyl	5.47	3
$C_{12}H_8Cl_2$	2,5-Dichlorobiphenyl	5.10	3
$C_{12}H_8Cl_2$	2,6-Dichlorobiphenyl	5.00	3
$C_{12}H_8O$	Dibenzofuran	4.12	1
$C_{12}H_9Cl$	2-Chlorobiphenyl	4.52	1
$C_{12}H_9Cl$	3-Chlorobiphenyl	4.58	1
$C_{12}H_9Cl$	4-Chlorobiphenyl	4.61	1
$C_{12}H_9N$	Carbazole	3.72	1
$C_{12}H_{10}$	Acenaphthene	3.96	4
$C_{12}H_{10}$	Biphenyl	3.76	6
$C_{12}H_{10}N_2$	Azobenzene	3.82	1
$C_{12}H_{10}O$	Diphenyl ether	4.21	1
$C_{12}H_{10}S$	Diphenyl sulfide	4.45	1
$C_{12}H_{11}N$	Diphenylamine	3.44	4
$C_{12}H_{12}$	1-Ethylnaphthalene	4.40	1
$C_{12}H_{12}$	1,2-Dimethylnaphthalene	4.31	1
$C_{12}H_{12}$	1,4-Dimethylnaphthalene	4.37	1
$C_{12}H_{14}O$	4-Phenylcyclohexanone	2.45	1
$C_{12}H_{18}$	Hexylbenzene	5.52	1
$C_{12}H_{18}$	Hexamethylbenzene	4.69	4
$C_{12}H_{22}O$	Cyclododecanone	4.10	1
$C_{12}H_{24}O_2$	Dodecanoic acid	4.6	1
$C_{12}H_{26}O$	1-Dodecanol	5.13	1
$C_{13}H_8O$	9H-Fluoren-9-one	3.58	1
$C_{13}H_9N$	Acridine	3.40	1
$C_{13}H_{10}$	9H-Fluorene	4.20	4
$C_{13}H_{10}O$	Benzophenone	3.18	1
$C_{13}H_{10}O_2$	Phenyl benzoate	3.59	1
$C_{13}H_{11}NO$	*N*-Phenylbenzamide	2.62	1
$C_{13}H_{12}$	Diphenylmethane	4.14	1
$C_{13}H_{12}$	4-Methylbiphenyl	4.63	1
$C_{13}H_{12}O$	Diphenylmethanol	2.67	1
$C_{13}H_{12}O$	Benzyl phenyl ether	3.79	1
$C_{14}H_{10}$	Anthracene	4.56	4
$C_{14}H_{10}$	Phenanthrene	4.52	4
$C_{14}H_{12}$	*trans*-Stilbene	4.81	1
$C_{14}H_{12}$	1-Methylfluorene	4.97	1
$C_{14}H_{12}O$	2-Phenylacetophenone	3.18	1
$C_{14}H_{12}O_2$	Benzyl benzoate	3.97	1
$C_{14}H_{14}$	1,2-Diphenylethane	4.70	1
$C_{14}H_{14}$	4,4′-Dimethylbiphenyl	5.09	1
$C_{14}H_{22}$	Octylbenzene	6.30	1
$C_{14}H_{28}O_2$	Tetradecanoic acid	6.1	1
$C_{15}H_{12}$	2-Methylanthracene	5.15	2
$C_{15}H_{12}$	9-Methylanthracene	5.07	1
$C_{15}H_{12}$	1-Methylphenanthrene	5.14	2
$C_{16}H_{10}$	Fluoranthene	5.07	4
$C_{16}H_{10}$	Pyrene	5.08	4
$C_{16}H_{14}$	9,10-Dimethylanthracene	5.69	1
$C_{16}H_{32}O_2$	Hexadecanoic acid	7.17	1

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OCTANOL-WATER PARTITION COEFFICIENTS (continued)

Mol. Form.	Name	log *P*	Ref.
$C_{17}H_{12}$	11H-Benzo[a]fluorene	5.40	1
$C_{17}H_{12}$	11H-Benzo[b]fluorene	5.75	1
$C_{18}H_{12}$	Benz[a]anthracene	5.91	1
$C_{18}H_{12}$	Chrysene	5.73	4
$C_{18}H_{12}$	Naphthacene	5.76	1
$C_{18}H_{12}$	Triphenylene	5.49	4
$C_{18}H_{15}N$	Triphenylamine	5.74	1
$C_{18}H_{30}O_2$	Linolenic acid	6.46	1
$C_{18}H_{32}O_2$	Linoleic acid	7.05	1
$C_{18}H_{34}O_2$	Oleic acid	7.64	1
$C_{18}H_{36}O_2$	Stearic acid	8.23	1
$C_{19}H_{16}O$	Triphenylmethanol	3.68	1
$C_{20}H_{12}$	Perylene	6.25	1
$C_{20}H_{12}$	Benzo[a]pyrene	6.20	4
$C_{20}H_{32}O_2$	Arachidonic acid	6.98	1
$C_{20}H_{40}O_2$	Arachidic acid	9.29	1
$C_{21}H_{16}$	1,2-Dihydro-3-methylbenz[j]aceanthrylene	6.75	1
$C_{22}H_{12}$	Benzo[ghi]perylene	6.90	1
$C_{24}H_{12}$	Coronene	6.05	4

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PROTECTION AGAINST IONIZING RADIATION

The following data and rules of thumb are helpful in estimating the penetrating capability of and danger of exposure to various types of ionizing radiation. More precise data should be used for critical applications.

Alpha Particles

Alpha particles of at least 7.5 MeV are required to penetrate the epidermis, the protective layer of skin, 0.07 mm thick.

Electrons

Electrons of at least 70 keV are required to penetrate the epidermis, the protective layer of skin, 0.07 mm thick.

The range of electrons in g/cm^2 is approximately equal to the maximum energy (E) in MeV divided by 2.

The range of electrons in air is about 3.65 m per MeV; for example, a 3 MeV electron has a range of about 11 m in air.

A chamber wall thickness of 30 mg/cm^2 will transmit 70% of the initial fluence of 1 MeV electrons and 20% of that of 0.4 MeV electrons.

When electrons of 1 to 2 MeV pass through light materials such as water, aluminum, or glass, less than 1% of their energy is dissipated as bremsstrahlung.

The bremsstrahlung from 1 Ci of ^{32}P aqueous solution in a glass bottle is about 1 mR/h at 1 meter distance.

When electrons from a 1 Ci source of ^{90}Sr - ^{90}Y are absorbed, the bremsstrahlung hazard is approximately equal to that presented by the gamma radiation from 12 mg of radium. The average energy of the bremsstrahlung is about 300 keV.

Gamma Rays

The air-scattered radiation (sky-shine) from a 100 Ci ^{60}Co source placed 1 ft behind a 4 ft high shield is about 100 mrad/h at 6 ft from the outside of the shield.

Within ±20% for point source gamma emitters with energies between 0.07 and 4 MeV, the exposure rate (R/h) at 1 ft is $6C{\cdot}E{\cdot}n$ where C is the activity in curies, E is the energy in MeV, and n is the number of gammas per disintegration.

Neutrons

An approximate HVL (thickness of absorber for which the neutron flux falls to half its initial value) for 1 MeV neutrons is 3.2 cm of paraffin; that for 5 MeV neutrons is 6.9 cm of paraffin).

Miscellaneous

The activity of any radionuclide is reduced to less than 1% after 7 half-lives (i.e., 2^{-7} = 0.8%).

For nuclides with a half-life greater than 6 days, the change in activity in 24 hours will be less than 10%.

10 HVL (half-value layers) attenuates approximately by 10^{-3}.

There is 0.64 mm^3 of radon gas at STP in transient equilibrium with 1 Ci of radium.

The natural background from all sources in most parts of the world leads to an equivalent dose rate of about 0.04 to 4 mSv per year for the average person. About 84% of this comes from terrestrial sources, the remainder from cosmic rays. The U. S. average is about 3.6 mSv/yr but can range up to 50 mSv/yr in some areas. A passenger in a plane flying at 12,000 meters receives 5 μSv/hr from cosmic rays (as compared to about 0.03 μSv/hr at sea level).

The ICRP recommended exposure limit to man-made sources of ionizing radiation (Reference 2) is 20 mSv/yr averaged over 5 years, with the dose in any one year not to exceed 50 mSv.

A whole-body dose of about 3 Gy over a short time interval will typically lead to 50% mortality in 30 days assuming no medical treatment.

Units

The gray (Gy) is the SI unit of absorbed dose; it is a measure of the mean energy imparted to a sample of irradiated matter, divided by the mass of the sample. Gy is a special name for the SI unit J/kg.

The sievert (Sv) is the SI unit of equivalent dose, which is defined as the absorbed dose multiplied by a weighting factor that expresses the long-term biological risk from low-level chronic exposure to a specified type of radiation. The Sv is another special name for J/kg.

1 curie (Ci) = $3.7{\cdot}10^{10}$ becquerel (Bq); i.e., $3.7{\cdot}10^{10}$ disintegrations per second.

1 roentgen (R) = $2.58{\cdot}10^{-4}$ coulomb per kilogram (C/kg); a measure of the charge (positive or negative) liberated by x-ray or gamma radiation in air, divided by the mass of air.

1 rad = 0.01 Gy

1 rem = 0.01 Sv

REFERENCES

1. Padikal, T.N., and Fivozinsky, S.P., *Medical Physics Data Book*, *National Bureau of Standards Handbook 138*, U. S. Government Printing Office, Washington, D.C., 1981.
2. *1990 Recommendations of the International Commission on Radiological Protection,* ICRP Publication 60, *Annals of the ICRP*, Pergamon Press, Oxford, 1991.
3. *Radiation: Doses, Effects, Risks*, United Nations Sales No. E.86.III.D.4, 1985.
4. *Review of Particle Properties, Phys. Rev. D*, 50, 1173, 1994 (p. 1268).

ANNUAL LIMITS ON INTAKES OF RADIONUCLIDES

K. F. Eckerman

The following table lists, for workers, the annual limits on oral and inhalation intakes (ALI) for selected radionuclides based on the occupational radiation protection guidance of the International Commission on Radiological Protection (References 1 and 2). An intake of one ALI corresponds to an annual whole body dose of 0.02 Sv (2 rem).

The ALI is expressed in the SI unit of activity, the becquerel (Bq), and in the conventional unit, the microcurie (μCi); 1 μCi = $3.7 \cdot 10^4$ Bq. The chemical form of inhaled radionuclides is, in most instances, stated in terms of the rate of absorption to blood from the lungs and the fractional absorption from the small intestine. Type F, M, and S denote chemical forms which are absorbed from the lungs at rates characterized as fast, moderate, and slow, respectively. The time to absorb 90% of the deposited radionuclide, in the absence of radioactive decay, corresponds to about 10 minutes, 150 days, and 7000 days for Type F, M, and S compounds, respectively. Type F compounds can be considered to be more soluble than M or S, S being the most insoluble. Chemical form consideration for ingestion is specified by the fractional absorption from the small intestine, denoted as f_1. The f_1 values range from 10^{-5} to 1. Higher fractional absorption is associated with greater solubility of the compound.

REFERENCES

1. *1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Annals of the ICRP 21, (1—3),* Pergamon Press, Oxford, 1991.
2. *Dose Coefficients for Intakes of Radionuclides by Workers, ICRP Publication 68, Annals of the ICRP*, 24(4), Pergamon Press, Oxford, 1995.

		Inhalation intakes			Oral intakes		
	Physical half-life	Chemical form Type/f_1	ALI Bq	ALI μCi	Chemical form f_1	ALI Bq	ALI μCi
^{3}H	12.3 y	HT gas	1.1E+13	3.0E+08	1.000	1.1E+13	3.0E+08
		HTO vapor	1.1E+09	3.0E+04			
^{11}C	0.340 h	CO	1.7E+10	4.5E+05	1.000	8.3E+08	2.3E+04
		CO_2	9.1E+09	2.5E+05			
		Organic compounds	6.2E+09	1.7E+05			
^{14}C	5730 y	CO	2.5E+10	6.8E+05	1.000	3.4E+07	9.3E+02
		CO_2	3.1E+09	8.3E+04			
		Organic compounds	3.4E+07	9.3E+02			
^{18}F	1.83 h	F 1.000	3.7E+08	1.0E+04	1.000	4.1E+08	1.1E+04
		M 1.000	2.2E+08	6.1E+03			
		S 1.000	2.2E+08	5.8E+03			
^{22}Na	2.60 y	F 1.000	1.0E+07	2.7E+02	1.000	6.3E+06	1.7E+02
^{24}Na	15.0 h	F 1.000	3.8E+07	1.0E+03	1.000	4.7E+07	1.3E+03
^{32}P	14.3 d	F 0.800	1.8E+07	4.9E+02	0.800	8.3E+06	2.3E+02
		M 0.800	6.9E+06	1.9E+02			
^{35}S	87.4 d	Inorganic compounds					
		F 0.800	2.5E+08	6.8E+03	0.800	1.4E+08	3.9E+03
		M 0.800	1.8E+07	4.9E+02	0.100	1.1E+08	2.8E+03
		Vapor	1.7E+08	4.5E+03			
		Organic compounds			1.000	2.6E+07	7.0E+02
^{42}K	12.4 h	F 1.000	1.0E+08	2.7E+03	1.000	4.7E+07	1.3E+03
^{43}K	22.6 h	F 1.000	7.7E+07	2.1E+03	1.000	8.0E+07	2.2E+03
^{45}Ca	163 d	M 0.300	8.7E+06	2.4E+02	0.300	2.6E+07	7.1E+02
^{47}Ca	4.53 d	M 0.300	9.5E+06	2.6E+02	0.300	1.3E+07	3.4E+02
^{51}Cr	27.7 d	F 0.100	6.7E+08	1.8E+04	0.100	5.3E+08	1.4E+04
		M 0.100	5.9E+08	1.6E+04	0.010	5.4E+08	1.5E+04
		S 0.100	5.6E+08	1.5E+04			
^{54}Mn	312 d	F 0.100	1.8E+07	4.9E+02	0.100	2.8E+07	7.6E+02
		M 0.100	1.7E+07	4.5E+02			
^{52}Fe	8.28 h	F 0.100	2.9E+07	7.8E+02	0.100	1.4E+07	3.9E+02
		M 0.100	2.1E+07	5.7E+02			
^{55}Fe	2.70 y	F 0.100	2.2E+07	5.9E+02	0.100	6.1E+07	1.6E+03
		M 0.100	6.1E+07	1.6E+03			

	Physical half-life	Inhalation intakes: Chemical form Type/f_1	Inhalation ALI Bq	Inhalation ALI μCi	Oral intakes: Chemical form f_1	Oral ALI Bq	Oral ALI μCi
^{59}Fe	44.5 d	F 0.100	6.7E+06	1.8E+02	0.100	1.1E+07	3.0E+02
		M 0.100	6.3E+06	1.7E+02			
^{57}Co	271 d	M 0.100	5.1E+07	1.4E+03	0.100	9.5E+07	2.6E+03
		S 0.050	3.3E+07	9.0E+02	0.050	1.1E+08	2.8E+03
^{58}Co	70.8 d	M 0.100	1.4E+07	3.9E+02	0.100	2.7E+07	7.3E+02
		S 0.050	1.2E+07	3.2E+02	0.050	2.9E+07	7.7E+02
^{60}Co	5.27 y	M 0.100	2.8E+06	7.6E+01	0.100	5.9E+06	1.6E+02
		S 0.050	1.2E+06	3.2E+01	0.050	8.0E+06	2.2E+02
^{64}Cu	12.7 h	F 0.500	2.9E+08	7.9E+03	0.500	1.7E+08	4.5E+03
		M 0.500	1.3E+08	3.6E+03			
		S 0.500	1.3E+08	3.6E+03			
^{59}Ni	75000 y	F 0.050	9.1E+07	2.5E+03	0.050	3.2E+08	8.6E+03
		M 0.050	2.1E+08	5.8E+03			
		Vapor	2.4E+07	6.5E+02			
^{63}Ni	96.0 y	F 0.050	3.8E+07	1.0E+03	0.050	1.3E+08	3.6E+03
		M 0.050	6.5E+07	1.7E+03			
		Vapor	1.0E+07	2.7E+02			
^{65}Zn	244 d	S 0.500	7.1E+06	1.9E+02	0.500	5.1E+06	1.4E+02
^{67}Ga	3.26 d	F 0.001	1.8E+08	4.9E+03	0.001	1.1E+08	2.8E+03
		M 0.001	7.1E+07	1.9E+03			
^{68}Ga	1.13 h	F 0.001	4.1E+08	1.1E+04	0.001	2.0E+08	5.4E+03
		M 0.001	2.5E+08	6.7E+03			
^{68}Ge	288 d	F 1.000	2.4E+07	6.5E+02	1.000	1.5E+07	4.2E+02
		M 1.000	2.5E+06	6.8E+01			
^{75}Se	120 d	F 0.800	1.4E+07	3.9E+02	0.800	7.7E+06	2.1E+02
		M 0.800	1.2E+07	3.2E+02	0.050	4.9E+07	1.3E+03
^{79}Se	65000 y	F 0.800	1.3E+07	3.4E+02	0.800	6.9E+06	1.9E+02
		M 0.800	6.5E+06	1.7E+02	0.050	5.1E+07	1.4E+03
^{86}Rb	18.6 d	F 1.000	1.5E+07	4.2E+02	1.000	7.1E+06	1.9E+02
^{85}Sr	64.8 d	F 0.300	3.6E+07	9.7E+02	0.300	3.6E+07	9.7E+02
		S 0.010	3.1E+07	8.4E+02	0.010	6.1E+07	1.6E+03
^{87m}Sr	2.80 h	F 0.300	9.1E+08	2.5E+04	0.300	6.7E+08	1.8E+04
		S 0.010	5.7E+08	1.5E+04	0.010	6.1E+08	1.6E+04
^{89}Sr	50.5 d	F 0.300	1.4E+07	3.9E+02	0.300	7.7E+06	2.1E+02
		S 0.010	3.6E+06	9.7E+01	0.010	8.7E+06	2.4E+02
^{90}Sr	29.1 y	F 0.300	6.7E+05	1.8E+01	0.300	7.1E+05	1.9E+01
		S 0.010	2.6E+05	7.0E+00	0.010	7.4E+06	2.0E+02
^{99}Mo	2.75 d	F 0.800	5.6E+07	1.5E+03	0.800	2.7E+07	7.3E+02
		S 0.050	1.8E+07	4.9E+02	0.050	1.7E+07	4.5E+02
^{99m}Tc	6.02 h	F 0.800	1.0E+09	2.7E+04	0.800	9.1E+08	2.5E+04
		M 0.800	6.9E+08	1.9E+04			
^{99}Tc	213000 y	F 0.800	5.0E+07	1.4E+03	0.800	2.6E+07	6.9E+02
		M 0.800	6.3E+06	1.7E+02			
^{106}Ru	1.01 y	F 0.050	2.0E+06	5.5E+01	0.050	2.9E+06	7.7E+01
		M 0.050	1.2E+06	3.2E+01			
		S 0.050	5.7E+05	1.5E+01			
^{111}In	2.83 d	F 0.020	9.1E+07	2.5E+03	0.020	6.9E+07	1.9E+03
		M 0.020	6.5E+07	1.7E+03			
^{113m}In	1.66 h	F 0.020	1.1E+09	2.8E+04	0.020	7.1E+08	1.9E+04
		M 0.020	6.3E+08	1.7E+04			
^{113}Sn	115 d	F 0.020	2.5E+07	6.8E+02	0.020	2.7E+07	7.4E+02
		M 0.020	1.1E+07	2.8E+02			
^{123}I	13.2 h	F 1.000	1.8E+08	4.9E+03	1.000	9.5E+07	2.6E+03
		Vapor	9.5E+07	2.6E+03			
^{125}I	60.1 d	F 1.000	2.7E+06	7.4E+01	1.000	1.3E+06	3.6E+01
		Vapor	1.4E+06	3.9E+01			
^{129}I	$1.57 \cdot 10^7$ y	F 1.000	3.9E+05	1.1E+01	1.000	1.8E+05	4.9E+00

		Inhalation intakes			Oral intakes		
	Physical half-life	Chemical form Type/f_1	ALI Bq	ALI μCi	Chemical form f_1	ALI Bq	ALI μCi
		Vapor	2.1E+05	5.6E+00			
^{131}I	8.04 d	F 1.000	1.8E+06	4.9E+01	1.000	9.1E+05	2.5E+01
		Vapor	1.0E+06	2.7E+01			
^{129}Cs	1.34 d	F 1.000	2.5E+08	6.7E+03	1.000	3.3E+08	9.0E+03
^{134}Cs	2.06 y	F 1.000	2.1E+06	5.6E+01	1.000	1.1E+06	2.8E+01
^{136}Cs	13.1 d	F 1.000	1.1E+07	2.8E+02	1.000	6.7E+06	1.8E+02
^{137}Cs	30.0 y	F 1.000	3.0E+06	8.1E+01	1.000	1.5E+06	4.2E+01
^{141}Ce	32.5 d	M 5.0E-04	7.4E+06	2.0E+02	5.0E-04	2.8E+07	7.6E+02
		S 5.0E-04	6.5E+06	1.7E+02			
^{144}Ce	284 d	M 5.0E-04	8.7E+05	2.4E+01	5.0E-04	3.8E+06	1.0E+02
		S 5.0E-04	6.9E+05	1.9E+01			
^{133}Ba	10.7 y	F 0.100	1.1E+07	3.0E+02	0.100	2.0E+07	5.4E+02
^{140}Ba	12.7 d	F 0.100	1.3E+07	3.4E+02	0.100	8.0E+06	2.2E+02
^{169}Yb	32.0 d	M 5.0E-04	9.5E+06	2.6E+02	5.0E-04	2.8E+07	7.6E+02
		S 5.0E-04	8.3E+06	2.3E+02			
^{198}Au	2.69 d	F 0.100	5.1E+07	1.4E+03	0.100	2.0E+07	5.4E+02
		M 0.100	2.0E+07	5.5E+02			
		S 0.100	1.8E+07	4.9E+02			
^{198m}Au	2.30 d	F 0.100	3.4E+07	9.2E+02	0.100	1.5E+07	4.2E+02
		M 0.100	1.0E+07	2.7E+02			
		S 0.100	1.1E+07	2.8E+02			
^{197}Hg	2.67 d	Inorganic compounds					
		F 0.400	2.4E+08	6.4E+03	1.000	2.0E+08	5.5E+03
					0.400	1.2E+08	3.2E+03
		Vapor	4.5E+06	1.2E+02			
		Organic compounds					
		F 0.020	2.0E+08	5.4E+03	0.020	8.7E+07	2.4E+03
		M 0.020	7.1E+07	1.9E+03			
^{203}Hg	46.6 d	Inorganic compounds					
		F 0.400	2.7E+07	7.2E+02	1.000	1.1E+07	2.8E+02
					0.400	1.8E+07	4.9E+02
		Vapor	2.9E+06	7.7E+01			
		Organic compounds					
		F 0.020	3.4E+07	9.2E+02	0.020	3.7E+07	1.0E+03
		M 0.020	1.1E+07	2.8E+02			
^{201}Tl	3.04 d	F 1.000	2.6E+08	7.1E+03	1.000	2.1E+08	5.7E+03
^{210}Pb	22.3 y	F 0.200	1.8E+04	4.9E-01	0.200	2.9E+04	7.9E-01
^{207}Bi	38.0 y	F 0.050	2.4E+07	6.4E+02	0.050	1.5E+07	4.2E+02
		M 0.050	6.3E+06	1.7E+02			
^{210}Po	138 d	F 0.100	2.8E+04	7.6E-01	0.100	8.3E+04	2.3E+00
		M 0.100	9.1E+03	2.5E-01			
^{224}Ra	3.66 d	M 0.200	8.3E+03	2.3E-01	0.200	3.1E+05	8.3E+00
^{226}Ra	1600 y	M 0.200	1.7E+03	4.5E-02	0.200	7.1E+04	1.9E+00
^{228}Ra	5.75 y	M 0.200	1.2E+04	3.2E-01	0.200	3.0E+04	8.1E-01
^{228}Th	1.91 y	M 5.0E-04	8.7E+02	2.4E-02	5.0E-04	2.9E+05	7.7E+00
		S 2.0E-04	6.3E+02	1.7E-02	2.0E-04	5.7E+05	1.5E+01
^{230}Th	77000 y	M 5.0E-04	7.1E+02	1.9E-02	5.0E-04	9.5E+04	2.6E+00
		S 2.0E-04	2.8E+03	7.5E-02	2.0E-04	2.3E+05	6.2E+00
^{232}Th	$1.40 \cdot 10^{10}$ y	M 5.0E-04	6.9E+02	1.9E-02	5.0E-04	9.1E+04	2.5E+00
		S 2.0E-04	1.7E+03	4.5E-02	2.0E-04	2.2E+05	5.9E+00
^{234}U	$2.44 \cdot 10^{5}$ y	F 0.020	3.1E+04	8.4E-01	0.020	4.1E+05	1.1E+01
		M 0.020	9.5E+03	2.6E-01	0.002	2.4E+06	6.5E+01
		S 0.002	2.9E+03	7.9E-02			

ANNUAL LIMITS ON INTAKES OF RADIONUCLIDES (continued)

		Inhalation intakes			Oral intakes		
	Physical half-life	Chemical form Type/f_1	ALI		Chemical form f_1	ALI	
			Bq	μCi		Bq	μCi
^{235}U	$7.04 \cdot 10^8$ y	F 0.020	3.3E+04	9.0E-01	0.020	4.3E+05	1.2E+01
		M 0.020	1.1E+04	3.0E-01	0.002	2.4E+06	6.5E+01
		S 0.002	3.3E+03	8.9E-02			
^{238}U	$4.47 \cdot 10^9$ y	F 0.020	3.4E+04	9.3E-01	0.020	4.5E+05	1.2E+01
		M 0.020	1.3E+04	3.4E-01	0.002	2.6E+06	7.1E+01
		S 0.002	3.5E+03	9.5E-02			
^{237}Np	$2.14 \cdot 10^6$ y	M 5.0E-04	1.3E+03	3.6E-02	5.0E-04	1.8E+05	4.9E+00
^{239}Np	2.36 d	M 5.0E-04	1.8E+07	4.9E+02	5.0E-04	2.5E+07	6.8E+02
^{238}Pu	87.7 y	M 5.0E-04	6.7E+02	1.8E-02	5.0E-04	8.7E+04	2.4E+00
		S 1.0E-05	1.8E+03	4.9E-02	1.0E-05	2.3E+06	6.1E+01
					1.0E-04	4.1E+05	1.1E+01
^{239}Pu	24100 y	M 5.0E-04	6.3E+02	1.7E-02	5.0E-04	8.0E+04	2.2E+00
		S 1.0E-05	2.4E+03	6.5E-02	1.0E-05	2.2E+06	6.0E+01
					1.0E-04	3.8E+05	1.0E+01
^{241}Pu	14.4 y	M 5.0E-04	3.4E+04	9.3E-01	5.0E-04	4.3E+06	1.2E+02
		S 1.0E-05	2.4E+05	6.4E+00	1.0E-05	1.8E+08	4.9E+03
					1.0E-04	2.1E+07	5.6E+02
^{241}Am	432 y	M 5.0E-04	7.4E+02	2.0E-02	5.0E-04	1.0E+05	2.7E+00
^{244}Cm	18.1 y	M 5.0E-04	1.2E+03	3.2E-02	5.0E-04	1.7E+05	4.5E+00
^{252}Cf	2.64 y	M 5.0E-04	1.5E+03	4.2E-02	5.0E-04	2.2E+05	6.0E+00

CHEMICAL CARCINOGENS

The following substances are listed in the *9th Report on Carcinogens 2000*, released by the National Institute of Environmental Health Sciences (NIEHS) under the National Toxicology Program (NTP). Substances are grouped in two classes:

- Known to be human carcinogens: There is sufficient evidence of carcinogenicity from studies in humans which indicates a causal relationship between exposure to the substance and human cancer.
- Reasonably anticipated to be human carcinogens: There is limited evidence of carcinogenicity from studies in humans which indicates that causal interpretation is credible, but that alternative explanations, such as chance, bias, or confounding factors, could not be adequately excluded; or there is sufficient evidence of carcinogenicity from studies in experimental animals.

The NTP report also lists many poorly defined materials such as soots, tars, mineral oils, coke oven emissions, etc. These materials are not included here.

The table lists the name normally used in the *Handbook of Chemistry and Physics*, followed by additional names by which the substance is known. In many cases the primary name given here is different from that used in the NTP report; however, names used in the NTP report appear in the *Other names* column. The Chemical Abstracts Service Registry Number (CAS RN), given in the last column, is taken from the NTP report. Extensive details on each substance are given in the reference.

REFERENCE

Public Health Service, National Toxicology Program, *9th Report on Carcinogens*, OCR Services, Inc., P.O. Box 12510, Research Triangle Park, NC 27709-2510. Also available on the Internet at http://ehis.niehs.nih.gov/roc/

Substance	Other names	CAS RN
Known to be Human Carcinogens		
Aflatoxins		1402-68-2
4-Aminobiphenyl	*p*-Biphenylamine	92-67-1
Arsenic compounds, inorganic		
Asbestos		1332-21-4
Azathioprine	1H-Purine, 6-[(1-methyl-4-nitro-1H-imidazol-5-yl)thio]-	446-86-6
Benzene		71-43-2
p-Benzidine	[1,1'-Biphenyl]-4,4'-diamine	92-87-5
Bis(2-chloroethyl) sulfide	Mustard gas	505-60-2
Bis(chloromethyl) ether		542-88-1
1,3-Butadiene		106-99-0
1,4-Butanediol dimethylsulfonate	Myleran; Busulfan	55-98-1
Cadmium and cadmium compounds		7440-43-9
Cadmium chloride		10108-64-2
Cadmium oxide		1306-19-0
Cadmium sulfate		10124-36-4
Cadmium sulfide		1306-23-6
Chlorambucil		305-03-3
Chloroethene	Vinyl chloride; Chloroethylene	75-01-4
1-(2-Chloroethyl)-3-(4-methylcyclohexyl)-1-nitrosourea	MeCCNU; Urea,	13909-09-6
Chloromethyl methyl ether		107-30-2
Chromium hexavalent compounds		
Cyclophosphamide	2H-1,3,2-Oxazaphosphorin-2-amine, *N*,*N*-bis(2-chloroethyl)tetrahydro-, 2-oxide	50-18-0
Cyclosporin A	Cyclosporine	59865-13-3
Diethylstilbestrol		56-53-1
Direct Black 38, disodium salt		1937-37-7
Direct Blue 6, tetrasodium salt		2602-46-2
Erionite		66733-21-9
Ethylene oxide	Oxirane	75-21-8
Lead(II) chromate		7758-97-6
Melphalan	*L*-Phenylalanine, 4-[bis(2-chloroethyl)amino]-	148-82-3
Methoxsalen (with UV therapy)	PUVA; 9-Methoxy-7H-furo[3,2-g][1]benzopyran-7-one	298-81-7
2-Naphthylamine	2-Aminonaphthalene; β-Naphthylamine	91-59-8
Piperazine estrone sulfate	Estrone, hydrogen sulfate, compd. with piperazine	7280-37-7
Radon		10043-92-2
Silicon dioxide (respirable size)	Quartz; Silica	14808-60-7
Silicon dioxide (respirable size)	Cristobalite; Silica	14464-46-1
Silicon dioxide (respirable size)	Tridymite; Silica	15468-32-3

Substance	Other names	CAS RN
Sodium equilin sulfate	Estra-1,3,5(10),7-tetraen-17-one, 3-hydroxy, hydrogen sulfate, sodium salt	16680-47-0
Sodium estrone sulfate	Estrone, hydrogen sulfate, sodium salt	438-67-5
Strontium chromate		7789-06-2
Tamoxifen		10540-29-1
Thorium(IV) oxide	Thorium dioxide	1314-20-1
Triethylenethiophosphoramide	Thiotepa; Tris(1-aziridinyl)phosphine, sulfide	52-24-4
Zinc chromate, basic		13530-65-9
Reasonably Anticipated to be Human Carcinogens		
Acetaldehyde	Ethanal	75-07-0
2-(Acetylamino)fluorene		53-96-3
Acrylamide	2-Propenamide	79-06-1
Acrylonitrile	Propenenitrile	107-13-1
Adriamycin, hydrochloride	Doxorubicin hydrochloride	25316-40-9
2-Amino-9,10-anthracenedione	2-Aminoanthraquinone	117-79-3
1-Amino-2-methyl-9,10-anthracenedione	1-Amino-2-methylanthraquinone	82-28-0
Arochlor 1254	Polychlorinated biphenyls (54% Cl)	11097-69-1
Arochlor 1260	Polychlorinated biphenyls (60% Cl)	11096-82-5
Azacitidine	5-Azacytidine; 1,3,5-Triazine-2(1H)-one, 4-amino-1-beta-*D*-ribofuranosyl-	320-67-2
Benz[a]anthracene		56-55-3
Benzo[b]fluoranthene	Benz[e]acephenanthrylene	205-99-2
Benzo[j]fluoranthene		205-82-3
Benzo[k]fluoranthene	2,3,1',8'-Binaphthylene	207-08-9
Benzo[a]pyrene		50-32-8
Beryllium and certain beryllium compounds		7440-41-7
Beryllium aluminum alloy		12770-50-2
Beryllium aluminum metasilicate	Beryl	1302-52-9
Beryllium chloride		7787-47-5
Beryllium fluoride		7787-49-7
Beryllium hydroxide		13327-32-7
Beryllium oxide	Beryllia	1304-56-9
Beryllium phosphate		13598-15-7
Beryllium sulfate		13510-49-1
Beryllium sulfate tetrahydrate		7787-56-6
Beryllium zinc silicate		39413-47-3
2,2'-Bioxirane	Diepoxybutane	1464-53-5
Bis(4-amino-3-chlorophenyl)methane	4,4-Methylene-bis(2-chloraniline); MBOCA	101-14-4
Bis(2-chloroethyl)methylamine	Nitrogen mustard hydrochloride	55-86-7
N,*N*'-Bis(2-chloroethyl)-N-nitrosourea	BCNU; Carmustine	154-93-8
Bis[4-(dimethylamino)phenyl]methane	Michler's Base; 4,4-Methylenebis(*N*,*N*-dimethylbenzenamine)	101-61-1
1,3-Bis(2,3-epoxypropoxy)benzene	Diglycidyl resorcinol ether	101-90-6
Bis(2-ethylhexyl) phthalate	DEHP; Di(2-ethylhexyl) phthalate	117-81-7
Bromodichloromethane		75-27-4
tert-Butyl-4-hydroxyanisole	BHA; Butylated hydroxyanisole	25013-16-5
N-Butyl-*N*-(4-hydroxybutyl)nitrosamine	*N*-Nitrosobutyl-*N*-(4-hydroxybutyl)amine	3817-11-6
Chlorendic acid	5-Norbornene-2,3-dicarboxylic acid, 1,4,5,6,7,7-hexachloro-	115-28-6
Chlorinated paraffins (C_{12}, 60% Cl)		108171-26-2
4-Chloro-1,2-benzenediamine	4-Chloro-*o*-phenylenediamine	95-83-0
2-Chloro-1,3-butadiene	Chloroprene	126-99-8
1-(2-Chloroethyl)-3-cyclohexyl-1-nitrosourea	CCNU; Lomustine; Belustine	13010-47-4
4-Chloro-2-methylaniline	*p*-Chloro-*o*-toluidine	95-69-2
4-Chloro-2-methylaniline hydrochloride	*p*-Chloro-*o*-toluidine hydrochloride	3165-93-3
1-Chloro-2-methylpropene	Dimethylvinyl chloride	513-37-1
3-Chloro-2-methylpropene		563-47-3
Chlorozotocin	*D*-Glucose, 2-[[[(2-chloroethyl)nitrosoamino]carbonyl]amino]-2-deoxy-	54749-90-5
C.I. Basic Red 9, monohydrochloride		569-61-9
Cupferron		135-20-6

Substance	Other names	CAS RN
Dacarbazine	1H-Imidazole-4-carboxamide, 5-(3,3-dimethyl-1-triazenyl)-	4342-03-4
Decabromobiphenyl		13654-09-6
cis-Diaminedichloroplatinum	Cisplatin	15663-27-1
2,4-Diaminoanisole sulfate	1,3-Benzenediamine, 4-methoxy, sulfate	39156-41-7
4,4'-Diaminodiphenyl ether	4,4-Oxydianiline	101-80-4
4,4'-Diaminodiphenylmethane	4,4'-Methylenedianiline	101-77-9
Dibenz[a,h]acridine		226-36-8
Dibenz[a,j]acridine		224-42-0
Dibenz[a,h]anthracene		53-70-3
7H-Dibenzo[c,g]carbazole		194-59-2
Dibenzo[a,e]pyrene	Naphtho[1,2,3,4-def]chrysene	192-65-4
Dibenzo[a,h]pyrene	Dibenzo[b,def]chrysene	189-64-0
Dibenzo[a,i]pyrene	Benzo[rst]pentaphene	189-55-9
Dibenzo[a,l]pyrene	Dibenzo[def,p]chrysene	191-30-0
1,2-Dibromo-3-chloropropane		96-12-8
1,2-Dibromoethane	Ethylene dibromide; EDB	106-93-4
2,3-Dibromo-1-propanol, phosphate (3:1)	Tris(2,3-dibromopropyl) phosphate	126-72-7
p-Dichlorobenzene	1,4-Dichlorobenzene	106-46-7
3,3'-Dichloro-*p*-benzidine	[1,1'-Biphenyl]-4,4'-diamine, 3,3'-dichloro-	91-94-1
3,3'-Dichloro-*p*-benzidine dihydrochloride	3,3'-Dichloro-[1,1'-biphenyl]-4,4'-diamine dihydrochloride	612-83-9
1,2-Dichloroethane	Ethylene dichloride	107-06-2
Dichloromethane	Methylene chloride	75-09-2
1,3-Dichloropropene (unspecified isomer)		542-75-6
Diethyl sulfate		64-67-5
2,3-Dihydro-6-propyl-2-thioxo-4(1H)-pyrimidinone	Propylthiouracil	51-52-5
1,8-Dihydroxy-9,10-anthracenedione	Danthron; 1,8-Dihydroxyanthraquinone	117-10-2
3,3'-Dimethoxybenzidine	Dianisidine	119-90-4
p-(Dimethylamino)azobenzene		60-11-7
2',3-Dimethyl-4-aminoazobenzene	*o*-Aminoazotoluene; 4-*o*-Tolylazo-*o*-toluidine	97-56-3
Dimethylcarbamic chloride	Dimethylcarbamoyl chloride	79-44-7
1,1-Dimethylhydrazine	UDMH	57-14-7
Dimethyl sulfate		77-78-1
1,6-Dinitropyrene		42397-64-8
1,8-Dinitropyrene		42397-65-9
1,4-Dioxane		123-91-1
1,2-Diphenylhydrazine	Hydrazobenzene	122-66-7
Disperse Blue No. 1	9,10-Anthracenedione, 1,4,5,8-tetraamino-	2475-45-8
Epichlorohydrin	(Chloromethyl)oxirane	106-89-8
1,2-Epoxy-4-(epoxyethyl)cyclohexane	4-Vinyl-1-cyclohexene dioxide	106-87-6
Estra-1,3,5(10)-triene-3,17-diol, (17β)-	Estradiol-17β	50-28-2
Estrone		53-16-7
N-(4-Ethoxyphenyl)acetamide	Phenacetin	62-44-2
Ethyl carbamate	Urethane	51-79-6
Ethyl methanesulfonate		62-50-0
N-Ethyl-*N*-nitrosourea	ENU; *N*-Nitroso-*N*-ethylurea	759-73-9
Formaldehyde		50-00-0
Furan		110-00-9
Hexabromobiphenyl (unspecified isomer)	Firemaster FF-1	67774-32-7
Hexachlorobenzene	Perchlorobenzene	118-74-1
1,2,3,4,5,6-Hexachlorocyclohexane, (1α,2α,3β,4α,5α,6β)	Lindane; γ-Hexachlorocyclohexane	58-89-9
1,2,3,4,5,6-Hexachlorocyclohexane, (1α,2α,3β,4α,5β,6β)	α-Hexachlorocyclohexane	319-84-6
1,2,3,4,5,6-Hexachlorocyclohexane, (1α,2β,3α,4β,5α,6β)	β-Hexachlorocyclohexane	319-85-7
Hexachlorocyclohexane (unspecified isomer)		608-73-1
Hexachloroethane	Perchloroethane	67-72-1
Hexamethylphosphoric triamide	Hexamethylphosphoramide; Tris(dimethylamino)phosphine oxide	680-31-9

CHEMICAL CARCINOGENS (continued)

Substance	Other names	CAS RN
Hydrazine		302-01-2
Hydrazine sulfate		10034-93-2
2-Imidazolidinethione	Ethylene thiourea	96-45-7
Indeno[1,2,3-cd]pyrene	1,10-(1,2-Phenylene)pyrene	193-39-5
Kanechlor 500	Polychlorinated biphenyls	37317-41-2
Kepone	Chlordecone	143-50-0
Lead(II) acetate		301-04-2
Lead(II) phosphate		7446-27-7
Mestranol	19-Norpregna-1,3,5(10)-trien-20-yn-17-ol, 3-methoxy-, (17 α)-	72-33-3
o-Methoxyaniline hydrochloride	*o*-Anisidine hydrochloride	134-29-2
2-Methoxy-5-methylaniline	*p*-Cresidine; 5-Methyl-*o*-anisidine	120-71-8
o-Methylaniline	*o*-Toluidine	95-53-4
o-Methylaniline hydrochloride	*o*-Toluidine hydrochloride	636-21-5
2-Methyl-1,3-butadiene	Isoprene	78-79-5
5-Methylchrysene		3697-24-3
4,4-Methylenedianiline dihydrochloride	Benzenamine, 4,4'-methylenedi-, dihydrochloride	13552-44-8
Methyl methanesulfonate		66-27-3
N-Methyl-*N*'-nitro-*N*-nitrosoguanidine		70-25-7
N-Methyl-*N*-nitrosourea	*N*-Nitroso-*N*-methylurea	684-93-5
Methyloxirane	1,2-Propylene oxide	75-56-9
Metronidazole	2-Methyl-5-nitro-1H-imidazole-1-ethanol	443-48-1
Mirex	1,3,4-Metheno-1H-cyclobuta[cd]pentalene, 1,1a,2,2,3,3a,4,5,5,5a,5b,6-dodecachlorooctahydro-	2385-85-5
Nickel		7440-02-0
Nickel(II) acetate		373-02-4
Nickel(II) carbonate		3333-67-3
Nickel carbonyl		13463-39-3
Nickel(II) hydroxide		12054-48-7
Nickel hydroxide (unspecified oxidation state)		11113-74-9
Nickelocene	Bis(η5-2,4-cyclopentadien-1-yl)nickel	1271-28-9
Nickel(II) oxide		1313-99-1
Nickel(III) sulfide	Nickel subsulfide	12035-72-2
Nitrilotriacetic acid	*N*,*N*-Bis(carboxymethyl)glycine	139-13-9
2-Nitroanisole	1-Methoxy-2-nitrobenzene	91-23-6
6-Nitrochrysene		7496-02-8
Nitrofen	Benzene, 2,4-dichloro-1-(4-nitrophenoxy)-	1836-75-5
2-Nitropropane		79-46-9
1-Nitropyrene		5522-43-0
4-Nitropyrene		57835-92-4
N-Nitrosobutyl-*N*-(3-carboxypropyl)amine	Butyl(3-carboxypropyl)nitrosoamine	38252-74-3
N-Nitrosodibutylamine		924-16-3
N-Nitrosodiethanolamine	Ethanol, 2,2'-(nitrosoimino)-	1116-54-7
N-Nitrosodiethylamine	DEN; Diethylnitrosamine	55-18-5
N-Nitrosodimethylamine	DMN; Dimethylnitrosamine	62-75-9
4-(*N*-Nitrosomethylamino)-1-(3-pyridyl)-1-butanone	NNK; Ketone, 3-pyridyl-3-(*N*-methyl-*N*-nitrosamino)propyl	64091-91-4
N-Nitroso-*N*-methylvinylamine	Ethenamine, *N*-methyl-*N*-nitroso-	4549-40-0
4-Nitrosomorpholine	*N*-Nitrosomorpholine	59-89-2
N-Nitrosonornicotine		16543-55-8
N-Nitrosopiperidine	1-Nitrosopiperidine	100-75-4
N-Nitroso-*N*-propyl-1-propanamine	*N*-Nitrosodipropylamine	621-64-7
N-Nitrosopyrrolidine		930-55-2
N-Nitrososarcosine	Glycine, *N*-methyl-*N*-nitroso-	13256-22-9
Norethisterone	19-Norpregn-4-en-20-yn-3-one, 17-hydroxy-, (17 α)-	68-22-4
19-Norpregna-1,3,5(10)-trien-20-yne-3, 17-diol, (17α)-	Ethinylestradiol	57-63-6
Ochratoxin A		303-47-9
Octabromobiphenyl (unspecified isomer)		61288-13-9
2-Oxetanone	β-Propiolactone	57-57-8

Substance	Other names	CAS RN
Oxiranemethanol	Glycidol	556-52-5
Oxymetholone	Androstan-3-one, 17-hydroxy-2-(hydroxymethylene)-17-methyl-	434-07-1
Phenazopyridine hydrochloride	2,6-Pyridinediamine, 3-(phenylazo)-, monohydrochloride	136-40-3
Phenolphthalein	3,3-Bis(4-hydroxyphenyl)-1(3H)-isobenzofuranone	77-09-8
Phenoxybenzamine hydrochloride	Benzenemethanamine, *N*-(2-chloroethyl)-*N*-(1-methyl-2-phenoxyethyl)-, hydrochloride	63-92-3
Phenytoin	5,5-Diphenyl-2,4-imidazolidinedione	57-41-0
Polychlorinated biphenyls	PCBs	1336-36-3
Procarbazine hydrochloride		366-70-1
Progesterone	Pregn-4-ene-3,20-dione	57-83-0
1,3-Propane sultone	1,2-Oxathiolane, 2,2-dioxide	1120-71-4
Propyleneimine	2-Methylaziridine	75-55-8
Reserpine		50-55-5
Safrole	5-(2-Propenyl)-1,3-benzodioxole	94-59-7
Selenium sulfide		7446-34-6
Streptozotocin	*D*-Glucopyranose, 2-deoxy-2-[[(methylnitrosoamino)carbonyl]amino]-	18883-66-4
Sulfallate	*N*,*N*-Diethyldithiocarbamic acid, 2-chloroallyl ester	95-06-7
2,3,7,8-Tetrachlorodibenzo-*p*-dioxin	TCDD; Dioxin	1746-01-6
Tetrachloroethene	Perchloroethylene	127-18-4
Tetrachloromethane	Carbon tetrachloride	56-23-5
Tetrafluoroethene	Tetrafluoroethylene	116-14-3
N,*N*,*N*',*N*'-Tetramethyl-4,4'-diaminobenzophenone	Bis(dimethylamino)benzophenone; Michler's Ketone	90-94-8
Tetranitromethane		509-14-8
Thioacetamide		62-55-5
Thiourea		62-56-6
o-Tolidine	3,3-Dimethylbenzidine	119-93-7
Toluene-2,4-diamine	2,4-Diaminotoluene	95-80-7
Toluene diisocyanate (unspecified isomer)		26471-62-5
Toxaphene	Polychlorocamphene	8001-35-2
1H-1,2,4-Triazol-3-amine	Amitrole	61-82-5
1,1,1-Trichloro-2,2-bis(4-chlorophenyl)ethane	DDT; Dichlorodiphenyltrichloroethane	50-29-3
Trichloroethene	Trichloroethylene	79-01-6
Trichloromethane	Chloroform	67-66-3
(Trichloromethyl)benzene	Benzotrichloride	98-07-7
2,4,6-Trichlorophenol		88-06-2
1,2,3-Trichloropropane		96-18-4